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Optimization of Refining and Deodorization Process of Beef Flank Fat and Analysis of Volatile Components

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ABSTRACT

To address the issues of missing processing standards for beef kidney fat and unstable flavor quality, this study aims to optimize refining and deodorizing process parameters and investigate their impact on volatile components to improve beef fat quality. In the refining process of beef kidney fat, three factors—refining temperature, refining time, and refining speed—were studied for their effects on sensory quality. Single-factor experiments and orthogonal experiments determined the optimal combination as a refining temperature of 150°C, refining time of 90 minutes, and refining speed of 600 rpm. In the deodorizing process, single-factor experiments and orthogonal experiments were used to determine the effects of deodorizing temperature, deodorizing speed, and deodorizing time on the iodine value of beef kidney fat, with the best combination being a deodorizing temperature of 55°C, deodorizing time of 30 minutes, and deodorizing speed of 70 rpm. Additionally, to further explore the impact of vacuum deodorization on the volatile components of beef kidney fat, purge-and-trap gas chromatography-mass spectrometry (P&T-GC-MS) was used for qualitative analysis of the volatile components in refined and deodorized beef kidney fat. Partial least squares discriminant analysis (PLS-DA) based on absolute content was employed to comprehensively evaluate flavor changes. The results showed that the optimized vacuum deodorization process systematically improved the flavor quality of beef kidney fat by enriching flavor substances and removing impurities, providing a theoretical basis for standardized industrial production.

KEYWORDS

Cow flank fat; Refine; Deodorization; Volatile Component; PLS-DA

1. INTRODUCTION

1.1. Research Background And Significance

Edible beef tallow is refined from fresh, clean, and intact fat tissues obtained during slaughter and butchery. It is rich in minerals, vitamins, and trace elements, making it highly nutritious. It is commonly used to make hot pot base and flavored seasoning oil [1]. However, rendered beef tallow has odor issues that need to be addressed by refining and deodorizing to remove undesirable substances such as aldehydes, ketones, and peroxides produced by oxidation and rancidity, thereby improving its color, texture, and flavor [2]. Currently, research on beef tallow processing technology within the country is not well-developed, and the industry lacks unified standards, resulting in inconsistent product quality. It is necessary to optimize and improve oil production processes to effectively ensure or enhance product quality, reduce production costs, and increase the competitiveness of domestic oil production enterprises [3].

The refining and deodorizing process used in this study, under reduced pressure conditions, involves rotary evaporation treatment. This method reduces reactions such as polymerization and oxidation of unsaturated fatty acids, significantly lowering peroxide content and eliminating odors [4]. Current research lacks a systematic understanding of the dynamic changes in volatile components during refining and deodorization processes, making it difficult to scientifically guide flavor regulation [5]. Therefore, this study aims to optimize the refining and deodorizing process parameters; uses P&T-GC-MS technology for qualitative analysis of volatile components; and combines PLS-DA method to analyze the variation patterns of components before and after deodorization, providing a theoretical basis for the standardized production of butter.

1.2. Research Content

1.2.1. Research on the refining process of beef kidney fat

The orthogonal test method was used to optimize the refining process of beef kidney fat. Single-factor experiments were conducted on the three main factors affecting the refining of beef kidney fat: refining temperature, refining time, and refining speed. The optimal range of each factor was selected based on sensory scores. On this basis, an orthogonal test was designed to compare the effects of the three factors on the sensory properties of beef kidney fat, resulting in the determination of the best refining process conditions for beef kidney fat.

1.2.2. Research on the deodorization process of beef kidney fat

Using refined beef kidney fat obtained from preliminary experiments as raw material, orthogonal test methods were used to optimize the deodorization process of beef kidney fat. Single-factor experiments were conducted on the three main factors affecting the deodorization of beef kidney fat: deodorization temperature, deodorization time, and deodorization speed. The optimal range of these three factors was selected based on calculating the iodine value of the beef kidney fat. On this basis, orthogonal tests were carried out, and the impact of the three factors on the deodorization degree of beef kidney fat was compared based on the iodine values. The optimal deodorization process conditions for beef kidney fat were determined.

1.2.3. Analysis of Volatile Components in Beef Short Plate Fat

To deeply investigate the effects of refining and deodorization under vacuum on the volatile components of beef loin fat, qualitative analysis of the volatile components of refined and deodorized beef loin fat was conducted using purge and trap-gas chromatography-mass spectrometry (P&T-GC-MS). OriginPro 2024 and SIMCA13.0 software were used for data image processing. Partial least squares discriminant analysis was performed based on the absolute content of the volatile components to systematically study the category and absolute content changes of volatile substances in beef loin fat before and after deodorization.

2. MATERIALS AND METHODS

2.1. Materials and Instruments

2.1.1. Raw material preparation

The raw materials used in this experiment are fresh beef kidney fat produced by Junbo Food Co., Ltd. of Linqing City. After removing the connective tissue, they are washed, cut into pieces, minced, and made into uniform samples, each weighing 50 grams.

