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Research Article

Does the Plant Growth Stage Affect Its Functionality? Impact of a Distinctive Plant-Derived Marinade on the Edible Quality and Biogenic Amine Safety of Sashimi

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Abstract: Some plant extract components may have played a remarkable role in the ancient processing techniques of traditional foods. *Arisaema fargesii* is a traditional fish marinade from southwestern China, and its mechanism of action remains unclear. This study aims to extract essential oil from *Arisaema fargesii* samples collected in different seasons and to evaluate its physiological function and application in sashimi. Component analysis indicates that over 50% of the essential oil's total composition consists of 11 major bioactive compounds with great antimicrobial and antioxidant properties. On this basis, the impact of *Arisaema fargesii* on preserving the quality of sashimi was elucidated by examining microbial characteristics, K value, TCA-soluble peptides, sensory evaluation, and biogenic amine content of the sashimi. The results showed that in the preserved sashimi samples, the effects of oxidative degradation and microbial infection were minimized, which effectively delayed the decline of sashimi sensory quality. Levels of different types of biogenic amine were controlled within an appropriate range. This study demonstrates that *Arisaema fargesii*, as a natural and effective marinade ingredient, provides a promising food-grade biopreservative. Its essential oil extract offers a novel solution for enhancing the safety and quality of sashimi.

Keywords: *Arisaema fargesii*; essential oils; sashimi; biogenic amines

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1 Introduction

Sashimi, widely embraced in Asian dietary culture, is usually made from fresh-cut sashimi from various fishery products, which can preserve the natural flavor and nutrition of fish products to the greatest extent. Sashimi is widely popular among consumers worldwide due to its beautiful appearance, smooth taste, and abundant nutritional content[1]. Concurrently, the consumption of sashimi is also gradually increasing[2]. The high demand for sashimi also puts forward greater requirements for its refrigeration and preservation[3]. Due to the unique manufacturing process, sashimi usually has a larger surface area, making it easier to come into contact with air and external microorganisms. Therefore, in the process of cold chain transport, sashimi is susceptible to contamination by gram-negative bacteria and produces a large amount of biogenic amines (BAs)[4], which are a class of low molecular weight organic bases synthesized by enzymatic decarboxylation of certain amino acids[5]. The accumulation of BAs poses a great threat to the health of consumers, affecting the functions of the human metabolic system, cardiovascular system and digestive system[6,7]. Traditional preservation methods such as refrigeration, freezing, and the use of chemical preservatives have certain limitations including potential health risks and alterations to the sensory qualities of fish. Moreover, these methods are ineffective in eliminating the production of biogenic amines and their adverse effects on consumers[8].

Traditional herbal medicine offers a rich repository of natural substances with potential applications in food preservation. *Arisaema fargesii*, commonly known as "jack-in-the-pulpit" in certain regions, is a widely distributed plant, primarily found in Asia. *Arisaema fargesii* has a long history of medicinal use in China, including treatment for persistent coughs, chest congestion, dizziness, stroke, epilepsy, and tetanus. In southwestern China, there is an ancient tradition of using *Arisaema fargesii* to prepare fermented fish dishes, a practice that has been passed down for thousands of years. Locals believe that this method preserves the fish's flavor and texture while extending its shelf life[9]. Given that *Arisaema fargesii* grows year-round,

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some people prefer using *Arisaema fargesii* harvested in the spring, believing it offers superior aroma and taste. Others opt for *Arisaema fargesii* collected in the autumn, as they believe it contributes to a longer shelf life for the fermented fish. For a long time, the limited technological capabilities have hindered a comprehensive understanding of *Arisaema fargesii* 's effects on fish. However, with recent advancements in technology, it has become feasible to tackle these challenges[10]. Therefore, this study aims to analyze the chemical composition of *Arisaema fargesii* harvested in different seasons and to elucidate its physicochemical effects on various quality parameters of the fish, including the formation of biogenic amines, and assess the impact of *Arisaema fargesii* essential oils (AFEOs) on maintaining the quality and prolonging the shelf life of sashimi, aiming to better understand how AFEO treatment preserves the quality of sashimi, providing new avenues for the industrial application of *Arisaema fargesii*.

