

The Effect of Liquid TOMIN Tech on the Quality Reduction Degree of Prefabricated Tomato Beef Brisket

Chunxia Chu¹, Yushu Wang¹, Zien Li^{1,*}, Jiaxuan Bai¹, Yihan Gong¹, Qian Jia², He Zhu^{1,*}

¹ College of Shandong Agricultural Engineering College University, Zibo, China

² China Juxinyuan Group, Heze, China

*Corresponding Author: He Zhu, Zien Li

ABSTRACT

In this paper, the effect of liquid TOMIN technology on the quality reduction degree of prefabricated tomato beef brisket was studied by comparing the freezing effect of traditional refrigerator with 0 d fresh tomato beef brisket as control and 1 d chilled beef brisket as blank. Texture, volatile components and Fourier transform infrared were used as evaluation indexes. The results showed that the texture changes of TOMIN tomato brisket treatment group at different storage times were significantly ($p < 0.05$) smaller than that of the refrigerator, the content of volatile components increased less than that of the refrigerator, and the protein secondary structure was more stable. In terms of texture index, the hardness, elasticity and chewiness of beef increased after TOMIN, but the degree of increase was smaller than that of refrigerator freezing. The hardness, springiness and chewiness were $3732.17 \text{ g} \pm 23.35$, $85.09\% \pm 0.10$, $1895.89 \text{ g} \pm 13.14$ respectively after 30 days of TOMIN. The hardness, elasticity and chewiness of the refrigerator after freezing for 30 days reached $4555.16 \text{ g} \pm 58.81$, $88.59\% \pm 1.03$, $2224.55 \text{ g} \pm 65.80$. In terms of volatile components, a total of 29 substances were measured, and the cumulative contribution rate of PCA was 94.8%. Among them, the variance contribution rate of volatile component PC1 in 30 d refrigerator was 90.2%. It was concluded that the content of volatile components frozen in refrigerator was high, and the variables highly correlated with PC1 were benzaldehyde, hexanal, nonanal and 2-heptanone, mainly from fat oxidation, indicating that the oxidation rate of tomato beef belly oil frozen in refrigerator was high. On the Fourier transform infrared, by analyzing the secondary structure of beef brisket protein, it was concluded that the secondary structure of liquid TOMIN tomato beef brisket protein was more stable. In summary, the quality of tomato brisket frozen in liquid TOMIN is higher than that frozen in refrigerator, and it has better fresh-keeping effect and can more effectively maintain the original edible quality of tomato brisket.

KEYWORDS

Liquid TOMIN tech; Refrigerator freezing; Tomato beef brisket; Freshness-keeping effect; Quality reduction degree

1. INTRODUCTION

1.1. Overview Of Tomato Beef Brisket Background

With the rapid development of social economy, people's quality of life has been greatly improved, beef food consumption is increasing, and consumption patterns tend to be characteristic and diversified. Tomato beef brisket is a beef dish with rich nutrition and delicious taste, which is widely loved by consumers. Beef contains high-quality proteins, fatty acids, minerals and vitamins, which not only helps to maintain the normal function and growth and development of the body, but also

provides energy for the body [1-2]. Tomatoes are rich in vitamin C, vitamin A, potassium, dietary fiber and other nutrients, which can promote digestion and anti-oxidation, and also help to protect the body from free radical damage. Because of these characteristics of tomato beef brisket and people's demand for convenient, fast, nutritious and safe prefabricated food, the market scale of tomato beef brisket prefabricated vegetable industry is expanding, and its sales volume and sales speed are also increasing [3-4].

1.2. The Current Research Status Of Preservation Methods On The Reduction Degree Of Tomato Beef Brisket

After consulting relevant literature and data, quality restoration degree of prefabricated dishes refers to the fact that the prefabricated dishes can maintain the color, smell, taste, shape and other characteristics of the raw materials to the greatest extent in the process of processing, storage and cooking, so that consumers can feel similar to the quality and flavor of the cooked dishes. Quality restoration degree has a crucial influence on the sales and consumption of prefabricated tomato beef brisket. Ahemd et al. [5] showed that with the extension of time, the prefabricated tomato sirloin will cause a large number of microorganisms to reproduce due to changes in gas environment, temperature and humidity during transportation and storage, affecting its reduction degree.

At present, researchers have explored a variety of preservation methods to ensure the original quality of prefabricated tomato beef brisket. Among them, low temperature preservation is one of the common methods. CAO et al. [6] have shown that low temperature freezing can freeze the water in beef and effectively inhibit the growth of microorganisms. However, freezing is easy to cause dry consumption of food, and the rate of juice loss increases during thawing, resulting in a decline in beef quality. In addition, vacuum packaging technology is also a commonly used preservation method. It can reduce the contact between food and oxygen, prevent food oxidation and pollution, further ensure food quality and prolong the preservation period. In addition, preservatives and preservatives are also used in the study of food preservation, such as citric acid, sodium benzoate, etc., but need to pay attention to the rational use of dosage, to ensure food safety. Irradiation preservation technology uses radiation to sterilize food, which can also prolong the shelf life of food to a certain extent, but it also needs to strictly control the irradiation dose. Almasi et al. [7] have shown that active packaging adds active functional components to food packaging materials or directly encapsulates active substances in packaging together with food. Because its materials are in direct contact with food, it will give people an unsafe psychological idea.

In general, these research advances in preservation provide more choices for the high degree of reduction of prefabricated tomato beef brisket, which can prolong the shelf life of food to a certain extent and maintain the original taste of food, but still face many challenges. Therefore, it is necessary to find a safer and more effective preservation method to solve the problem of reduction degree of prefabricated tomato beef brisket.

1.3. Research Status Of Liquid TOMIN Technology In The Reduction Degree Of Prefabricated Food

TOMIN technology is a new type of high-speed freezing technology with liquid as the medium. It was invented by Yoshio Yamada, president of Teknikon Corporation in Japan in the 1990s. TOMIN can keep the diameter of ice crystals in cells below 5 microns. The freezing process does not destroy the cell membrane and cell wall. After thawing, the original state of the cells can be restored. It is safe, non-toxic, low cost, environmentally friendly and non-destructive. On May 31, 2018, Yoshio Yamada made his first speech at the United Nations Headquarters in New York entitled "What Does TOMIN Technology Change." He pointed out that TOMIN Technology can solve the serious problem of food waste, and seasonal food can ensure a stable supply throughout the year. At present, TOMIN

technology is widely used in Japan, Europe and the United States and other countries and regions, and TOMIN food can be seen in large and small restaurants, supermarkets and so on.

In China, many quick-frozen food enterprises are also gradually introducing TOMIN technology. In order to ensure the freshness of shrimp, Zhu 'aotong Supply Chain Co., Ltd., which is set up at the special port of Zhu 'ao cross-border industrial zone, uses TOMIN technology to lock fresh shrimp immediately after packaging and packaging, and sells them to major cities. According to the relevant person in charge of the company, the cooked shrimp after TOMIN completely maintains the freshness and crispness of the freshly cooked shrimp, and the taste is delicious, which is very popular with consumers. Hainan Wenchang chicken, Chaoshan beef balls... The application scenario of TOMIN technology is gradually being pushed forward in China.

1.4. Research Content

At present, there are many studies on the quality of samples under different freezing methods, but there are few studies on the quality analysis of samples under the TOMIN method, and there are few studies on the effect of TOMIN technology on the reduction degree of prefabricated tomato beef brisket. Therefore, it is of great practical significance to study the effect of liquid TOMIN technology on the quality restoration degree of prefabricated tomato beef brisket at different storage time, which is helpful to meet consumers' requirements for fresh and high-quality prefabricated tomato beef brisket food.

In this paper, tomato beef brisket was pretreated, and 0 d fresh tomato beef brisket was used as the control. The sensory evaluation, color, water content, texture, volatile components and Fourier transform infrared of tomato beef brisket were compared and analyzed in different time (10 d, 20 d, 30 d) of liquid TOMIN and ordinary refrigerator freezing. The physical and chemical properties, explore the effect of liquid TOMIN technology on the quality reduction of tomato beef brisket, and find out which can better maintain the original quality of tomato beef brisket and prolong the storage period of tomato brisket compared with refrigerator freezing. This study provides a theoretical basis for the comprehensive preservation technology of extending tomato beef brisket.

2. EXPERIMENTAL MATERIALS

2.1. Raw Material Preparation

In this experiment, fresh and high-quality beef brisket and tomato were used as the main raw materials, and spices, scallions, ginger, edible salt, white sugar, monosodium glutamate, raw smoke, tomato sauce and so on were used as auxiliary materials to cook the dishes. The tomatoes and beef sirloin used in this experiment were purchased uniformly. The tomatoes were selected without damage to the surface, without pest erosion, and the quality was good. The raw materials were food grade.

2.2. Reagents And Equipment

Table 1. Main Reagents

Reagent	Level	Producer
95% ethyl alcohol	AR	Tianjin Fuyu Fine Chemical Co., Ltd.

Table 2. Main instruments and equipment

Apparatus	Model	Producer
Electronic analytical balance	AL104	METTLER TOLEDO Instrument Co., Ltd.
Vacuum sealing insurance machine	QH-66	Zhejiang Qunhai Electronic Technology Co., Ltd.
Colorimeter	WR-10QC	Shenzhen Weifu Optoelectronic Technology Co., Ltd.
Water content detector	0222	Detuo Electronics
Texture instrument	TA.XT	UK SMS
Gas-mass spectrometry analyzer	7890A-5975C	Agilent Technology (China) Co., Ltd.
Fourier Transform Infrared Analyzer	ATR-iD7	Zhejiang Zhengtai Electric Co., Ltd.
Vacuum packaging bag	30cm×20cm	Foshan Hongchen Packaging Materials Co., Ltd.
Low temperature constant temperature water tank refrigerator	DC-3010	Changzhou Guowang Instrument Manufacturing Co., Ltd.
	BCD-471WDCD	haier group

3. EXPERIMENTAL METHODS

3.1. Sample Preparation And Experimental Design

3.1.1. Sample preparation and processing

Clean the beef brisket and tomatoes → trim and cut the beef brisket → blanch the beef brisket → add water and spices to stew until nine mature → add tomatoes → stew with a small fire for 1 h → add edible salt, monosodium glutamate, and white pepper to season → finished product → pre-cooled packaging → frozen.

3.1.2. Experimental design

In this experiment, 95% ethanol was used as the refrigerant. After the start-up, the most suitable freezing temperature was set, and the cycle was started. After the temperature reached the preset temperature, the sample was placed, frozen for 24 hours, and taken out and placed in the refrigerator. With 0 d tomato sirloin as the control, 1 d cold fresh tomato beef brisket as the blank, the sensory score, color difference, water content, texture, volatile substances, Fourier transform infrared and other physical and chemical indexes of tomato beef brisket with different freezing treatments at different times in the experimental group of Table 3 were measured.

Table 3. Experimental group

Experimental group	Time		
	10 d	20 d	30 d
TOMIN equipment (-25°C)			
Refrigerator (-18°C)			

3.2. Comparative Determination With The Control Group

3.2.1. Sensory evaluation

Sensory evaluation samples of 0 d fresh, 1 d chilled, 10 d TOMIN, 10 d refrigerator, 20 d TOMIN, 20 d refrigerator, 30 d TOMIN and 30 d refrigerator were prepared. Fresh samples were prepared according to the method of tomato beef brisket prefabrication, and other samples were reheated in

boiling water bath for 20 minutes. The tomato beef brisket was put into a clean stainless steel plate (bowl) and randomly assigned to a three-digit code. Ten evaluators with sensory evaluation experience were invited to score the taste, texture, taste and color of the randomly coded samples. The comprehensive score of each score was the sensory score of the sample. The specific evaluation criteria are shown in Table 4. After each sample was evaluated, another sample should be evaluated after rinsing.