2.1.2. Experimental reagents and instruments

Sodium thiosulfate, Tianjin Kemio Chemical Reagents Co., Ltd.; Potassium periodate, China National Pharmaceutical Group Chemical Reagents Co., Ltd.; Potassium iodide, Tianjin Beilun Fine

Chemical Development Co., Ltd.; Glacial acetic acid, Wuxi Jingke Chemical Co., Ltd.; Cyclohexane, Tianjin Kemio Chemical Reagents Co., Ltd.; Viers' reagent, Tianjin Kemio Chemical Reagents Co., Ltd.; Sulfuric acid, Yantai Far East Fine Chemical Co., Ltd.; Sodium carbonate, Tianjin Kemio Chemical Reagents Co., Ltd.; Soluble starch, Xilong Science & Technology Co., Ltd.

AL104 electronic analytical balance, Mettler-Toledo Instruments Co., Ltd.; DF-101S integrated heating constant temperature magnetic stirrer; DRHH-S6 digital constant temperature water bath pot, Shanghai Chengjie Instrument Equipment Co., Ltd.; SHB-III vacuum pump, Tianjin Saide Li Experimental Analysis Instrument Manufacturing Plant; MLMQYJR09BLWSD meat grinder, Hunan Yangzi Intelligent Technology Co., Ltd.; BCD-290W low-temperature refrigerator, Qingdao Haier Co., Ltd.; RE-201D rotary evaporator, Zhengzhou Haiqi Instrument Technology Co., Ltd.; R201C constant temperature water bath pot, Gongyi Yingyu High-Tech Instrument Factory; 7890A gas chromatography-mass spectrometry analyzer, Agilent Technologies Inc.; KLol metal bath, Beijing Kanglin Technology Co., Ltd.

2.2. Experimental Method

2.2.1. Refining and deodorization process flow of beef kidney fat

Beef short ribs fat → Remove fascia → Wash clean → Cut into pieces → Shred → To refine → Remove odor

2.2.2. Refined beef kidney fat single-factor experiment

During the refining process of beef tallow, the main factors affecting its sensory characteristics include refining temperature, refining time, and refining speed. Therefore, this experiment uses these factors for single-factor tests and selects 10 sensory evaluators to assess the refined beef tallow.

(1) The selection of single-factor range for refined beef kidney fat

When selecting the refining temperature, a temperature that is too high can cause some aldehyde compounds in beef kidney fat to be lost, reducing its flavor. Therefore, the temperature should be chosen within an appropriate range. The constant temperature heating magnetic stirrer was set to temperatures of 90°C, 110°C, 130°C, and 150°C, respectively, while keeping other conditions unchanged for the refining process. Sensory evaluation methods were used to assess the impact of different refining temperatures on the sensory characteristics of beef kidney fat, thereby determining the optimal refining temperature.

When selecting the refining time for beef kidney fat, if the time is too short, it may retain the raw greasy smell; if the time is too long, it may become overly oxidized and cloudy. Therefore, the time should be chosen within an appropriate range.Set the temperature-controlled heating magnetic stirrer time to 50 minutes, 70 minutes, 90 minutes, and 110 minutes respectively, while keeping other conditions unchanged for refining. Evaluate the impact of different refining times on the sensory characteristics of beef loin fat using sensory evaluation methods, thereby determining the optimal refining time.

When selecting an optimal stirring speed, it is also necessary to choose an appropriate range. The refining process should be carried out in a constant temperature heating magnetic stirring pot, with rotation speeds set at 300 rpm, 450 rpm, 600 rpm, and 750 rpm, while keeping other conditions unchanged. Sensory evaluation methods should be used to assess the impact of different stirring speeds on the sensory characteristics of beef loin fat, thereby determining the best stirring speed.

2.2.3. Refined beef kidney fat orthogonal experiment

Based on the results of the single-factor experiment from version 2.2.2, an L9(3^3) experimental design was conducted. The specific factor levels are shown in Table 1:

Table 1. Orthogonal experimental factors levels

Level	Factors		
	A Refined temperature [℃]	B Condense time [Min]	C Refined speed [Rpm]
1	110	70	300
2	130	90	450
3	150	110	600

2.2.4. Sensory evaluation criteria and methods

With reference to the scoring standards and the sensory requirements specified in GB/T 10146—2015 National Food Safety Standard for Edible Animal Fats [6, 7] Based on the sensory results of pure butter, establish a sensory evaluation standard for butter. Select 10 sensory evaluators involved in food research to form a sensory evaluation panel. They will score the samples according to the sensory evaluation standard, with a total score of 30 points.

Table 2. Sensory Evaluation Criteria

Project	Scoring criteria	Rate
Color and luster	Golden yellow	7~10
	Pale yellow Appear brown	4~6 1~3
Smell	Rich and fragrant oil flavor The oil flavor is light and mild.	7~10 4~6
	sour taste and other unpleasant odors	1~3
Organizational Status	Clear and transparent with no sediment Cloudy with sediment	7~10 4~6
	The substance is oily, blackened, and has sediment	1~3

2.2.5. Single-factor experiment on deodorized beef kidney fat

During the deodorization process of beef kidney fat, the main factors affecting its quality are deodorization temperature, deodorization time, and deodorization speed [8]. The iodine value has a certain correlation with changes in the flavor of beef fat. The iodine value can be used to evaluate the degree of unsaturation in oils or fats. A higher iodine value indicates more unsaturated fatty acids in the oil, which also means a relatively higher quality. Therefore, this experiment uses the aforementioned factors for single-factor tests, and the iodine value is used as an evaluation criterion for beef loin fat.