2 Materials and Methods

2.1 Preparation and characterization of the essential oils

Four groups of *Arisaema fargesii* were obtained from 10 plant communities in Ta-pa Mountains, Hubei Province, China (Latitude: 31°21'20"N-31°36'20"N; Longitude: 110°03'05"E-110°33'50"E; Average altitude: 1,700 m; Annual mean temperature: 17.9 °C; Annual average precipitation: 1,000 mm; Average annual sunshine duration: 1,800 h). These groups of samples were respectively collected in May (S_M, spring, Average temperature range: 10-18 °C), August (S_A, summer, Average temperature range: 20-28 °C), November (S_N, autumn, Average temperature range: 10-20 °C), 2013 and February (S_F, winter, Average temperature range: −2-8 °C), 2014. Each plant was dried at room temperature (~15 °C) and deposited in the Kunming Institute of Botany, Chinese Academy of Sciences. Each sample was minced into a suitable size and subjected into a Clevenger-type apparatus (Clevenger, Kesijia Co., Beijing, China) for 6 h of hydro-distillation to collect essential oils (Eos). The obtained EOs were dried by hydrous sodium sulfate for 24 h and stored at 4 °C until used. The components of EOs were analyzed using a GC-MS 6890-5975 system (Agilent Technologies, Palo Alto, CA, USA), components were identified based on the Kovats index using the Wiley (V.7.0) and National Institute of Standards and Technology (NIST) V.2.0 GC-MS libraries, and the relative mass fractions of each component were determined using the area normalization method[11].

Antioxidant activities of the prepared materials were determined by the radical scavenging capacity[12]. 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) radical cation ($ABTS^+$) were used in the assays. Antimicrobial activities of the prepared materials were observed through the inhibition zones[13]. The suspension (~100 CFU/mL) of *Bacillus subtilis*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli* and *Candida albicans* was spread on Mueller-Hinton solid media plates. A sterile filter paper disc (6 mm in diameter) with 10 μL of EO was placed on an inoculated plate, and then the inoculated plates EO were incubated at 37 °C for 24 h. In this assay, some common chemical antimicrobials were used as positive controls.

2.2 The preparation and storage of sashimi samples

More than 600 pieces of sashimi fillets (~4 cm × ~2 cm × ~0.5 cm) were obtained from the back flesh of more than 50 fresh salmon (Salmo salar) individuals (5.6 ± 0.6 kg) using traditional skills in a local aquaculture base. The fillets were transported by cold chain to the laboratory within ~3 h. The prepared fillets were divided into 5 groups. The control group was stored at ~1 °C for 10 days' storage without glazing treatment, while the other 4 groups (S_M, S_A, S_N, and S_F) were respectively immersed into aqueous solutions with 1 % of the corresponding AFEOs at 0 °C for 10 min, and then stored at the same conditions. Every 2 days, several preserved fillets were taken out from each group for analysis.

2.3 Sensory analysis of sashimi samples during storage

The sensory analysis of sashimi was performed using a 5-point hedonic scale (1: dislike extremely; 2: dislike; 3: neither like nor dislike; 4: like; 5: like extremely) referring to the method described by Yu *et al.*[14] with some modifications. Ten trained panelists from laboratory staff in the sensory laboratory individually assessed the color, odor, texture and general acceptability of sashimi. Before sensory evaluation, five pieces of random sashimi from each group were anonymously presented on white plates. Participants were asked to rinse their mouths with pure water before tasting each sample.

2.4 Antimicrobial and antioxidant analysis in the sashimi samples

The antibacterial ability was demonstrated by microbial counting using the method of He *et al.*[11]. All plates were incubated at 15 °C for 72 h, and the total bacterial count (TBC) was determined using iron agar plates containing 10 g/L NaCl. The determination of total aerobic count (TAC) was carried out using spread plates of plate count agar.