Table 4. Sensory evaluation standard table of tomato brisket

Item	Standard	Sensory scores
Tincture	Pink, uniform color, high surface color saturation	14 ~ 20
	Light brown, uniform color, surface color saturation in general	7 ~ 13
	Dark brown, uneven color, bleak surface	0 ~ 6
Taste	It has full taste, moderate aftertaste and no peculiar smell.	14 ~ 20
	The taste is stronger or lighter, the aftertaste is general, and the odor is light.	7 ~ 13
	The taste is not pure, no aftertaste, smell heavy.	0 ~ 6
	Aroma rich coordination, rich sense of hierarchy.	14 ~ 20
Fragrance	The spice flavor covers the meat flavor and the sense of hierarchy is not clear.	7 ~ 13
	There is a different aroma, if there is no aroma, the sense of hierarchy is poor	0 ~ 6
Sense	Soft moderate rotten, fresh meat, smooth entrance.	14 ~ 20
	Slightly woody, dry, slightly sticky	7 ~ 13
	Not rotten, hard and dry, sticky.	0 ~ 6
Overall Acceptability	High (generally liked)	14 ~ 20
	mezzo	7 ~ 13
	Low (generally not liked)	0 ~ 6

3.2.2. Color difference measurement

Three groups of each sample were taken as a large group, and each group was recorded as 0 d fresh, 1 d chilled, 10 d TOMIN, 10 d refrigerator, 20 d TOMIN, 20 d refrigerator, 30 d TOMIN, 30 d refrigerator. Fresh samples were prepared according to the method of tomato beef brisket prefabrication. Other samples were reheated in boiling water bath for 20 minutes, and the surface moisture was wiped off at room temperature. The chromaticity of tomato beef brisket treated by different freezing methods was measured by precision colorimeter. Take the sample carefully placed under the color difference measuring instrument, read the L value, a value, b value, measure three times to take the average, and then cut the beef to measure the color difference inside the meat. L* represents brightness, and the larger the value, the more obvious the color brightness of the sample; a* represents redness, and the larger the value, the brighter the redness of the sample; the b* represents yellowness, and the larger the b* value, the yellower the meat color [8].

3.2.3. Determination of water content

Three groups of each sample were taken as a large group, and each group was recorded as 0 d fresh, 1 d chilled, 10 d TOMIN, 10 d refrigerator, 20 d TOMIN, 20 d refrigerator, 30 d TOMIN, 30 d refrigerator. Fresh samples were prepared according to the method of tomato beef brisket prefabrication. Other samples were reheated in boiling water bath for 20 minutes, and the surface moisture was wiped off at room temperature. The water content of tomato beef brisket treated by different freezing methods was measured by water content meter. The sample was placed in the tray, and the water content measuring instrument was inserted into the sample to be tested. After the reading was stable, the results were recorded, and the average value was taken three times.

3.2.4. Texture determination

Each sample was taken 1.5 cm × 1.5 cm × 1.5 cm complete size of the beef block 6 groups as a large group, each group were recorded as 0 d fresh, 1 d chilled, 10 d TOMIN, 10 d refrigerator, 20 d TOMIN, 20 d refrigerator, 30 d TOMIN, 30 d refrigerator. Fresh samples were prepared according to the method of tomato beef brisket prefabrication. Other samples were reheated in boiling water bath for 20 minutes, standing at room temperature, and the surface moisture was wiped off. The samples to be tested were placed on the texture analyzer stage for TPA experiment. Hardness, elasticity, cohesiveness and chewiness were selected as the detection indexes of texture characteristics of beef [9].

The full texture mode was adopted, and the height correction distance was 30 mm. Test conditions of texture analyzer: TPA was measured by P/ 36R probe. The parameters were as follows: pre-test speed 1.0 mm/ s, mid-test speed 5.0 mm / s, post-test speed 5.0 mm / s, strain mode 40 %, trigger force 5 g, collection rate 200, parallel measurement for 6 times.

3.2.5. Determination of volatile components

The volatile components of tomato beef brisket under different freezing methods and different freezing time were determined by purge and trap-gas chromatography-mass spectrometry. Tomato sirloin samples of 0 d fresh, 1 d chilled, 10 d frozen, 10 d refrigerator, 20 d frozen, 20 d refrigerator, 30 d frozen and 30 d refrigerator were prepared. The fresh samples were prepared according to the method of tomato beef brisket prefabrication, and the other samples were reheated in a boiling water bath for 20 minutes and stood at room temperature. Stir the sample, accurately weigh 5.00 g in the purge bottle, refer to the method of [10-11], and make some modifications, the specific parameters are as follows:

GC-MS conditions: chromatographic column: HP-5MS; the initial temperature was 40 °C and kept for 10 min. Then it was heated to 120 °C at 5 °C / min. Then it was heated to 230 °C at 10 °C / min for 7 min. The inlet temperature was 250 °C, the carrier gas was helium, and the electron energy was 70 eV.

3.2.6. Fourier transform infrared determination

Tomato beef brisket samples of 0 d fresh, 1 d chilled, 10 d TOMIN, 10 d refrigerator, 20 d TOMIN, 20 d refrigerator, 30 d TOMIN and 30 d refrigerator were prepared. Fresh samples were prepared according to the method of tomato beef brisket prefabrication. and the other samples were reheated in a boiling water bath for 20 minutes and stood at room temperature. The sample to be tested was cut into small pieces and dried in a constant temperature drying oven at 40 °C for 3 hours. The sample was taken out, and the sample was further ground with a clean mortar and pestle to make it more homogenized. A certain amount of ground sample was put into a clean sample pool to ensure that the sample was evenly distributed in the sample pool without obvious accumulation or voids. Wipe clean with ethanol when changing samples.

3.3. Data Processing And Plotting

The experimental data were averaged from three experiments. SPSS 26.0 was used for data analysis and processing. Origin 2019, OMNIC and PeakFit were used for drawing graphics.

4. RESULTS AND DISCUSSION

4.1. Sensory Analysis

Sensory score results are shown in Table 5. The average sensory scores of liquid TOMIN tomato beef brisket at different storage time (10 d, 20 d, 30 d) were 85.90 ± 0.80 , 79.80 ± 0.80 , 73.40 ± 0.77 ,

respectively. The average scores of the refrigerator freezing group at different storage time (10 d, 20 d, 30 d) were 80.90 ± 0.77 points, 72.90 ± 0.67 points, 63.50 ± 0.86 points, respectively. It can be seen from Fig.1 that the sensory scores of the liquid TOMIN tomato beef brisket treatment group at different storage times were higher than those of the refrigerator, and the difference in scores was relatively small. Especially after 20 days, the sensory scores of the two freezing methods were significantly different. In addition, the sensory scores of tomato beef brisket treated by liquid TOMIN and refrigerator freezing decreased with the extension of storage time.

The reason is that the ice crystal formation zone of the food is below -1°C to -5°C . When the food is frozen, the phase change process of water into ice is an important stage affecting the final quality of the food [12]. The liquid TOMIN equipment adopts advanced rapid cooling technology, which can reduce the temperature of tomato beef brisket to a suitable storage temperature in a short time. This rapid cooling process can minimize the nutritional loss and quality change of tomato sirloin, so that it can maintain the original taste, color and nutritional value, so the sensory evaluation score is high. In contrast, the refrigeration process of the refrigerator is relatively slow. Although the tomato beef brisket can also be refrigerated or frozen, it takes a certain amount of time to reach the ideal temperature. The longer the time to reach the ideal temperature, the more unstable the food quality will be, which may lead to poor taste, poor color and loss of nutrition. It cannot meet the needs of evaluators for fresh and high-quality food, so the sensory evaluation score is low.

Table 5. Sensory evaluation score table of tomato sirloin

Specimen	Tincture	Taste	Fragrance	Sense	Overall Acceptability	Sensory Scores
0 d Freshness	19.00 ± 0.67^a	18.80 ± 0.63^a	19.10 ± 0.74^a	19.00 ± 0.67^a	19.00 ± 0.47^a	94.90 ± 0.62^a
1 d Chilled	18.40 ± 0.52^{ab}	17.80 ± 0.79^b	18.10 ± 0.74^b	18.20 ± 0.60^b	18.20 ± 0.63^b	90.70 ± 0.67^b
10 d TOMIN	17.90 ± 0.74^b	16.50 ± 0.71^c	17.20 ± 0.63^c	17.10 ± 0.70^c	17.20 ± 0.63^c	85.90 ± 0.80^c
10 d refrigerator	16.90 ± 0.74^c	15.80 ± 0.63^d	16.10 ± 0.74^d	16.00 ± 0.60^d	16.10 ± 0.74^d	80.90 ± 0.77^d
20 d TOMIN	16.80 ± 0.63^c	15.90 ± 0.74^{cd}	15.80 ± 0.63^e	15.30 ± 0.60^e	16.00 ± 0.67^d	79.80 ± 0.80^d
20 d refrigerator	14.80 ± 0.63^d	14.50 ± 0.53^e	14.50 ± 0.71^e	14.20 ± 0.60^f	14.90 ± 0.74^e	72.90 ± 0.67^e
30 d TOMIN	15.10 ± 0.74^d	14.50 ± 0.71^e	14.70 ± 0.48^e	14.00 ± 0.60^f	15.10 ± 0.74^e	73.40 ± 0.77^e
30 d refrigerator	12.70 ± 0.95^e	12.50 ± 0.71^f	12.90 ± 0.74^f	12.20 ± 0.70^g	13.20 ± 0.92^f	63.50 ± 0.86^f

Note: The data in the table are mean \pm standard deviation, and the data in the same row or column are marked with completely different English letters to indicate that the mean value of the data is significantly different ($p < 0.05$).

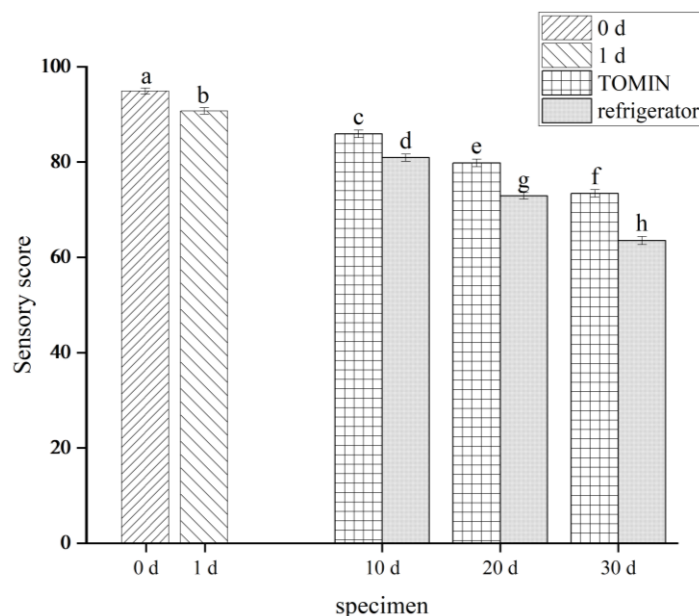


Figure 1. Sensory score of tomato brisket

4.2. Color Difference Analysis

Color difference is not only an important index to evaluate the senses, but also an important index to measure the freshness of meat [13]. The experimental results of Table 6 and Figure 2-7 show that the L* value of tomato beef brisket frozen by liquid TOMIN and refrigerator freezing increases to varying degrees after 1 day of refrigeration, but with the extension of freezing time, the surface and inner L* brightness values of the two groups of freezing methods are showing a downward trend, and the brightness value of the refrigerator decreases rapidly. The longer the storage time, the lower the a* redness value and the lower the b* yellowness value. The color of the two freezing methods changes with time. As the same as the sensory score results, all the color difference changes of the liquid TOMIN tomato beef brisket are smaller than those of the refrigerator, so the liquid TOMIN frozen tomato beef brisket is more stable in the color difference index, the quality reduction degree is higher, and the preservation effect is better.