(1) The selection of single-factor range for deodorized beef kidney fat

When selecting deodorization temperature, a higher temperature can accelerate the oxidation rate of unsaturated fatty acids in oils, producing substances such as ketones that have irritating odors [9]. Therefore, an appropriate deodorization temperature must be chosen. The heating pot temperatures of the rotary evaporator were set to 35°C, 45°C, 55°C, and 65°C, respectively, while keeping other conditions constant for deodorization. The iodine value of the samples was measured to determine the optimal deodorization time.

When selecting the deodorization time, the length of the deodorization period also affects the deodorization effect. A short deodorization time can result in incomplete deodorization of beef kidney fat, leaving undesirable flavors, while an excessively long deodorization time can increase the peroxide content in the beef kidney fat. Therefore, it is necessary to choose an appropriate deodorization time. The rotation times for the rotary evaporator were set at 15 minutes, 30 minutes, 45 minutes, and 60 minutes, respectively, while keeping other conditions constant for deodorization. By measuring the iodine value of the samples, the optimal deodorization time was determined.

When selecting the deodorization rotation speed, it is also necessary to choose an appropriate range. A good rotation speed can make the sample form a thin film on the bottle wall, increasing the evaporation area. Therefore, an appropriate rotational speed should be selected. The rotation speeds were set at 40 rpm, 55 rpm, 70 rpm, and 85 rpm, respectively, while keeping other conditions unchanged for deodorization. By measuring the iodine value of the sample, the optimal deodorization rotation speed was determined.

2.2.6. Deodorized beef kidney fat orthogonal experiment

Based on the results of the single-factor experiment from version 2.2.5, an L9 (3^3) experimental design was conducted. The specific factor levels are shown in Table 3:

Table 3. Orthogonal Test Factors Levels

Level	Factor		
	A Deodorization temperature [°C]	B Deodorization time [Min]	C Deodorizing speed [Rpm]
1	45	15	30
2	55	30	50
3	65	45	70

2.2.7. The method for determining iodine value

Determine iodine value according to GB 5532-2022 'Determination of Iodine Value of Animal and Vegetable Oils [10].

2.2.8. Methods for determining volatile flavor components

For different processed beef kidney fat, P&T-GC-MS was used to determine volatile components [11]

The specific parameters are as follows:

Purge and trap conditions: Precisely weigh 2 grams of butter sample (accurate to 0.0001g) into a headspace vial, add 3 mL of saturated NaCl solution, then add 40 μL of internal standard solution of sec-octanol at 200 μg/mL and seal it. Heat it in a constant temperature heating pot at 50°C for 15 minutes to reach equilibrium.

Chromatographic conditions: Modify according to the experimental conditions [12]. Using an HP-5MS chromatography column, high-purity helium as the carrier gas, injection port temperature of 250°C, flow rate of 1 mL/min, split ratio of 4:1. Temperature program: initial temperature of 40°C, held for 1 minute, then increased at a rate of 5°C/min to 250°C and held for 5 minutes.

Mass spectrometry conditions: Electron impact (EI) ion source energy 70 eV, ion source temperature 230°C, transfer line temperature 250°C, scan range 35~500.

Qualitative analysis involves initially identifying volatile components using a database, followed by spectral interpretation based on relevant literature to complete the final qualitative determination of the volatiles.

Quantitative analysis: using n-octanol as an internal standard, applying the internal standard method according to the formula

Calculate the absolute content of each component

$$w = \frac{\rho 2 \times V2 \times A2}{A2 \times m \times 1000} \tag{1}$$

In the formula: w represents the absolute content of a single component, mg/kg; A1 represents the peak area of a single component; A2 represents the peak area of the internal standard; ρ2 represents the mass concentration of the internal standard, μg/mL; V2 represents the volume of the internal standard, μL; m represents the sample mass, g [13, 14].

2.2.9. Beef short rib fat partial least squares discriminant analysis method

VIP stands for Variable Projection Importance, indicating the significance of a variable in causing differences between groups. When VIP > 1.0, the variable shows significant differences between groups. Further, based on the criteria of VIP > 1 and $p < 0.05$, multiple volatile compounds were identified as process characteristic markers in deodorized and refined butter samples [15].