Sashimi oxidation was evaluated by determining the content of thiobarbituric acid reactive substances (TBARS) according to Hui *et al.*[10] with slight modifications. The chopped samples (200 mg) were dissolved in 1 mL of weighed n-butanol and diluted to 25 mL. The processed samples were mixed with an equal volume of thiobarbituric acid solution and let it placed in a 95 °C water bath for 120 min. TBARS content was calculated using Eq (1):

$$\mathrm{TBARS\,(mgMDA/kg)} = \frac{50 \times (As - Ab)}{200} \quad (1)$$

where A_s and A_b denoted the absorbance of the mixture and water blank measured at 530 nm, respectively.

Referred to the method of Hui *et al.*[15] to determine the peroxide value (PV) of the sashimi samples. The extract of the samples was titrated with 0.01 mol/L of $Na_2S_2O_3$, and the PV was calculated according to the consumption of $Na_2S_2O_3$.

2.5 Variations in the muscle in the sashimi samples

The K-values of sashimi were measured using the method of Song *et al.* [16] with some modifications. Take 2 g of sashimi samples cut into appropriate sizes, homogenize with 2 mL of 50 g/L perchloric acid, Added speed, and the supernatant was collected for later use. After filtering the supernatant, HPLC (Shimadzu, LC-20AT, Japan) equipped with SPD-20AV detector and VP-ODS C_{18} column (4.6 mm id × 250 mm, 5 μm) was used for analysis. The sample (20 μL) was injected at a flow rate of 1.0 mL/min, and the peak was detected at 254 nm.

Based on the method of Lowry *et al.*[17] , analyzed trichloroacetic acid (TCA)-soluble peptides. Take 3 g of chopped sample and homogenize with 27 mL of 50 g/L cold TCA. The homogenate

was kept in ice for 30 min and centrifuged (~800 × g) for 5 min at 4 °C. Then took the supernatant for later analysis.

The total volatile basic nitrogen (TVB-N) contents in the sashimi samples were determined by the semi-micro Kjeldahl method, referring to the method described by Li *et al.*[18] with some modifications. Use a Kjeldahl nitrogen analyzer (KDY-9820, Ruibangxingye Co., Beijing, China) to absorb volatile alkaline nitrogen or ammonia, titrated with 1 mL/L HCl solution, and calculate the amount of captured ammonia.

2.6 Measurement of biogenic amines in the samples

Based on Wang *et al.*'s method[19], the determination of BA content in sashimi samples was carried out using optimized reverse-phase HPLC (Agilent, 1,260 LC) equipped with an Agilent C_{18} (5 μm, 4.6 mm × 250 mm) column. BA contents were determined using the peaks detected at 254 nm.

2.7 Statistical analysis

Each test was repeated at least 3 times using different samples. The data from the above assays were statistically analyzed by SPSS 27.0 software and represented as mean ± standard deviation (SD). The Duncan test and one-way analysis of variance (ANOVA) were applied to compare the values ($P \leq 0.05$).

3 Results and Discussion

3.1 Preparation, composite identification, and activity analysis of AFEOs

After the hydro-distillation, light-greenish EO with distinct smell was obtained from the *Arisaema fargesii* samples. Table 1 lists major identified compounds in the essential oils and their bioactivities. Linalool, a key compound with antimicrobial and antioxidative properties, varied widely between groups, ranging from 9.62% in S_N to 17.89% in S_A. Similarly, limonene showed higher concentrations in S_N (8.87%) compared to S_M (5.05%), indicating that temperature and sunlight may have enhanced its synthesis. Carvacrol and eugenol also fluctuated, with carvacrol peaking in S_M (11.20%) and decreasing in S_A (7.49%), likely due to differences in rainfall. These findings suggest that climatic factors, such as temperature and precipitation, directly impact the yield and concentration of bioactive compounds in essential oils[13].