The first reason is that during freezing, the TOMIN technology freezes the tomato beef brisket quickly, resulting in no obvious change in the internal color of the tomato beef brisket. Secondly, after thawing and reheating, the main reason for the increase of L* brightness value is that the cold storage of tomato beef brisket leads to the loss of water on the surface of the meat, and the brightness of the meat surface increases after the loss of water, so that the L* brightness value increases. However, with the extension of the freezing time of tomato beef brisket, the L* value showed a downward trend and the refrigerator freezing showed a large downward trend, because the refrigerator freezing effect was poor, resulting in a high degree of oil oxidation in tomato beef brisket, thus reducing the brightness of the meat. The a* redness value has been declining because the sample is exposed to the air, so that the myoglobin in the beef is in contact with oxygen, and the surface forms and accumulates high-iron myoglobin [14]. The reason for the continuous decrease of b* yellow value may be due to fat oxidation and protein decomposition in beef brisket. On the whole, there is a certain gap between the color difference of tomato beef brisket frozen by TOMIN equipment and the refrigerator freezing method.

Table 6. Color of tomato beef brisket

Specimen	Surface			Inner		
	L*(brightness)	a*(redness)	b*(yellowness)	L*(brightness)	a*(redness)	b*(yellowness)
0 d Freshness	43.26±0.19 ^b	21.23±0.19 ^a	34.72±0.02 ^a	56.30±0.09 ^b	14.84±0.17 ^a	29.32±0.09 ^a
1 d Chilled	44.41±0.03 ^a	20.86±0.13 ^b	33.36±0.13 ^b	57.61±0.52 ^a	13.83±0.08 ^b	26.62±0.48 ^b
10 d TOMIN	42.85±0.10 ^c	17.57±0.04 ^c	31.43±0.08 ^c	55.07±0.05 ^c	13.34±0.55 ^c	26.75±0.02 ^c
10 d refrigerator	42.10±0.20 ^d	16.73±0.02 ^d	30.42±0.05 ^d	53.73±0.05 ^d	11.12±0.01 ^e	25.14±0.12 ^d
20 d TOMIN	41.92±0.08 ^d	16.73±0.05 ^d	29.42±0.41 ^e	54.73±0.23 ^c	12.94±0.04 ^d	24.74±0.01 ^e
20 d refrigerator	40.64±0.04 ^e	15.12±0.04 ^e	27.48±0.27 ^f	53.68±0.10 ^d	11.44±0.07 ^d	22.71±0.29 ^f
30 d TOMIN	40.81±0.16 ^e	14.16±0.02 ^f	25.22±0.09 ^g	51.24±0.20 ^e	10.41±0.07 ^f	22.24±0.06 ^g
30 d refrigerator	39.52±0.26 ^f	11.19±0.02 ^g	23.37±0.04 ^h	49.86±0.09 ^f	8.21±0.03 ^g	19.96±0.08 ^h

Note: The data in the table are mean ± standard deviation, and the data in the same row or column are marked with completely different English letters to indicate that the mean value of the data is significantly different (p<0.05).