3. RESULTS AND ANALYSIS

3.1. Analysis of the Results of A Single-Factor Experiment on Refined Beef Kidney Fat

3.1.1. The determination of refining temperature

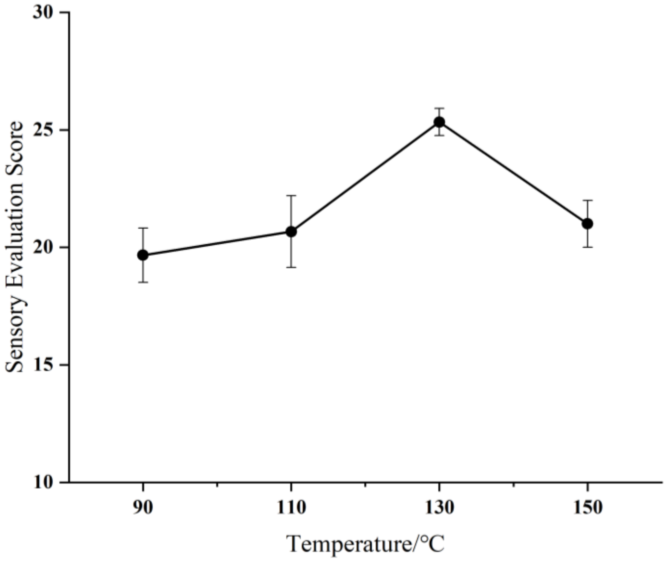

Figure 1. The effect of refining temperature on sensory scores

From Figure 1, it can be seen that as the temperature increases, the sensory score first rises and then decreases, reaching its highest at 25.33 points at 130°C, and the lowest at 90°C. The scores are relatively higher between 110°C and 130°C, during which the beef kidney fat appears bright and has better sensory quality. As the temperature continues to rise, the fishy smell intensifies, causing discomfort.

3.1.2. Determining the refined time

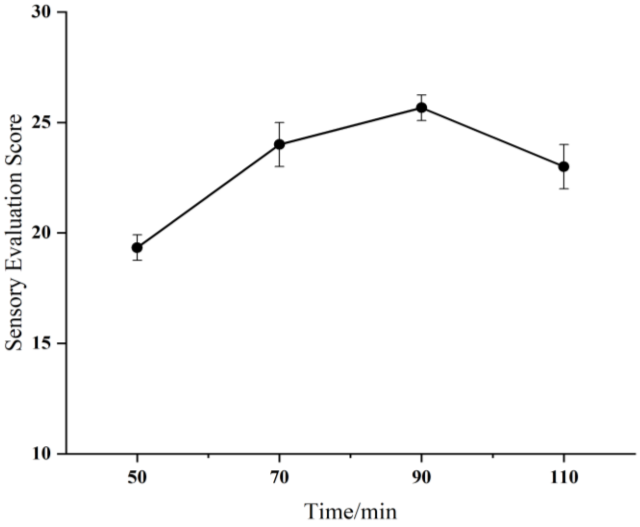

Figure 2. The effect of processing time on sensory scores

From Figure 2, it can be seen that as time increases, the sensory score first rises and then decreases, reaching its highest at 25.66 points at 90 minutes, and the lowest score at 50 minutes. The refining time between 70 to 110 minutes has relatively higher scores, better flavor, while too long a time results in an overly strong taste.

3.1.3. The determination of optimal speed

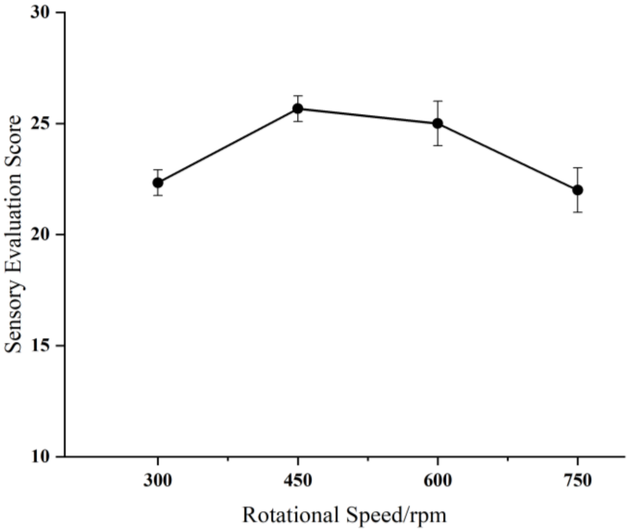

Figure 3. The effect of refined speed on sensory scores

From Figure 3, it can be seen that as the speed increases, the sensory score first rises and then decreases, but the overall change is not significant. Through analysis, it is known that the rotational rate affects the sensory characteristics of butter. At 450 rpm, the sensory score of the butter reaches its highest at 25.66 points, while at 750 rpm, the sensory score is the lowest. Between 300 rpm and 600 rpm, the scores are relatively high, with a rich aroma and good flavor.

3.2. Analysis of the Results of Orthogonal Experiments on Refined Beef Short Loin Fat

Table 4. Orthogonal Test Results

Experiment number	Factor			Sensory score
	A Refined temperature [℃]	B Condense time [Min]	C Refined speed [Rpm]	
1	1	1	1	25.11
2	1	2	2	26.04
3	1	3	3	24.84
4	2	1	2	24.21
5	2	2	3	27.36
6	2	3	1	26.17
7	3	1	3	28.39
8	3	2	1	26.82
9	3	3	2	25.77
K1	75.99	77.71	78.10	
K2	77.74	80.22	76.02	
K3	80.98	76.78	80.59	
k1	25.33	25.90	26.03	
k2	25.91	26.74	25.34	
k3	26.99	25.59	26.86	
R	1.66	1.15	1.52	A>C>B

Table 4 shows that the order of influence of each factor is A > C > B, and the relationships between the levels of each factor are as follows: A3 > A2 > A1; B2 > B1 > B3; C3 > C1 > C2. By combining the k-values and direct comparison, the optimal combination is determined to be A3B2C3. The sequence of influence of each factor on the flavor of beef loin fat is as follows: the most significant is the refining temperature, followed by the refining speed, and the least influential is the refining time. Therefore, the optimal refining conditions for beef loin fat are: refining temperature at 150°C, refining time at 90 minutes, and refining speed at 600 rpm. Sensory validation tests of this optimal combination resulted in a sensory score of 28.74.