Antioxidant activity of the essential oils was exhibited in Table 2. The AFEOs treatment groups all exhibited a certain degree of antioxidant activity. The difference between DPPH and ABTS assays may be due to the resonance effect in double bond[35]. Compared with the same type of plant essential oils)[36], all groups showed better antioxidant ability. At the same time, the radicals scavenging was a dose-dependent process.

As shown in Table 3, all groups showed moderate antibacterial activity against all tested strains. The diameter of the inhibitory zones of EOs ranged from 8.9 mm to 19.5mm for different microbial species. The growth of microbial populations in samples treated with AFEOs was significantly inhibited, although the effectiveness varied slightly. This variation may be attributed to differences in the levels of oxidative compounds resulting from seasonal variations in precipitation[37].

3.2 Effect of AFEOs treatment on microbial properties

TBC and TAC are important quality indicators for evaluating the spoilage potential of sashimi. Figure 1 presents the variations in TBC (as Fig. 1A) and TAC (as Fig.1B) of the sashimi during the storage.

The initial values of TBC and TAC in the control sample were 2.51 log CFU/g and 2.11 log CFU/g, respectively, while the initial values of TBC and TAC in the essential oil treated sample were 2.10-2.31 log CFU/g and 1.62-1.84 log CFU/g. During storage, the TBC and TAC of each sashimi group showed a continuously increasing trend. Relatively speaking, essential oil treatment can reduce the TBC and TAC of samples, and this inhibitory effect becomes more pronounced with increasing storage time. At the end of storage, the TBC and TAC of the control sample were 7.83 log CFU/g and 6.93 log CFU/g, respectively, while the TBC and TAC of the essential oil treated sample were 3.58-4.24 log CFU/g and 2.91-3.31 log CFU/g. The reduced number of microorganisms in samples treated with AFEOs can be attributed to the presence of antibacterial compounds within the essential oil. The mechanism is likely related to its hydrophobic compounds, which enable the essential oil to penetrate bacterial cell membranes and mitochondria, thereby disrupting their structure[38].

3.3 Effect of AFEOs treatment on oxidation degree

TBARS (thiobarbituric acid reactive substances) and PV (Peroxide value) levels can indicate that essential oils exhibit antioxidant effects during storage[39]. Oxidative spoilage typically

Table 1 Main effects composition in the *Arisaema fargesii* essential oils

Rerention Index (RI) [a]	Component	S_M (%) [b]	S_A (%) [b]	S_N (%) [b]	S_F (%) [b]	Reported bioactivity	Ref.
1,017	*p*-Cymene	2.64	0.95	3.37	3.42	Antimicrobial antioxidative	[20, 21]
1,030	Limonene	5.05	5.19	8.87	6.02	Antimicrobial,antioxidative	[22, 23]
1,033	Eucalyptol	2.12	0.37	1.35	1.97	Antimicrobial,antioxidative	[24, 25]
1,078	*cis*-Linalool oxide	3.57	7.94	4.43	5.17	Antimicrobial	[26]
1,099	Linalool	12.38	17.89	9.62	11.00	Antimicrobial,antioxidative	[27, 28]
1,297	Carvacrol	11.20	7.49	6.10	11.08	Antimicrobial, antioxidative	[29]
1,357	Eugenol	5.21	4.85	6.22	7.55	Antimicrobial	[30]
1,402	Methyl eugenol	3.69	1.88	2.48	3.70	Antimicrobial	[31]
1,418	*β*-Caryophyllene	7.32	3.72	5.07	4.36	Antimicrobial, antioxidative	[32]
1,578	Caryophyllene oxide	2.95	3.05	2.68	2.54	Antimicrobial	[33]
1,682	*α*-Bisabolol	0	2.14	4.21	1.09	Antimicrobial	[34]
	Total identified	56.13	55.47	54.40	59.90		

[1] Retention index relative to n-alkanes on HP-5 MS capillary column.
[2] Relative % (peak area relative to the total peak area).