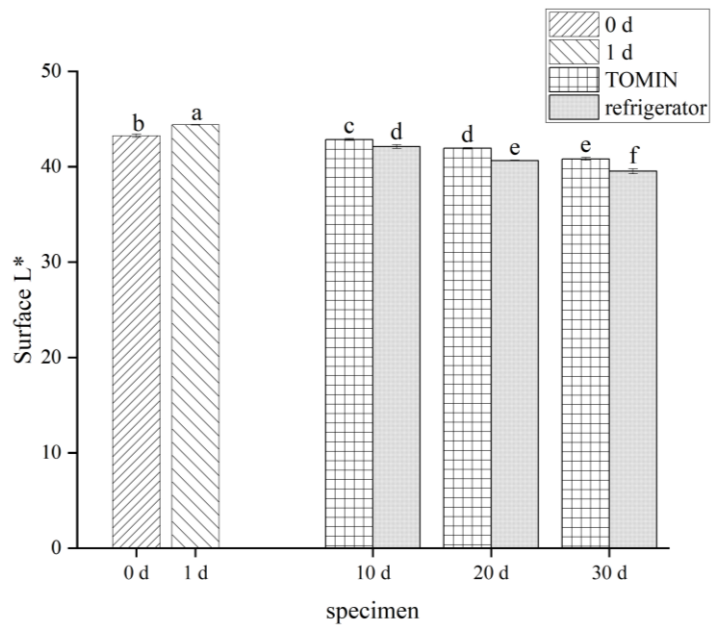


Figure 2. L* brightness value of tomato brisket surface

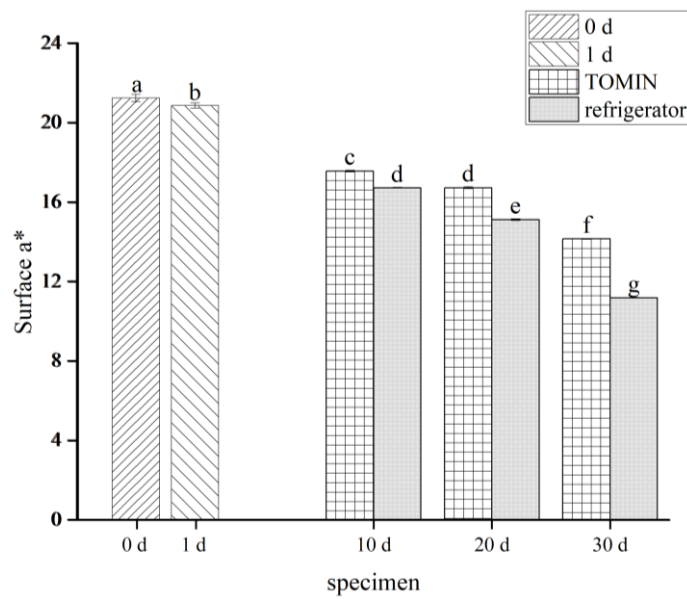


Figure 3. The a* redness value of tomato brisket surface

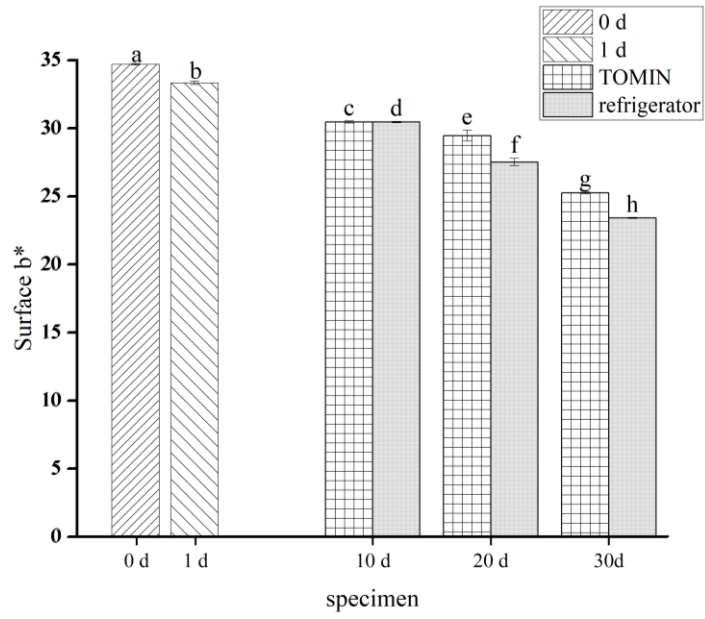


Figure 4. The b * yellowness value of tomato brisket surface

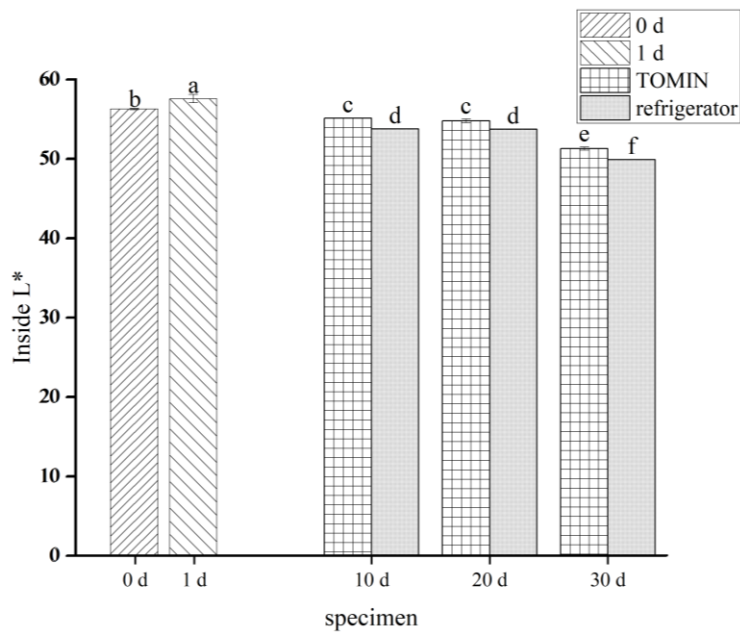


Figure 5. L * brightness value in tomato brisket

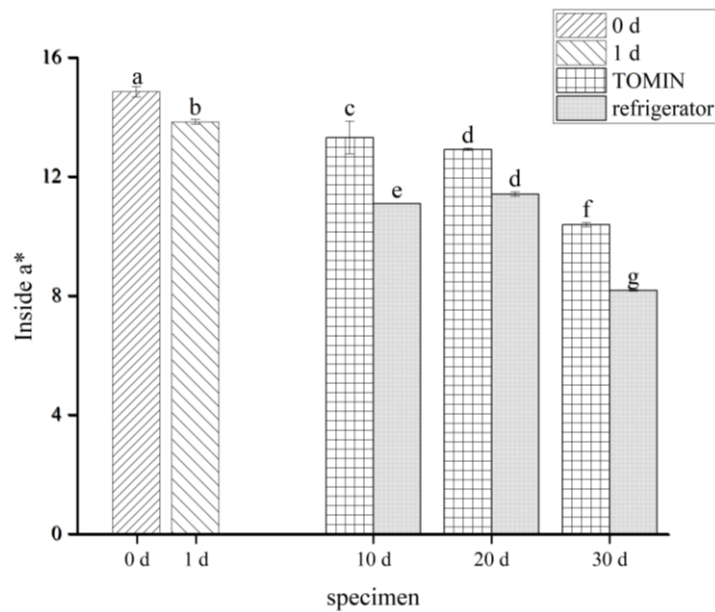


Figure 6. The a* redness value in tomato brisket

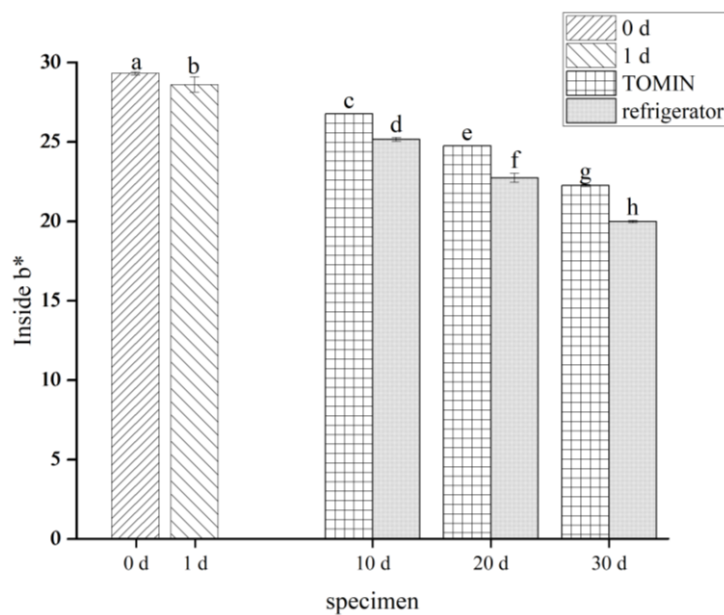


Figure 7. Tomato brisket b* inner yellow value

4.3. Water Content Analysis

The effects of different storage time under different freezing methods on the water content of beef sirloin are shown in Table 7. The water contents of liquid TOMIN beef brisket at different storage time (10 d, 20 d, 30 d) were $53.50\% \pm 0.10$, $51.67\% \pm 0.06$, $49.93\% \pm 0.15$, respectively. The water contents of the refrigerator frozen group at different storage time (10 d, 20 d, 30 d) were $52.83\% \pm 0.12$, $49.63\% \pm 0.21$, $47.30\% \pm 0.20$, respectively. It can be seen from Fig.8 that the change of water content in tomato beef brisket is not significant, but the water content of tomato beef brisket treated with liquid TOMIN is higher than that of refrigerator at different storage time, and the change value of water content is smaller than that of refrigerator.

The reason is that the food cells are about 20 microns at room temperature. Due to the slow freezing speed of the ordinary refrigerator, the ice crystal diameter is about 50-100 microns, which is easy to

destroy the food cell membrane, resulting in the outflow of juice in the cells and the decrease of the water content of the food. The size of ice crystals formed by water is only five microns inside the food cells treated by TOMIN, which will not cause physical damage to the cell membrane wall. Since the cell tissue is not destroyed, the inherent juice nutrition of the food will not be lost after natural thawing, and the freshness is as good as before.

Table 7. Changes in moisture content of tomato beef brisket

Specimen	Moisture content%
0 d Freshness	55.23±0.15 ^a
1 d Chilled	54.57±0.15 ^b
10 d TOMIN	53.50±0.10 ^c
10 d refrigerator	52.83±0.12 ^d
20 d TOMIN	51.67±0.06 ^e
20 d refrigerator	49.63±0.21 ^f
30 d TOMIN	49.93±0.15 ^f
30 d refrigerator	47.30±0.20 ^g

Note: The data in the table are mean ± standard deviation, and the data in the same row or column are marked with completely different English letters to indicate that the mean value of the data is significantly different ($p < 0.05$).

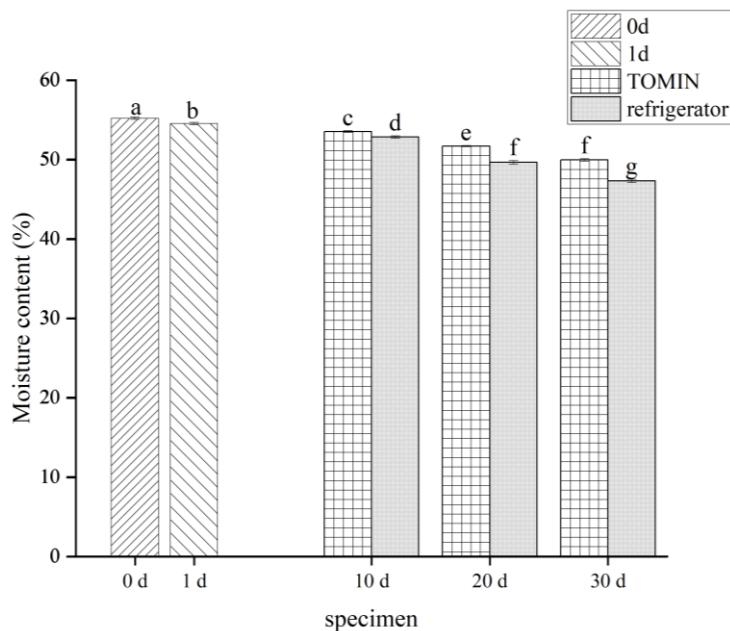


Figure 8. Changes in water content of tomato brisket

4.4. Texture Analysis

Muscle fiber, muscle connective tissue and intramuscular fat are the most important factors affecting the tenderness of meat. Texture indicators can more intuitively reflect the tenderness of meat^[15]. The effects of different storage time under different freezing methods on the texture of beef brisket are shown in Table 8. In terms of fresh-keeping texture, there are obvious differences between liquid TOMIN equipment and refrigerator. It can be seen from Fig.9-12 that the hardness, elasticity and chewiness of beef brisket increased significantly after freezing at -18°C in the refrigerator, while the texture index of TOMIN samples showed an upward trend compared with refrigerator freezing, but the increase was relatively small. It can be seen from Table 8 that the changes of hardness, elasticity and chewiness of the two freezing methods were significantly different, especially after 20 days. In

terms of hardness, the hardness of 20 d TOMIN was 3143.66 ± 43.37 g, the hardness of 20 d refrigerator freezing was 3927.03 ± 93.30 g, the hardness of 30 d TOMIN freezing was 3732.17 ± 23.35 g, and the hardness of 30 d refrigerator freezing was 4555.16 ± 58.81 g. In terms of elasticity, the elasticity of 20 d TOMIN freezing was $82.33 \% \pm 0.47$, the elasticity of 20 d refrigerator freezing was $85.85 \% \pm 1.47$, the elasticity of 30 d TOMIN freezing was $85.09 \% \pm 0.10$, and the elasticity of 30 d refrigerator freezing was $88.59 \% \pm 1.03$. In terms of chewiness, the chewiness of 20 d TOMIN was 1731.56 ± 21.07 g, 20 d frozen samples was 2015.12 ± 44.85 g, 30 d TOMIN was 1895.89 ± 13.14 g, 30 d frozen samples was 2224.55 ± 65.80 g.

Texture index, like sensory score, color difference and water content, changed with time. The reason is that TOMIN can better protect the cell structure of food and prevent the deterioration of texture. Due to the relatively unstable temperature and humidity environment in the refrigerator, food may dehydrate and harden, resulting in changes in texture. This is consistent with the results of TAN et al. [16-17]. The study showed that under the condition of -18°C , the color of spiced beef became brown and formed hard ice. After natural thawing, the elasticity and texture of spiced beef gradually deteriorated, the loss of taste and nutrition was serious, and the characteristics of spiced beef were basically lost. Especially for some foods with high texture requirements, such as meat and seafood, this texture change may affect the taste and quality of food. Through comparison, it is found that the liquid TOMIN equipment can better maintain the texture and taste of the food, so that the food can still maintain the original freshness and elasticity after storage.

Table 8. Texture results of tomato beef brisket

Specimen	Hardness g	Elasticity %	Cohesion %	Chewing property g
0 d Freshness	1777.16±21.11h	76.05±1.90e	0.67±3.26b	1120.13±83.81h
1 d Chilled	2131.16±24.45g	79.30±1.62d	0.68±0.61b	1282.68±35.04g
10 d TOMIN	2349.95±37.58f	80.84±0.48cd	0.70±1.04b	1400.15±17.03f
10 d refrigerator	2825.69±72.61e	82.29±0.95c	0.71±6.48b	1646.16±37.68e
20 d TOMIN	3143.66±47.37d	82.33±0.47c	0.72±0.84ab	1731.56±21.07d
20 d refrigerator	3927.03±93.30c	85.85±1.47b	0.73±1.11ab	2015.12±44.85c
30 d TOMIN	3732.17±23.35b	85.09±0.10b	0.73±3.45ab	1895.89±13.14b
30 d refrigerator	4555.16±58.81a	88.59±1.03a	0.78±5.80a	2224.55±65.80a

Note: The data in the table are mean \pm standard deviation, and the data in the same row or column are marked with completely different English letters to indicate that the mean value of the data is significantly different ($p < 0.05$).