3.3. Analysis of the Results of the Single-Factor Experiment on the Deodorization of Beef Kidney Fat

3.3.1. The determination of deodorization temperature

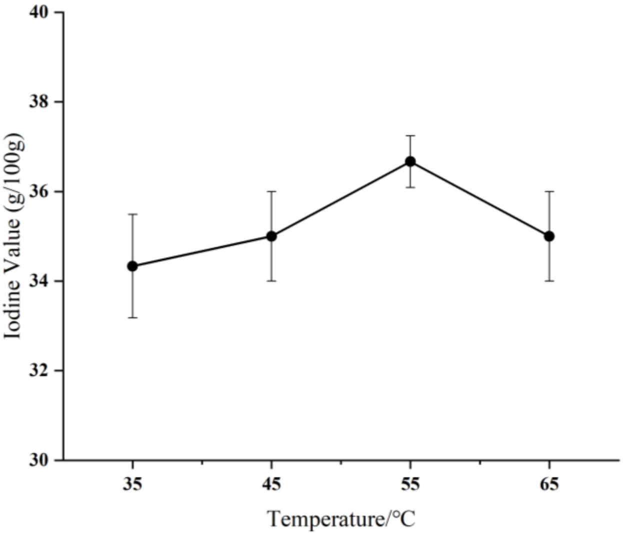

Figure 4. Shows the effect of deodorization temperature on the iodine value.

As shown in Figure 4, as the temperature increases, the iodine value first rises and then decreases. At 55°C, the iodine value reaches its highest point of 36.6g/100g, while at 35°C, it is at its lowest.

3.3.2. Determining the deodorization time

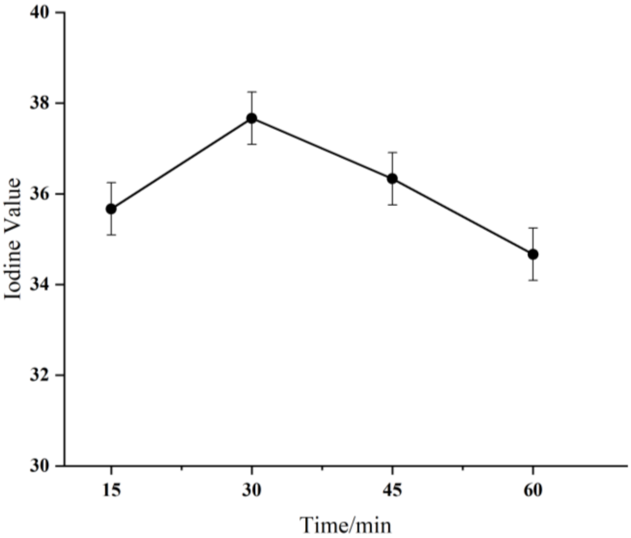

Figure 5. The effect of deodorization time on the iodine value

As shown in Figure 5, with the increase in time, the iodine value first rises and then decreases. At 30 minutes, the iodine value reaches its highest point of 37.6g/100g, and at 60 minutes, it reaches its lowest point.

3.3.3. Determining the deodorization speed

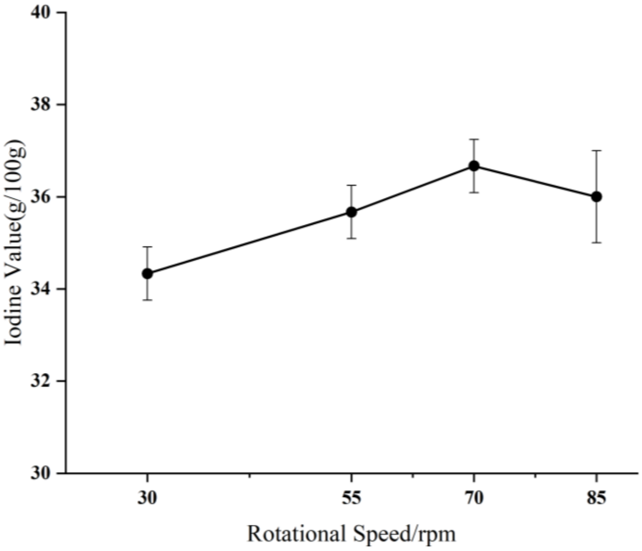

Figure 6. The effect of deodorization speed on iodine value

From Figure 6, it can be seen that as the speed increases, the iodine value first rises and then decreases. When the rotational speed of the rotary evaporator reaches 70 rpm, the iodine value reaches its highest point at 36.66 g/100g, while at 40 rpm, the iodine value is at its lowest. An optimal speed allows the sample to form a thin film on the bottle wall, increasing the evaporation area.