Table 2 Oxidation resistance of the essential oils from *Arisaema fargesii*

Group	Concentration (μg/mL)	DPPH		ABTS	
		Inhibition (%)	IC_{50} (μg/mL)	Inhibition (%)	IC_{50} (μg/mL)
S_M	100	15.96 ± 3.41	996.11	20.61 ± 0.70	444.63
	200	23.64 ± 0.95		33.83 ± 4.25	
	400	33.88 ± 4.12		47.01 ± 1.36	
	800	46.15 ± 2.00		62.90 ± 5.27	
S_A	100	13.66 ± 1.74	1 152.81	19.34 ± 3.13	486.02
	200	22.39 ± 4.53		32.09 ± 5.88	
	400	30.92 ± 2.69		45.52 ± 2.51	
	800	43.30 ± 6.77		60.71 ± 1.83	
S_N	100	12.61 ± 0.65	864.68	22.9 ± 3.64	397.08
	200	23.59 ± 1.90		35.71 ± 0.32	
	400	34.80 ± 4.42		50.55 ± 1.68	
	800	47.46 ± 2.38		64.45 ± 2.27	
S_F	100	12.15 ± 5.07	1 009.94	25.87 ± 2.44	413.84
	200	20.44 ± 3.22		37.94 ± 4.19	
	400	33.30 ± 2.63		49.86 ± 1.27	
	800	44.03 ± 7.01		61.07 ± 5.25	
BHT	-	-	133.42	-	159.70

Table 3 Antimicrobial activities of *Arisaema fargesii* essential oils

Extracts	Diameter of the inhibitory zone (mm)				
	B. subtilis	*S. aureus*	*P. aeroginosa*	*E. coli*	*C. albicans*
S_M	10.2 ± 0.4^b	18.2 ± 0.9^b	14.3 ± 0.2^c	12.6 ± 0.4^b	11.2 ± 1.0^b
S_A	12.6 ± 2.7^a	19.5 ± 1.0^a	16.5 ± 0.9^a	15.3 ± 2.3^a	11.5 ± 0.5^b
S_N	8.9 ± 1.3^c	17.3 ± 1.2^c	15.1 ± 2.2^b	12.1 ± 1.0^b	12.9 ± 1.7^a
S_F	9.1 ± 1.5^c	16.0 ± 0.9^d	15.0 ± 1.5^b	9.7 ± 0.3^c	9.1 ± 2.0^c
Penicillin	30.3 ± 0.6	36.5 ± 2.9	29.2 ± 6.3	13.2 ± 1.2	-
Ampicillin	15.4 ± 2.3	21.0 ± 0.0	17.3 ± 1.2	12.0 ± 1.0	--
Nystatin	-	-	-	-	36.3 ± 0.6

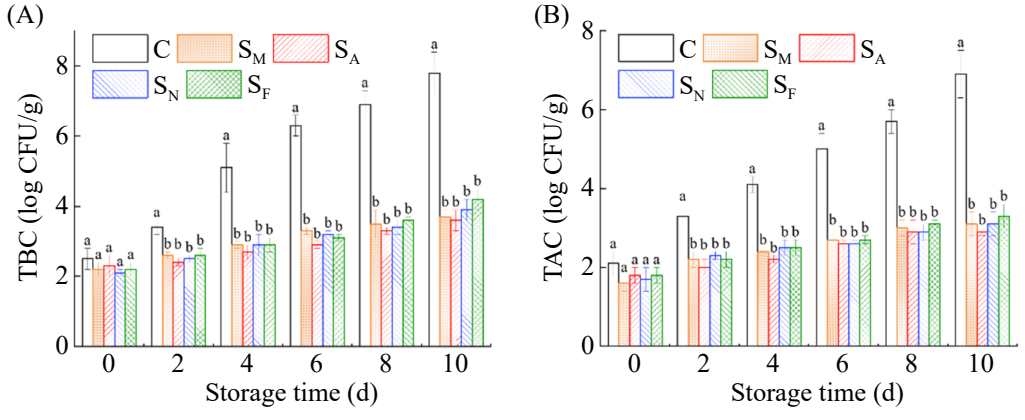

Figure 1 The microbial properties of preserved sashimi during the storage. (A) Total bacterial count (TBC) and (B) total aerobic count (TAC).