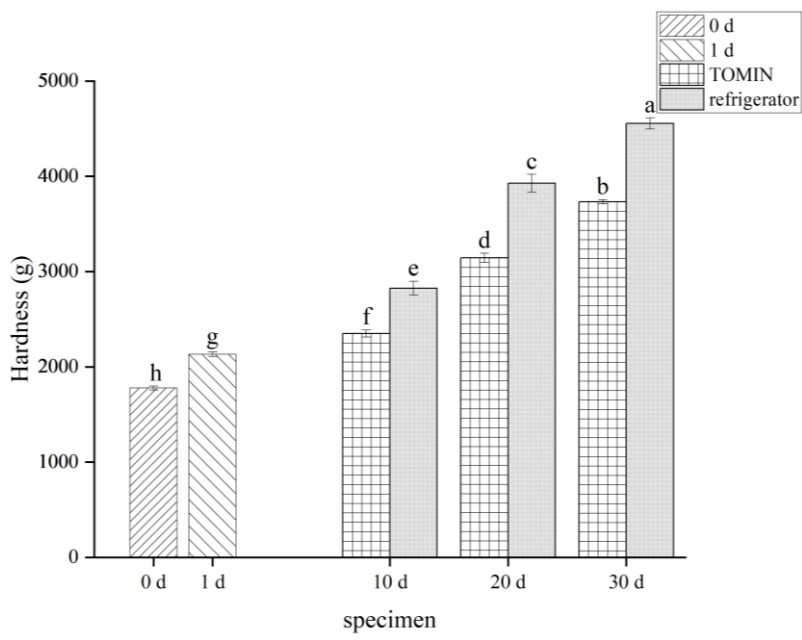


Figure 9. Tomato brisket hardness

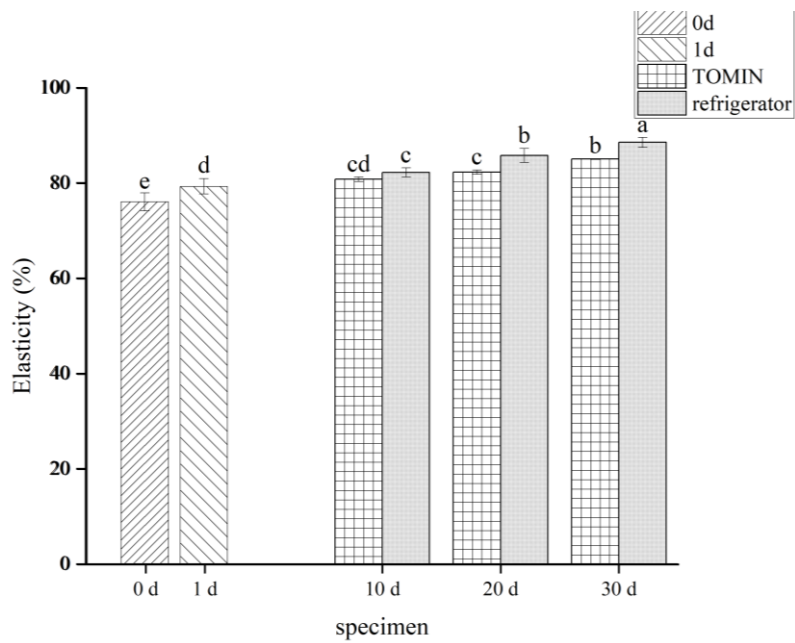


Figure 10. Tomato brisket elasticity

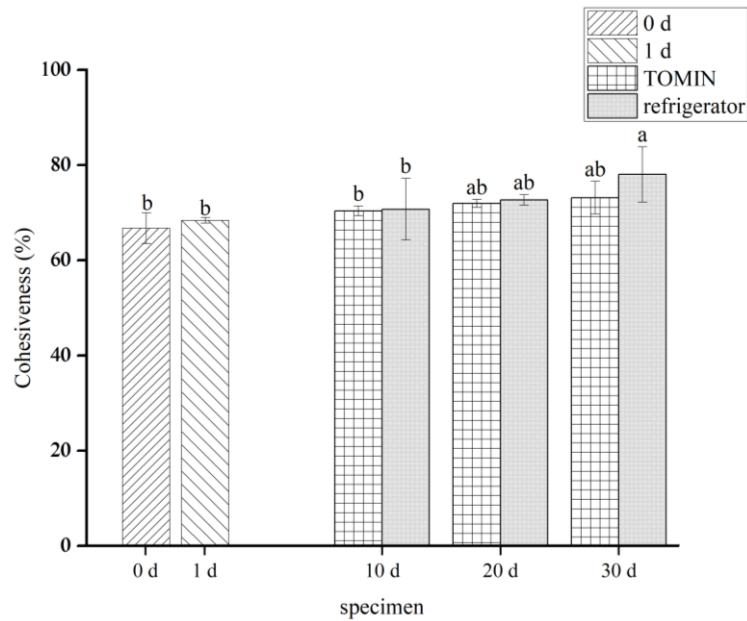


Figure 11. Cohesiveness of tomato brisket

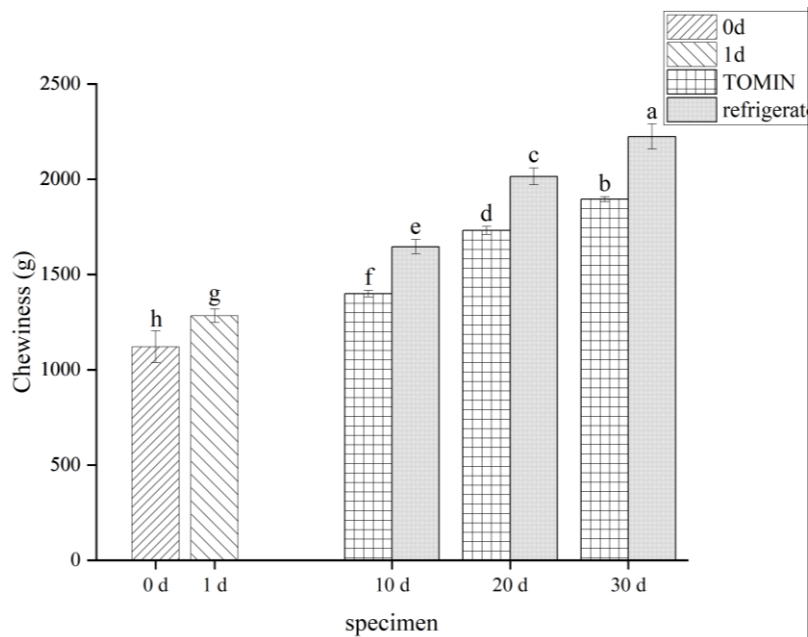


Figure 12. Chewiness of tomato brisket

4.5. Analysis Of Volatile Components

The volatile components of tomato beef brisket were different in different freezing time after liquid TOMIN and refrigerator freezing. According to the purge and trap-gas chromatograph-mass spectrometer, the volatile components of tomato beef brisket treated with different freezing methods for different freezing time are shown in Appendix Table 9, the total ion current diagram of volatile components is shown in Fig.13-20, and the heat map of volatile components after normalization is shown in Fig.23. A total of 29 substances were detected, including 10 aldehydes, 3 ketones, 3 alcohols, 5 hydrocarbons, 2 esters, 2 ethers, 2 phenols and 2 other substances. The key analysis of various flavor substances is as follows:

Table 9. Flavor components of tomato brisket with different freezing methods at different times

structural formula	name of compound	Relative content of compounds %							
		0 d fresh	1 d fresh	TOMIN			Refrigerator		
				10 d	20 d	30 d	10 d	20 d	30 d
Aldehydes									
C ₆ H ₁₂ O	hexanal	3.92	3.94	4.00	4.24	4.13	4.01	4.37	4.53
C ₇ H ₆ O	benzaldehyde	-	-	0.59	0.95	0.73	0.60	0.99	1.34
C ₈ H ₁₆ O	caprylic aldehyde	1.07	1.10	1.24	1.31	1.28	1.26	1.32	1.33
C ₁₀ H ₁₈ O	(E) -2-Decenal	0.02	0.07	0.24	0.36	0.29	0.28	0.35	0.48
C ₉ H ₁₈ O	nonanal	10.31	10.46	11.03	12.79	11.56	11.81	12.63	13.32
C ₁₀ H ₁₆ O	(E, E) -2, 4-decadienal	-	-	-	0.06	0.02	0.04	0.09	0.12
C ₁₀ H ₁₆ O	α -citral	-	-	0.30	0.38	0.35	0.31	0.39	0.44
C ₁₄ H ₂₈ O	tetradecyl aldehyde	-	1.03	1.07	1.13	1.10	0.09	1.12	1.17
C ₆ H ₆ O ₂	5-methylfurfural	-	-	-	0.52	0.48	0.28	0.59	0.62
C ₁₀ H ₁₂ O	cuminaldehyde	1.43	1.46	1.53	1.65	1.59	1.57	1.67	1.73
Ketone									
C ₇ H ₁₄ O	methylacetyl urea amyl ketone	2.07	2.11	2.34	2.71	2.63	2.49	2.74	2.87
C ₁₀ H ₁₆ O	camphor	0.35	0.38	0.54	0.77	0.61	0.72	0.94	0.99
C ₉ H ₁₈ O	2-nonanone	-	0.23	0.44	0.52	0.47	0.43	0.55	0.57
Alcohols									
C ₁₀ H ₁₈ O	linalool	0.12	0.15	0.37	0.52	0.44	0.41	0.53	0.55
C ₁₀ H ₁₈ O	geraniol	1.26	1.34	1.43	1.61	1.57	1.46	1.65	1.74
C ₈ H ₁₀ O	phenylethyl alcohol	1.19	1.27	1.46	1.75	1.59	1.68	1.76	1.87
Hydrocarbons									
C ₁₀ H ₁₆	camphene	3.52	3.56	3.64	3.81	3.77	3.76	3.81	3.82
C ₁₀ H ₁₆	nopinene	-	-	2.11	2.19	2.16	2.14	2.24	2.26
C ₁₀ H ₁₆	3-carene	2.03	2.57	2.75	3.91	3.38	3.44	3.99	4.84
C ₁₀ H ₁₄	1-methyl-3-isopropylbenzene	1.49	1.51	1.63	2.06	1.77	1.85	2.12	2.21
C ₁₀ H ₁₆	terpinolene	1.02	1.09	1.33	1.71	1.64	1.55	1.96	2.88
Ester									
C ₁₂ H ₂₀ O ₂	terpinyl acetate	1.03	1.07	1.31	1.42	1.38	1.34	1.49	1.55
C ₁₁ H ₁₂ O ₂	cinnamyl acetate	-	0.07	0.25	0.36	0.32	0.29	0.41	0.47
Ethers									
C ₁₀ H ₁₈ O	eucalyptol	1.36	1.48	1.52	1.74	1.68	1.65	1.85	1.92
C ₁₀ H ₁₂ O	anethole	1.56	1.61	1.72	2.04	1.79	1.83	1.92	2.19
Phenols									
C ₁₅ H ₂₄ O	2,6-di-tert-butyl-4-methylphenol	-	-	0.07	0.18	0.13	0.12	0.20	0.24
C ₁₁ H ₁₆ O ₂	5-Pentyl-1, 3-benzenediol	-	0.05	0.13	0.32	0.26	0.28	0.35	0.46
Miscellaneous									
C ₇ H ₅ NS	benzothiazole	1.25	1.26	1.49	1.68	1.65	1.57	1.70	1.72
C ₆ H ₆ O ₂	2-acetylfuran	-	-	-	0.08	0.05	0.03	0.12	0.16

Aldehydes in the volatile flavor components of meat are produced by lipid oxidation, which contribute greatly to the aroma of meat due to its low threshold. [18] The detected nonanal is a typical fat oxidation product, and hexanal is an important aroma component of tomato [19-20]. The contents of nonanal and hexanal detected by different freezing methods at different freezing time were different. The sources of ketones are mostly the oxidative degradation of unsaturated fatty acids, and some are important intermediates for the formation of heterocyclic compounds [21]. The detected 2-heptanone and 2-nonanone had sweet fruity, floral and green flavor, which may have a great contribution to the flavor of tomato.

Alcohols mainly come from fat oxidation. The threshold of linear saturated alcohol in alcohols is high, which has little effect on the overall flavor. The detected phenylethanol is considered to play an important role in the flavor of soy sauce. Linalool and geraniol are present in the volatile components of cinnamon.

Hydrocarbon volatile substances are mainly derived from the cleavage of fatty acid alkoxy radicals [22]. Among them, hydrocarbons are mainly terpene spices, camphene, 3-carene, terpinolene. These terpene compounds have a great relationship with the spices added in the cooking process of meat, and the smell is strong.

The esters, ethers and phenols detected were mostly related to the spices added in the cooking process of tomato brisket. The esters of cinnamyl acetate and terpinyl acetate have rose-yew aroma and woody aroma, respectively, which is also related to the spices added in the cooking process of tomato beef brisket. The anisole detected by ethers mainly comes from *Zanthoxylum bungeanum*, with fennel, spicy, licorice, and eucalyptol is present in the volatile components of cinnamon. The 2,6-di-tert-butyl-p-cresol detected by phenols is mostly in animal and vegetable oils, which has little effect on the flavor of tomato brisket.

Benzothiazole in other classes has a similar fennel oil odor, strong aroma, low threshold, and has a significant effect on meat flavor. 2-Acetylfuran has almonds, roasted incense, smoked incense, and low threshold value. It is an important flavoring substance in beef and plays an important role in the formation of unique flavor of tomato beef brisket.