3.4. Analysis of the Results of the Orthogonal Experiment on the Deodorization of Beef Kidney Fat

Table 5. Results of Orthogonal Experiment

experiment number	Factors			Iodine Value
	A Deodorization temperature [℃]	B Deodorization time [Min]	C Deodorizing speed [Rpm]	
1	1	1	1	35.41
2	1	2	2	35.39
3	1	3	3	36.12
4	2	1	2	36.34
5	2	2	3	37.71
6	2	3	1	37.12
7	3	1	3	36.32
8	3	2	1	36.06
9	3	3	2	35.67
K1	106.92	108.07	108.59	
K2	111.17	109.16	107.40	
K3	108.05	108.91	110.15	
k1	35.64	36.02	36.20	
k2	37.06	36.39	35.80	
k3	36.02	36.30	36.72	
R	1.42	0.37	0.92	

Table 5 shows that the order of influence of each factor is A > C > B, and the relationships between the levels of each factor are as follows: A2 > A3 > A1; B2 > B3 > B1; C3 > C1 > C2. By combining the k values and direct comparison, the optimal combination is determined to be A2B2C3. The sequence of influence of each factor on the flavor of beef loin fat is evaluated, with the largest impact being the deodorization temperature, followed by the deodorization speed, and the smallest impact being the deodorization time. Therefore, the optimal deodorization process conditions for beef loin fat are: deodorization temperature of 55°C, deodorization time of 30 minutes, and deodorization speed of 70 rpm. Under these conditions, the iodine value is 37.71 g/100g.

3.5. Analysis of Volatile Flavor Components in Beef Short Plate Fat

3.5.1. Volatile flavor components of butter

The total ion flow chromatogram of volatile components from beef short loin fat is shown in Figure 7.

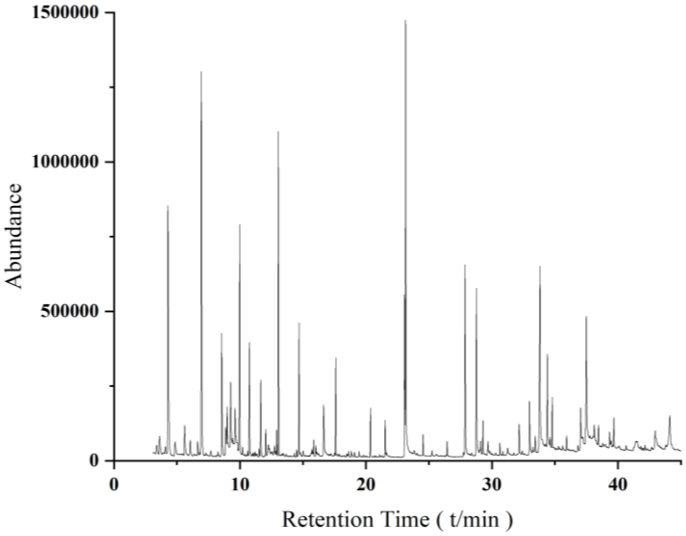

Figure 7. Total ion current chromatogram of volatile components in refined beef kidney fat by *GC-MS*

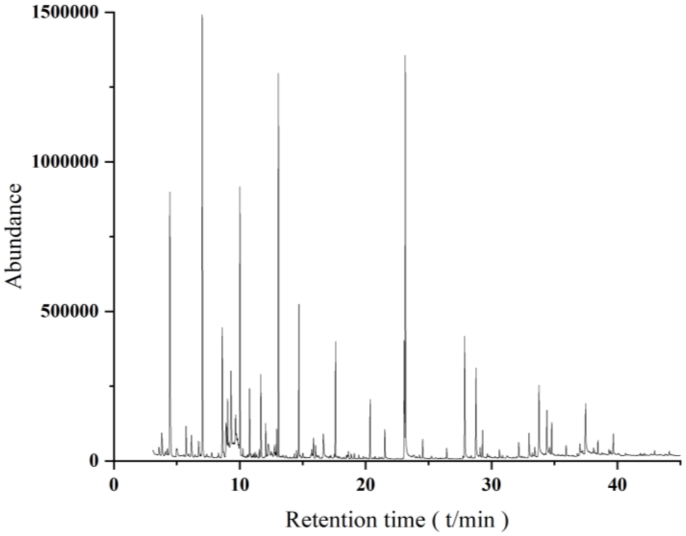

Figure 8. Total ion current chromatogram of volatile components in deodorized beef kidney fat by GC-MS