imparts unpleasant odors, off-flavors, and undesirable textures to seafood, along with nutritional loss. This spoilage occurs when unsaturated fats are exposed to oxygen, causing the double bonds in unsaturated fatty acids to break and release volatile ketones and aldehydes[40]. The variation of TBARS values during storage of sashimi were shown in Fig. 2A, and the initial values of all samples were around 0.3 mgMAD/kg. The TBARS values of each group of samples increase with the increase of storage time, and at the end of storage, the TBARS value of the control group was 1.37 mgMAD/kg, while the TBARS value of the essential oil treatment group was 0.56-0.65 mgMAD/kg. Meanwhile, as shown in Fig. 2B, the PV values showed a similar trend to TBARS, which may be due to the fact that essential oils provide a protective barrier for the sashimi to expel air and significantly inhibit oxidative changes in the sashimi samples.

3.4 Effect of AFEOs treatment on K-value, TCA-soluble peptides and TVB-N

The K value is considered the most effective and reliable

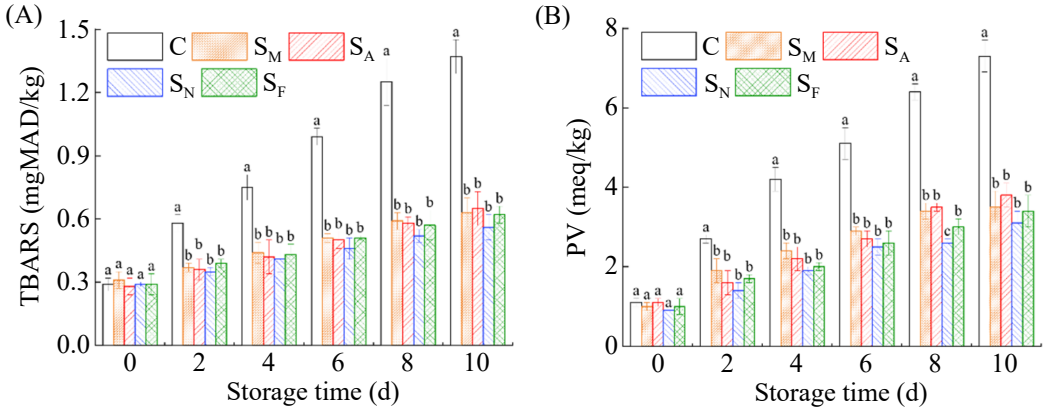

Figure 2 Oxidative changes in sashimi samples during the storage. (A) Thiobarbituric acid reactive substances (TBABS), and (B) Peroxide value (PV).

indicator for measuring the freshness of fish and has a good correlation with the storage time of fish. Generally speaking, fish products with K value below 20% are very fresh, those with K value below 50% are medium fresh, and those with K value above 70% are not recommended to be eaten, and a K value of 20% has been defined by Japanese researchers as the limit for raw fish ("sashimi" grade) consumption[41]. In this study, the K value changes of the sashimi during storage are shown in Fig. 3A. The initial K value of the sashimi sample was 6.40%, indicating that the sashimi sample is very fresh. The K value of all samples increased with time, but the rate of increase in the K value of samples treated with essential oil was significantly lower than that of the untreated group. After 10 days of storage, the K value of the control group was 60.81%, while the K value of the essential oil treatment group ranged from 18.53 to 20.41%, showing a significant difference, and the results of the treatment group were still near the consumption standard of "sashimi" grade. This may be due to the inhibitory effect of AFEOs treatment on the decomposition of adenosine triphosphate (ATP) and its derivatives during storage, resulting in a decrease in the rate of nucleotide degradation[42].