The PCA results of volatile components are shown in Fig.21 and Fig.22. The main purpose of PCA is to eliminate the random errors in the principal components, thereby reducing the dimension of complex problems and minimizing the influence of measurement errors [23-24]. According to the two figures, it can be seen that fresh samples and cold fresh samples are obviously separated from samples with different days of TOMIN and refrigerator freezing. The cumulative contribution rate of PCA was 94.8 %. The variance contribution rate of PC1 is 90.2 %, which can represent the volatile components of 30 d refrigerator. Therefore, it can be seen that the volatile components of the refrigerator treatment group are relatively more. The variables highly correlated with PC1 are benzaldehyde, hexanal, nonanal, and 2-heptanone, mainly from fat oxidation, and PC2 is related to β -pinene and 2-nonanone. Kilgannon et al. [25] showed that hexanal, nonanal and 2-heptanone were negatively correlated with sweet and umami amino acids, that is, the higher the content of these volatile flavor compounds, the lower the content of sweet and umami amino acids. The results of this experiment showed that the contents of hexanal, nonanal and 2-heptanone in tomato brisket frozen in refrigerator were high, so it could be explained that the refrigerator had a worse effect than the frozen-dormant freezing, and the effect of maintaining the original flavor of the sample was poor. The results of volatile components were consistent with the results of taste and aroma scores in sensory evaluation, which indicated that the TOMIN tomato beef brisket could better maintain the original flavor.