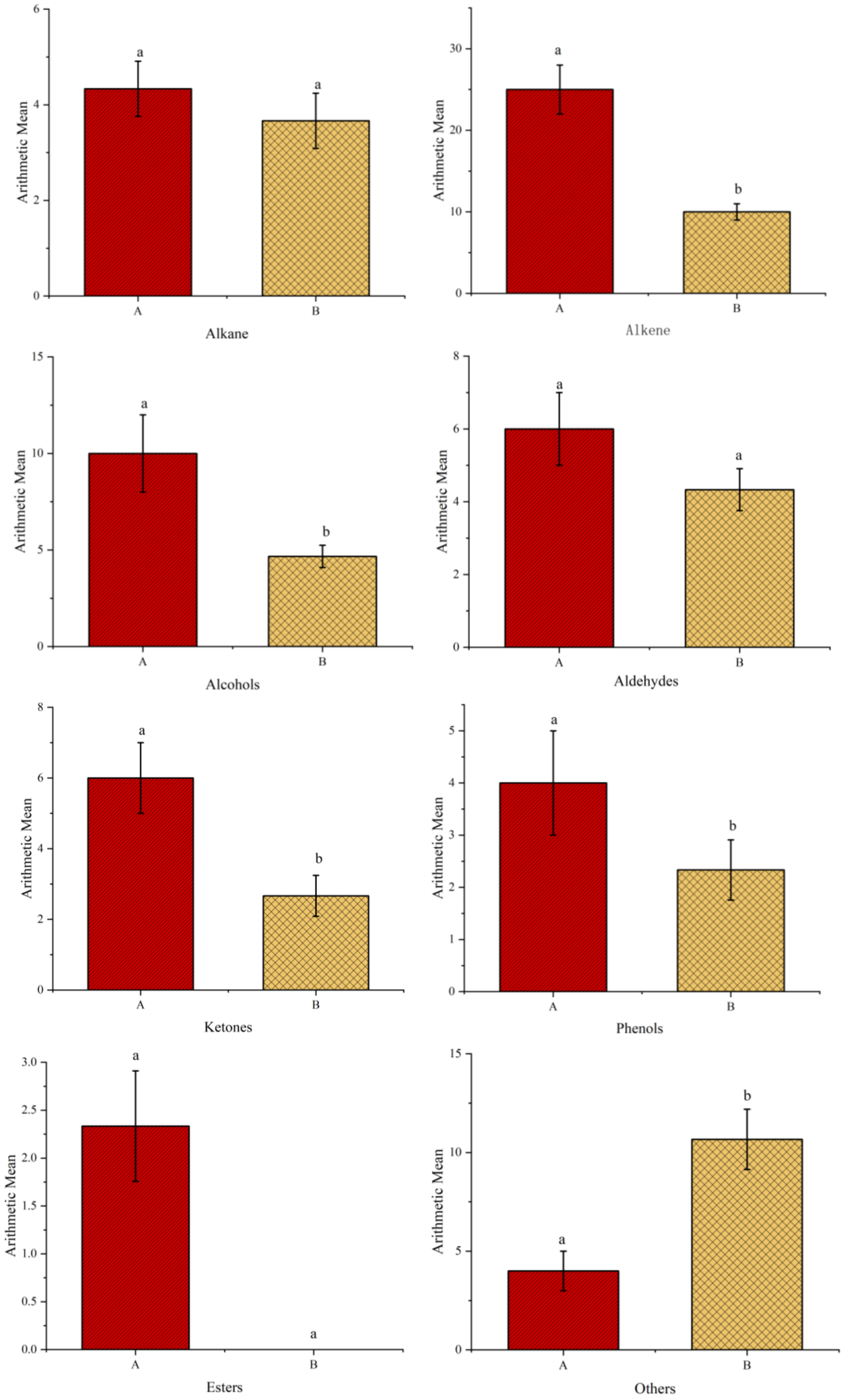

Figure 9. Comparison of the number of volatile substances between refined beef kidney fat (Group B) and deodorized beef kidney fat (Group A)

Note: Column height represents the number of volatile substances detected in each group of samples for that category; different letters indicate significant differences between Group A and Group B within the same category ($p < 0.05$).

After deodorization (Group A) and refining (Group B) of beef loin fat, a total of 106 volatile components were identified, with 56 types found in refined beef loin fat and 72 types in deodorized beef loin fat. The analysis of substances showed that after optimizing the deodorization process, the average absolute content of alkanes in beef tallow did not show a significant difference compared to refined beef tallow, which aligns with its stable molecular structure that is less affected by processing conditions. In contrast, the types and contents of olefins in deodorized beef tallow were significantly higher than those in refined beef tallow. Combined with the experimental results showing a significant reduction in iodine value loss during deodorization, it indicates that the optimized mild deodorization conditions effectively reduced the oxidation and volatilization of olefins that might occur in traditional processes, thereby better preserving such components. Volatile oxygen-containing compounds (aldehydes, alcohols, ketones, esters) had higher types and contents in optimized deodorized beef tallow compared to the refined group. These substances are key contributors to the flavor of fats, and their increased content suggests that the mild optimized process effectively inhibited oxidation decomposition reactions, retaining more flavor precursors; meanwhile, the selective removal of odor impurities during deodorization can relatively enhance the signal strength of characteristic flavor substances in detection. Phenolic substances were only stably detected in deodorized beef tallow, indicating that mild process conditions may have suppressed their oxidation decomposition, helping to preserve natural antioxidant components. The content and types of 'others' class substances significantly decreased after deodorization, confirming the effectiveness of the process in removing non-volatile complex impurities, further enhancing the purity of beef tallow [16]. In summary, the deodorization process systematically optimizes the flavor quality of butter by retaining unsaturated components (olefins), enriching flavor precursors (oxygenates), stabilizing functional substances (phenols), and removing impurities. This collectively demonstrates the potential of process optimization to improve the flavor quality of butter.

3.5.2. Analysis of volatile components differences in beef kidney fat based on PLS-DA

To deeply analyze the differences in the volatile component composition of beef loin fat caused by refining and optimizing the deodorization process, and to identify key characteristic markers, this study used Partial Least Squares Discriminant Analysis (PLS-DA) for modeling based on the absolute content data of volatile components measured by GC-MS.