TCA-soluble peptides represent the degree of protein degradation in sashimi. During storage, the changes in TCA-soluble peptides in sashimi samples are shown in Fig. 3B. The content of TCA-soluble peptides is generally on the rise. In the early stage of storage, TCA-soluble peptides may mainly be composed of endogenous oligopeptides and free amino acids produced during post-mortem processing. With the increase of storage time, the TCA-soluble peptide content in the control group increased significantly, which may be due to high protease activity leading to an increase in nitrogen degradation products,

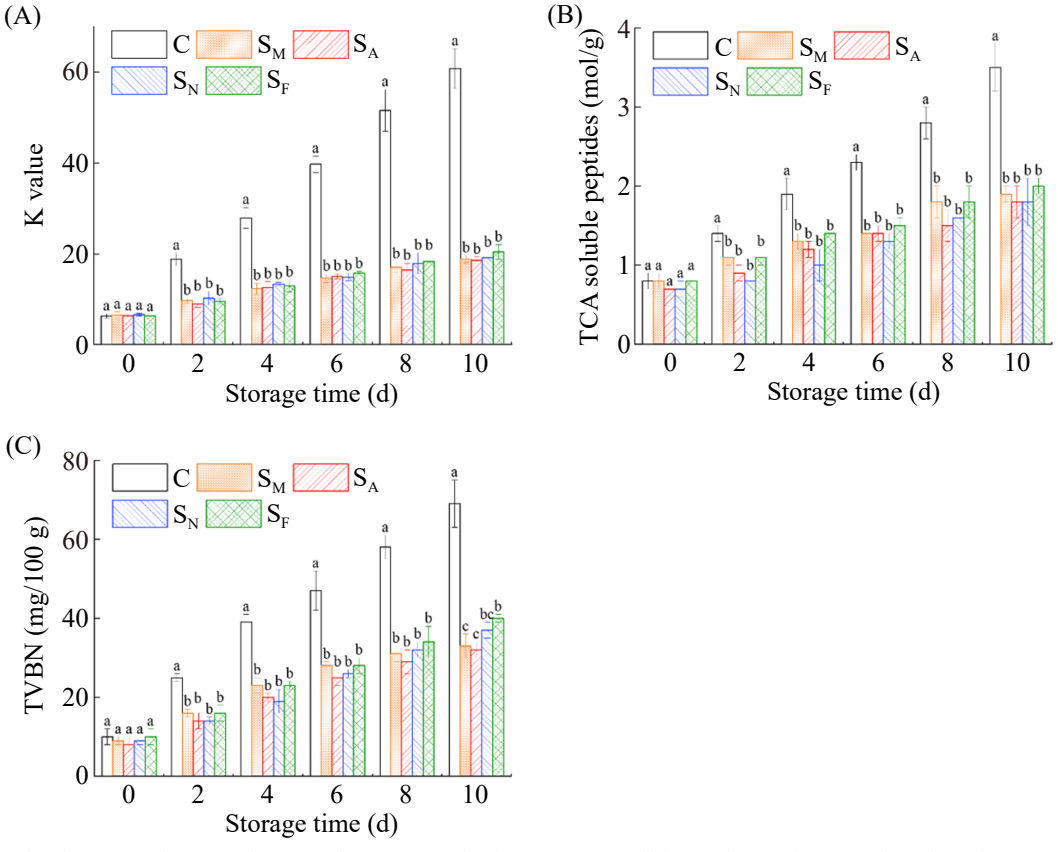

Figure 3 (A) K-value changes in sashimi samples during the storage, (B) the changes in TCA-soluble peptides in sashimi samples, and (C) the variations in TVB-N of the sashimi.

resulting in bacterial proliferation and rapid decomposition[43]. The AFEOs treatment group has good water holding capacity and antioxidant activity, which can better inhibit protein degradation and achieve better preservation effects.