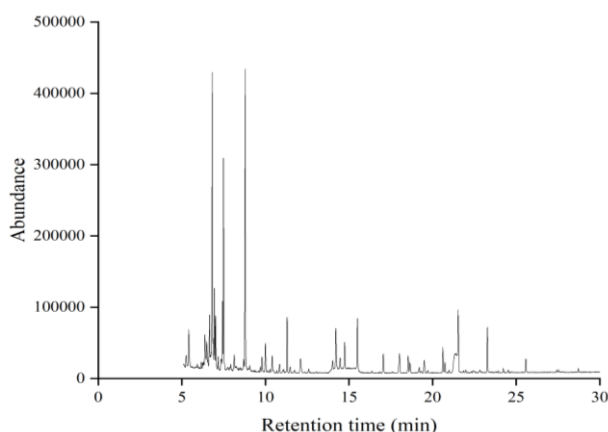


Figure 13. 0 d total ion flow diagram of fresh tomato beef brisket

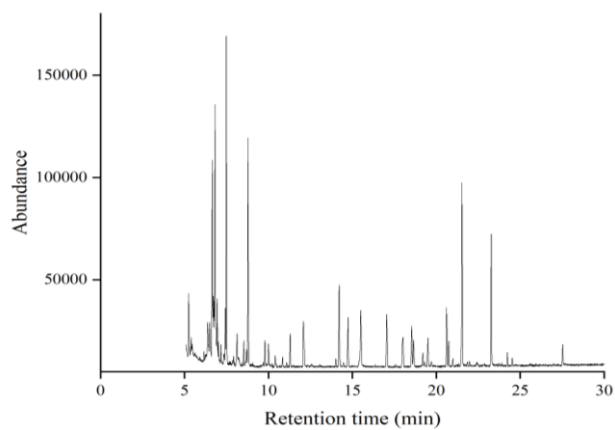


Figure 14. Total ion flow diagram of 1 d chilled tomato brisket

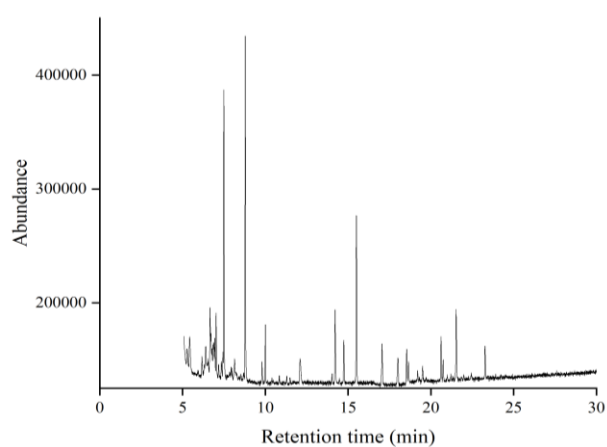


Figure 15. 10 d total ion flow diagram of frozen hibernation tomato brisket

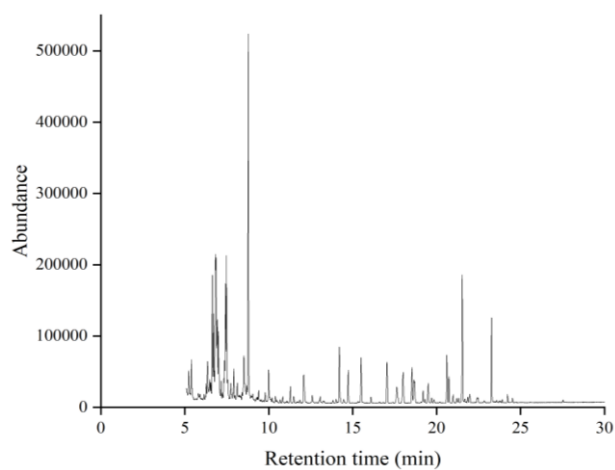


Figure 16. Total ion flow diagram of 10 d refrigerator tomato brisket

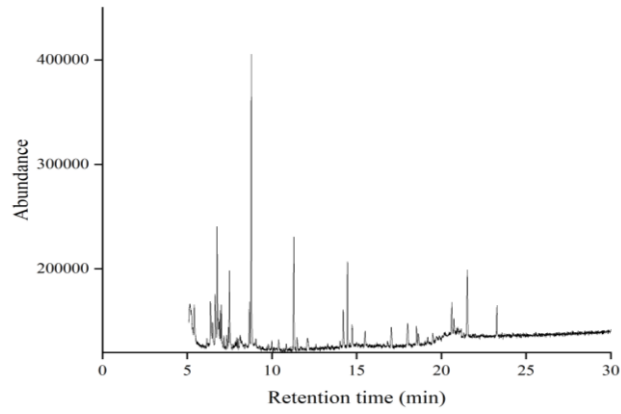


Figure 17. Total ion flow diagram of 20 d frozen hibernation tomato beef brisket

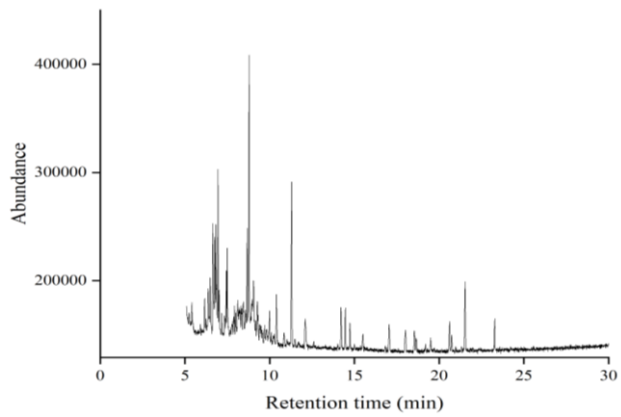


Figure 18. Total ion flow diagram of 20 d refrigerator tomato brisket

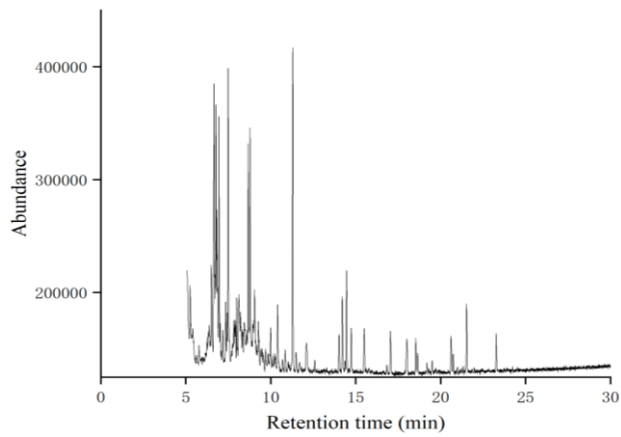


Figure 19. Total ion current diagram of 30 d frozen tomato brisket

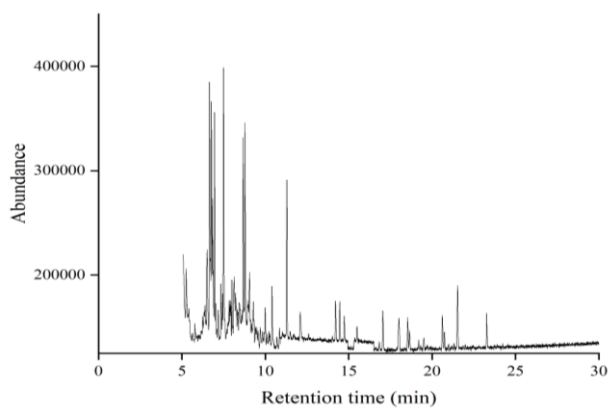


Figure 20. 30 d total ion flow diagram of tomato brisket in refrigerator

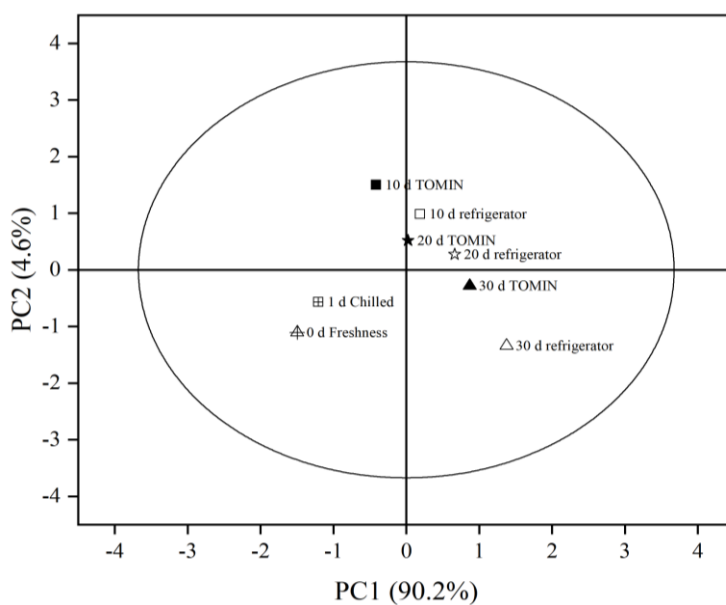


Figure 21. Principal component score plot

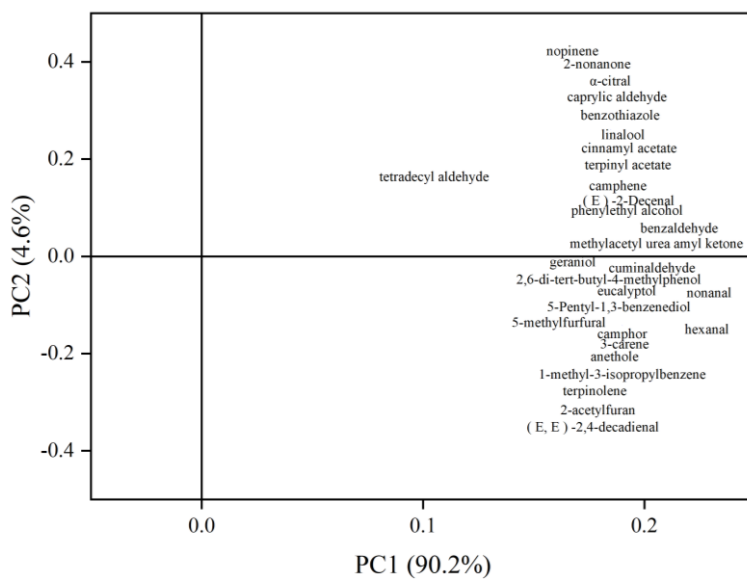


Figure 22. Principal component load diagram

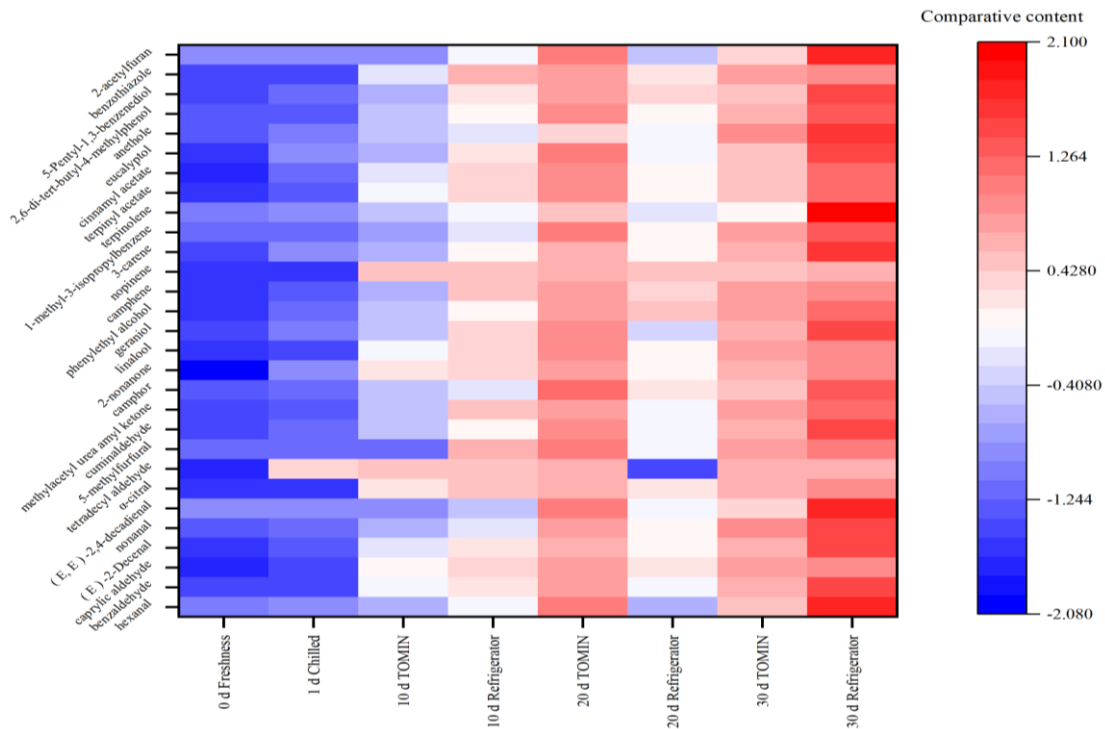


Figure 23. Heat map of relative content of volatile components

4.6. Fourier Transform Infrared Analysis

The functional properties of proteins affect the quality of meat and meat products [26]. The secondary structure of a protein reflects the spatial arrangement of its main chain atoms, excluding the conformational changes of the side chains. As shown in Table 10, the main conformations include four structures: α -helix, β -sheet, β -turn, and random coil. The $1600 \sim 1639 \text{ cm}^{-1}$ band represents the β -sheet structure; the $1640 \sim 1650 \text{ cm}^{-1}$ band represents a random coil structure (C = O forms hydrogen bonds with water); the band of $1651 \sim 1660 \text{ cm}^{-1}$ represents the α -helix structure. The $1661 \sim 1700 \text{ cm}^{-1}$ band represents the β -turn structure, and the relative content of each secondary structure is calculated according to the peak area.

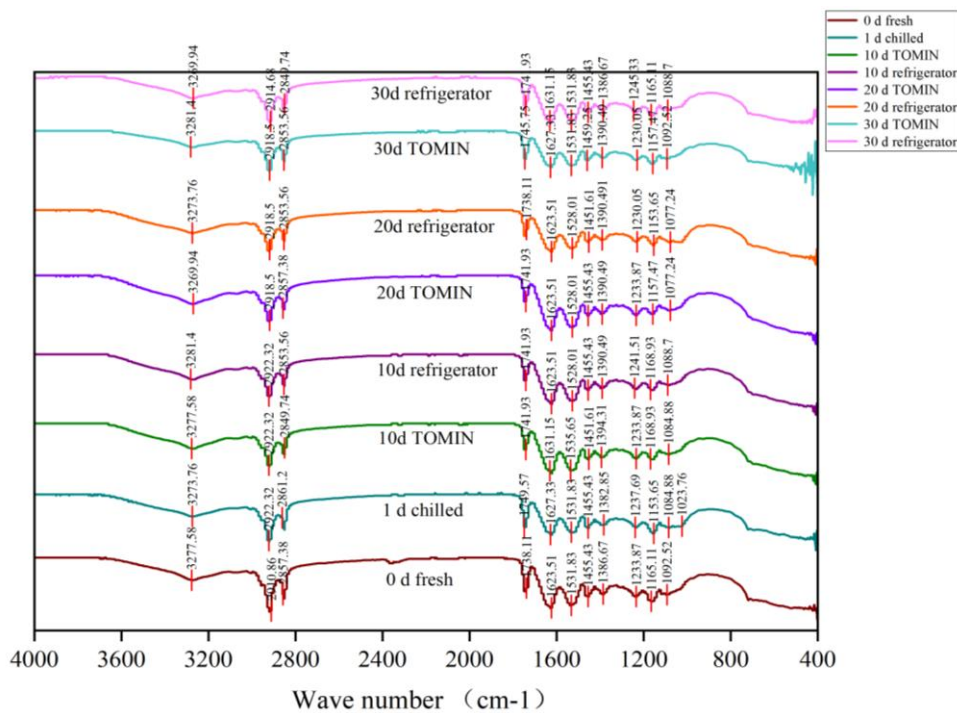
The content of each secondary structure of the protein in the tomato brisket was determined by Fourier transform infrared spectrometer as shown in Table 10. The Fourier infrared analysis spectrum is shown in Fig. 24, and the content change of the secondary structure is shown in Fig. 25. The change of protein secondary structure content of TOMIN tomato beef brisket was different from that of refrigerator frozen, which indicated that the protein spatial structure of tomato beef brisket frozen by different freezing methods had different changes. The results showed that the content of β -sheet was high and the change was small in the frozen samples, The contents of TOMIN 10 d, 20 d and 30 d were 44.24 %, 42.25 % and 41.16 %, respectively. The contents of different freezing time in the refrigerator group were 41.67 %, 39.32 % and 40.68 %, respectively. The content of α -helix in the TOMIN frozen for different time was 16.01 %, 14.12 % and 12.64 %, respectively. The content of α -helix in the samples frozen in refrigerator for different time was 14.03 %, 13.74 % and 10.21 %, respectively. The protein conformation in these two groups of freezing methods changed from order to disorder with the extension of time.

The β -turn and random coil content of the two experimental groups changed to varying degrees. The stability of α -helix is derived from the formation of hydrogen bonds. The existence and interaction of β -sheet and α -helix determine the tertiary structure and function of proteins. The β -turn and random coil also play an important role in the function and stability of proteins. The content of β -sheet and α -helix in the TOMIN group was high and the change was small, indicating that the protein structure of the frozen-dormancy group was more stable. This stability indicated that the protein in the TOMIN

group could play its role in the extreme environment, which indicated that the TOMIN group had good preservation effect and high quality reduction. Xiaoli et al [27] also showed that after freezing in the refrigerator, the muscle fibers in the beef became irregular, the protein molecules might be denatured or agglomerated, and the degree of water loss increased, making the beef inside become drier and tighter. This is consistent with the texture test results. YANG et al [28] also showed that protein oxidation often caused changes in the physical and chemical properties of proteins, resulting in deterioration of beef color, decreased water holding capacity and reduced nutritional value.

Table 10. The content of protein secondary structure in tomato beef brisket

Specimen	β strands%	Random coil%	Alpha-helix%	β corner%
	1600-1640	1640-1650	1650-1660	1660-1700
0 d Freshness	45.46	16.69	17.28	20.57
1 d Chilled	44.82	17.28	16.04	21.86
10 d TOMIN	44.24	16.13	16.01	23.62
10 d refrigerator	41.67	14.10	14.03	30.20
20 d TOMIN	42.25	18.83	14.12	24.79
20 d refrigerator	39.37	18.61	13.74	28.28
30 d TOMIN	41.16	16.14	12.64	30.05
30 d refrigerator	40.68	13.53	10.21	35.59



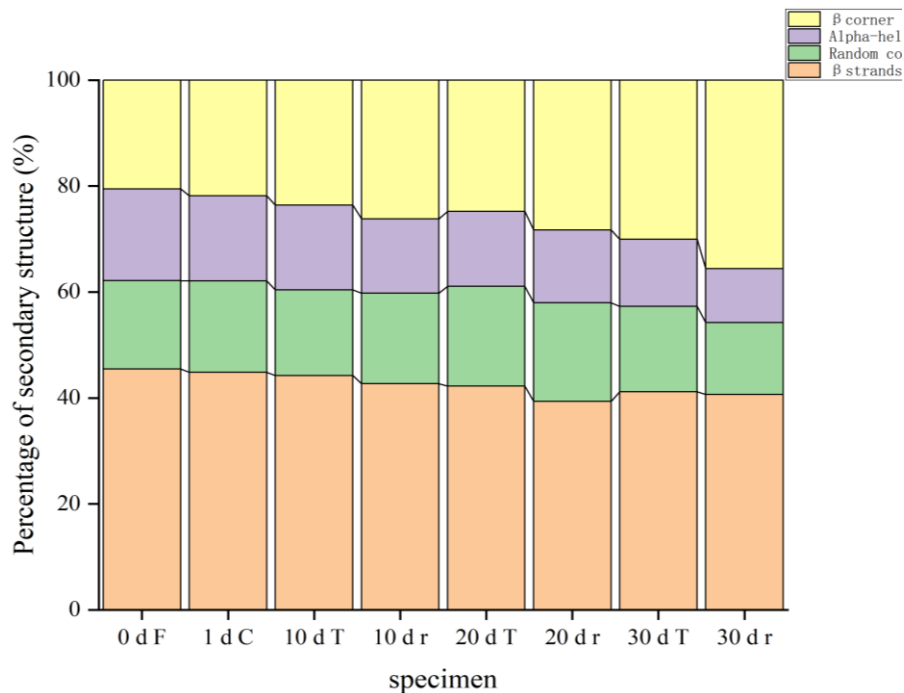


Figure 25. Protein secondary structure diagram

5. CONCLUSIONS AND PROSPECTS

5.1. Conclusion

In this paper, the effects of liquid TOMIN and refrigerator freezing on the sensory, color, water content, texture, volatile components and sensory evaluation of tomato beef brisket at different times were compared and studied. It was found that when the beef brisket was stored for the same time, the sensory score of tomato beef brisket treated by liquid TOMIN technology was higher, and the water content, color difference and texture change were small.