Partial least squares discriminant analysis, as a supervised multivariate analysis method, can obtain variables with significant differences, filter out noise irrelevant to the research object, and significantly enhance classification and discrimination efficiency [16, 17].

The PLS-DA score plot based on the absolute content of volatile components (Figure 9) shows that the PLS-DA model successfully distinguishes between refined beef tallow samples (Group B) and deodorized beef tallow samples (Group A). The two groups of samples exhibit a clear spatial separation trend on the PLS-DA score plot, intuitively confirming that the deodorization process significantly alters the overall volatile flavor profile of beef tallow . Further analysis based on the criteria of VIP > 1 and $p < 0.05$ identified multiple volatile compounds as process characteristic markers in both deodorized and refined beef tallow samples. These compounds can be categorized into four types: aldehydes and ketones (nonanal, 2-heptanone), which are typically products of lipid oxidation or Maillard reactions and contribute importantly to the flavor of fats (such as grassy or fatty notes). Their increased or decreased levels in optimized deodorized beef tallow reflect the process's regulation of flavor formation. Alkenes (1-octene, limonene), which corroborate the results of reduced iodine value loss during deodorization, indicate that mild deodorization conditions effectively reduce the oxidative decomposition and volatilization loss of unsaturated components. Phenols (4-ethylphenol), which often have antioxidant properties and can also contribute specific flavors (such as smoky notes), are consistently detected in optimized deodorized beef tallow but may be absent or present in very low amounts in refined oil, suggesting that the optimized process favors the retention or formation of such potentially functional components. Others (pyrazines, octadecane), which are usually associated with off-flavors or impurities from raw materials or incomplete removal during processing. Their significant reduction in the optimized deodorized group directly reflects the core role of vacuum deodorization in effectively removing undesirable flavor substances and complex impurities, enhancing the purity and flavor quality of the beef tallow.

The analysis results of PLS-DA are highly consistent with the absolute content and variation trends of various volatile components described in Section 3.5.1. The deodorization process enhances the abundance of olefins, oxygen-containing compounds (aldehydes, ketones, alcohols), and phenolic substances while significantly reducing the presence of off-flavor impurities. From a multivariate statistical perspective, specific key compounds driving this overall flavor improvement have been identified and validated. This provides strong data support for understanding the chemical mechanism by which the deodorization process optimizes the flavor quality of butter.

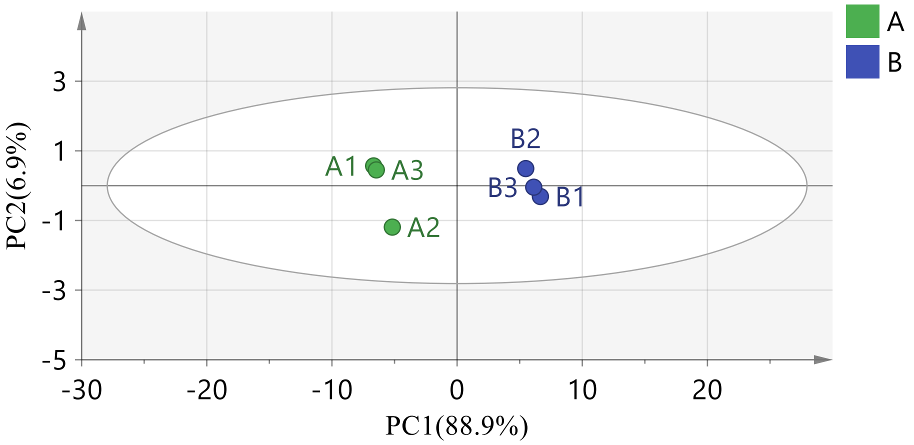

Figure 10. Shows the PLS-DA score plot of deodorized butter (Group A) and refined butter (Group B) along with key differential markers (VIP > 1 & $p < 0.05$)

4. CONCLUSION AND OUTLOOK

This study determined the optimal refining process for beef kidney fat as 150°C, 90 minutes, and 600 rpm through single-factor and orthogonal experiments; the deodorization process was set at 55°C, 30 minutes, and 70 rpm. This process significantly improved the quality of the oil (iodine value increased to 37.71 g/100g) and confirmed via volatile component analysis that the content and variety of olefins, oxygenated compounds, and phenols increased in the deodorized beef fat, while 'other' impurities were significantly reduced. PLS-DA component analysis clearly distinguished between the deodorized and refined groups, validating the dual optimization effect of the process in retaining beneficial components and removing harmful impurities. Implementing standardized processes will enhance product stability and promote the application of beef kidney fat in food seasoning (such as hot pot base) and industrial fields. Given the future direction of butter development, how butter can transition towards healthiness has become a new issue. At this point, one cannot be limited by conventional processing frameworks; instead, high-tech methods should be used to improve butter, Enzyme hydrolysis technology can be combined with genetic engineering for innovative development, endowing butter with functional properties and laying the foundation for it to capture more market share in the future. Through engineering collaboration and innovation, functional roles have been attributed to butter [18], laying the foundation for it to capture more market share in the future.

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