In the change of color difference, the longer the storage time of the two treatment groups, the brightness value and redness value showed a downward trend, and the yellowness value also showed a downward trend, but the change of color difference of TOMIN frozen was smaller than that of refrigerator frozen. It can be judged that the preservation effect of TOMIN treated tomato beef brisket on color difference is more stable and the quality reduction degree is high.

In terms of water content, under the same storage time, the water content of tomato beef brisket in the TOMIN treatment group and the refrigerator treatment group showed a downward trend, and the longer the storage time, the lower the water content. The water content of the refrigerator treatment group was lower than that of the TOMIN treatment. It can be judged that TOMIN freezing can better maintain the water content of the food itself and maintain the freshness of the food.

The changes of hardness, elasticity, chewiness and cohesiveness of texture indexes can better explain the good preservation effect of liquid TOMIN treatment group. Under the same storage time, the rising trend of hardness, elasticity, chewiness and cohesiveness of TOMIN treatment group is lower than that of refrigerator. Especially after 20 days, the changes of physical and chemical indexes of refrigerator treatment group are larger than those of TOMIN treatment group. Therefore, it can be judged that TOMIN tomato sirloin has good preservation effect on texture indexes.

In the analysis of volatile substances, the content of various volatile substances in different freezing methods at different times was different. The content of volatile substances in the two freezing methods increased with the extension of storage time, but it can be clearly seen that the content of

volatile substances in the TOMIN frozen was increased. Less, indicating that the oil oxidation rate of TOMIN frozen tomato beef brisket is lower than that of the refrigerator, and the preservation effect is good.

In the Fourier transform infrared index, it was concluded that the secondary structure of the liquid TOMIN tomato beef brisket protein was more stable.

In summary, the reduction degree of liquid TOMIN dormancy on the quality of prefabricated tomato beef brisket is higher than that of refrigerator. Liquid TOMIN technology can better maintain the quality and freshness of tomato beef brisket, reduce the water loss of food, maintain the original taste and nutritional value of food, and has certain advantages in the preservation effect of tomato beef brisket. Therefore, in order to have higher edible quality and better preservation effect, the liquid TOMIN technology with shorter freezing time and lower storage temperature should be selected as far as possible.

5.2. OUTLOOK

Liquid TOMIN technology is expected to become one of the mainstream ways of food preservation in the future. With the continuous development of science and technology and the promotion of market demand, liquid TOMIN technology may be continuously improved and upgraded in the preservation of food processing, logistics and transportation, catering industry and other fields. Through more advanced equipment and technology, the cooling system can be optimized, the microcrystalline material can be improved, or other preservation technologies can be combined to achieve more accurate temperature control and faster cooling speed, so as to further improve the preservation effect. It may automatically sense the state and environmental conditions of food through sensors, Internet of Things and other technologies, adjust preservation parameters, provide more personalized preservation solutions, and realize intelligent control and management of preservation technology. May pay more attention to energy conservation and environmental protection, by improving energy efficiency, reducing the use of refrigerants or the use of renewable energy, reduce the energy consumption of equipment and the impact on the environment.

In short, in the future, from production and processing to transportation and storage, and then to the sales terminal, better preservation effect and longer preservation period will become an important factor for consumers to choose fresh-keeping equipment. Liquid TOMIN technology has great potential and broad development prospects in the field of food preservation. The application of liquid TOMIN technology will bring a new revolution to the field of food preservation and bring more convenience and health protection to people's lives. We look forward to the continuous innovation and development of this technology, so that our table more rich and safe.

6. ACCEPTANCE SPEECH

At the end of this thesis, I want to express my sincere gratitude to those who have given special support and influence in my academic journey.

First of all, I would like to thank my mentor, the teacher with a unique perspective and in-depth insights to guide me to explore the mysteries of academic, not only in the research direction of the paper gives valuable advice, more when I encountered difficulties to give encouragement and support, let me continue to grow in the academic road.

Secondly, I want to thank my classmates and all the students who helped me in the laboratory, especially my experimental partners. We inspired each other during the experiment and supported each other in difficult moments. The communication and cooperation with experimental partners make my research work richer and more meaningful.

I would like to thank my family and friends, they have been giving me selfless support and encouragement on the way of my study, is that they let me under pressure can still remain optimistic and positive, so that I can persist.

Finally, I would like to thank myself for my persistence and efforts in this process. Every confusion and frustration has made me more determined to pursue knowledge and growth. This paper is not only a node of my academic career, but also a valuable experience in my life. I will continue to move forward with gratitude.

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REFERECES

- [1] LYU F, SHEN K J, DING Y T, et al. Effect of pretreatment with carbon monoxide and ozone on the quality of vacuum packaged beef meats [J]. *Meat Science*, 2016, 117: 137-146.
- [2] HUANG Y F, WANG Y F, LI Y Q, et al. Covalent immobilization of poly peptides on polylactic acid films (PLA) and their application to fresh beef preservation [J]. *Journal of Agricultural and Food Chemistry*, 2020, 68(39):10 532-10 541.
- [3] GAUTHIER I, FIESTAN G. Individual Differences in the Recognition of Prepared Food [J]. *Journal of Vision*, 2022, 22(14): 4101.
- [4] MCKERNAN C, LAVELLE F, MCCLOAT A, et al. A Qualitative Exploration of Consumers' Perceptions, Attitudes and Use of Smart Devices while Preparing Food in the Domestic Kitchen [J]. *Proceedings of the Nutrition Society*, 2023, 82(OCE1): 8.
- [5] AHMED S, SAMEEN D E, LU Rui, et al. Research Progress on Antimicrobial Materials for Food Packaging [J]. *Critical Reviews in Food Science and Nutrition*, 2022, 62(11): 3088-3102.
- [6] CAO Y, HAO R, GUO Z, et al. Combined effects of superchilling and natural extracts on beef preservation quality [J]. *LWT- Food Science and Technology*, 2022, 153: 112520.
- [7] ALMASI H, JAHANBAKHS OSKOUIE M, SALEH A. A Review on Techniques Utilized for Design of Controlled Release Food Active Packaging [J]. *Critical Reviews in Food Science and Nutrition*, 2021, 61(15): 2601-2621.
- [8] EGELANDSDAL B, ABIE S M, BJARNADOTTIR S, et al. Detectability of the degree of freeze damage in meat depends on analytic-tool selection [J]. *Meat Science*, 2019, 152: 8-19.
- [9] Lyu H, Na Q, Wang L, et al. Effects of Muscle Type and Aging on Glycolysis and Physicochemical Quality Properties of Bactrian camel (*Camelus bactrianus*) Meat [J]. *Animals*, 2024, 14(4).
- [10] AL-DALALI A, LI Cong, XU Baocai. Effect of frozen storage on the lipid oxidation, protein oxidation, and flavor profile of marinated raw beef meat [J]. *Food Chemistry*, 2022, 376: 131881. DOI:10.1016/ j. foodchem. 2021. 131881.
- [11] HAN Ge, ZHANG Lang, LIA Qixuan, et al. Impacts of different altitudes and natural drying times on lipolysis, lipid oxidation and flavour profile of traditional Tibetan yak jerky [J]. *Meat Science*, 2020, 162: 108030. DOI:10. 1016/ j. meatsci. 2019. 108030.
- [12] LI Y M, LIN H F, YANG Z D. The effect of magnetic field on freezing point of water [J]. *Journal of Physics: Conference Series*, 2022, 2194(1):012034.
- [13] MANCINI R A, HUNT M C. Current research in meat color [J]. *Meat Science*, 2005, 71(1): 100-121. DOI: 10. 1016/ j. meatsci. 2005. 03. 003.
- [14] NGUYEN T, PHAN K N, LEE J B, et al. Met-myoglobin formation, accumulation, degradation, and myoglobin oxygenation monitoring based on multiwavelength attenuance measurement in porcine meat [J]. *Journal of Biomedical Optics*, 2016, 21(5): 57002. DOI: 10. 1117/ 1. JBO. 21. 5. 057002.

- [15] JM Gonzalez DDJ, MAElzo. Effect of Brahman genetic influence on collagen enzymatic crosslinking gene expression and meat tenderness [J]. *Animal Biotechnology*, 2014, 25: 165-178.
- [16] FU H, PAN L, WANG J, et al. Sensory Properties and Main Differential Metabolites Influencing the Taste Quality of Dry-Cured Beef during Processing [J]. *Foods*, 2022, 11(4): 531.
- [17] TAN F J, LI D C, KAEWKOT C, et al. Application of principal component analysis with instrumental analysis and sensory evaluation for assessment of chicken breast meat juiciness [J]. *British Poultry Science*, 2022, 63(2): 164-170.
- [18] SUN Weizheng, ZHAO Q Z, ZHAO H F, et al. Volatile compounds of Cantonese sausage released at different stages of processing and storage [J]. *Food Chemistry*, 2009, 121(2): 319-325. DOI: 10. 1016/ j. foodchem. 2009. 12. 031.
- [19] ALIM A, SONG H L, LIU Y, et al. Research of beef-meaty aroma compounds from yeast extract using carbon module labeling (CAMOLA) technique [J]. *LWT-Food Science and Technology*, 2019, 112: 108239.
- [20] CHIANG J H, EYRES G T, SILCOCK P J, et al. Changes in the physicochemical properties and flavour compounds of beef bone hydrolysates after Maillard reaction [J]. *Food Research International*, 2019, 123: 642-649.
- [21] ZHAO D, HUANG M X, WANG T L, et al. Influence of proteolytic enzyme treatment on the changes in volatile compounds and odors of beef longissimus dorsi [J]. *Food Chemistry*, 2020, 333: 127549.
- [22] ZHOU R Y, GRANT J, GOLDBERG E M, et al. Investigation of low molecular weight peptides (< 1 kDa) in chicken meat and their contribution to meat flavor formation [J]. *Journal of the Science of Food and Agriculture*, 2018, 99: 1 728-1 739.
- [23] GANIESH R, NAIK G R. Adances in principal component analysis research and development [M]. Singapore: Springer Nature Singapore Pte Ltd, 2018.
- [24] SAUTHIER M C D S, SILVAE G P D, SANTOS B R D S, et al. Screening of *Mangifera indica* L. functional content using PCA and neural networks (ANN) [J]. *Food Chemistry*, 2019, 273: 115-123. DOI: 10. 1016/ j. foodchem. 2018. 01. 129.
- [25] KILGANNON A K, HOLMAN B W B, FRANK D C, et al. Temperature-time combination effects on aged beef volatile profiles and their relationship to sensory attributes [J]. *Meat Science*, 2020, 168: 108193.
- [26] CHEN X, XU X L, LIU D M, et al. Rheological behavior, conformational changes and interactions of water-soluble myofibrillar protein during heating [J]. *Food Hydrocolloids*, 2018, 77: 524-533. DOI: 10. 1016/ j. foodhyd. 2017. 10. 030.
- [27] Xiaoli P, Jinggang R, Zhicheng W, et al. Changes in Texture Characteristics and Special Requirements of Sichuan-Style Braised Beef for Industrial Production: Based on the Changes in Protein and Lipid of Beef [J]. *Foods(Basel, Switzerland)*, 2023, 12(7).
- [28] YANG H H, ZHONG C, SUN L C, et al. Effects of partial substitution of NaCl on myofibrillar protein properties from pearl mussel *Hyriopsis cumingii* muscle: Structural characteristics and aggregation behaviors [J]. *Food Chemistry*, 2021, 356(15): 129734. DOI: 10. 1016/ j. foodchem. 2021. 129734.