Similarly, the TVB-N curve also shows a continuous upstream trend (as shown in Fig. 3C), with an initial TVB-N value of approximately 9 mg/100 g muscle for each sashimi sample. During the storage process of animal food, the higher the TVB-N content, the more amino acids are destroyed. After 10 days of storage, the TVB-N levels in the control group soared to 69.23 mg/100 g muscle, respectively. In contrast, the data of the AFEOs treatment group was 31.69-40 mg/100 g muscle, indicating that essential oil treatment can better maintain the quality of the sashimi sample.

3.5 Effect of AFEOs treatment on sensory evaluation

The changes in the sensory quality of the sashimi were driven during the spoilage process. The sensory evaluation results of the sashimi samples are shown in Fig. 4. After 2 days of storage, the sashimi exhibited a relatively healthy color, odor, and texture, with good acceptability. As the storage time increased, the freshness of the sample decreased, the surface faded, and the elasticity and texture decreased. Considering the role of microorganisms and protein oxidation, the sensory score of the control group decreased more significantly. On the 10th day, the sensory score dropped to around 1, while the treatment group remained around 3. The deterioration of sashimi quality was significantly inhibited, which may be attributed to multiple mechanisms, including antimicrobial, antioxidant, and enzyme inhibition activities[19].

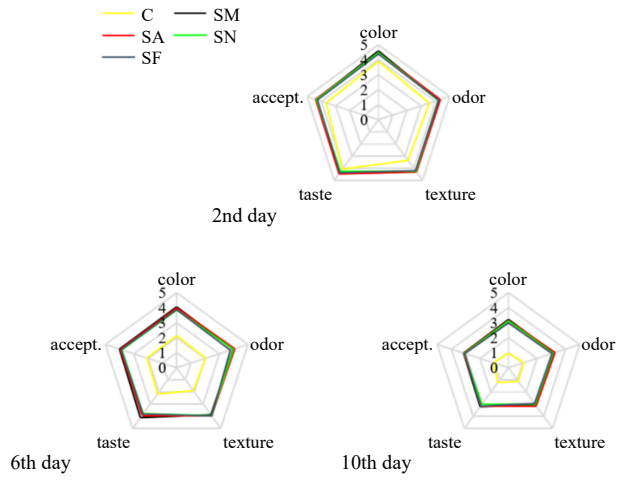

Figure 4 The sensory quality of preserved sashimi during the storage.

3.6 Effect of AFEOs treatment on biogenic amines

Table 4 lists the changes in BA content during storage. Putrescine, cadaverine, and histamine can serve as spoilage indicators, as they are produced from their respective free amino acids. Therefore, the formation of biogenic amines is closely related to the decarboxylation of amino acids by microorganisms. Among them, histamine is the most toxic biogenic amine in fish, and putrescine and cadaverine can enhance the toxicity of histamine[44]. In this study, the control group had the highest histamine level (32.7 mg/kg), while the essential oil treatment group had a much lower histamine concentration (6.9~9.2 mg/kg), indicating that AFEOs can effectively inhibit the growth of bacteria producing histidine decarboxylase, thereby reducing histamine content. Essential oils have a potential inhibitory effect similar to histamine on the accumulation of putrescine and cadaverine, which may be due to the natural antibacterial and antioxidant components contained in plant extracts[45].

Spermine and spermidine have higher initial concentrations at the beginning of storage, possibly due to their presence as natural components of living cells in sashimi. However, their

Table 4 Changes in BAs concentration in the preserved samples

BAs	Sample	Concentration of BAs (mg/kg)					
		0th day	2nd day	4th day	6th day	8th day	10th day
HIM	Control	ND	1.9 ± 0.1^{a}	6.3 ± 0.9^{a}	13.8 ± 2.4^{a}	24.8 ± 1.9^{a}	32.7 ± 5.1^{a}
	S_M	ND	1.4 ± 0.2^{b}	2.7 ± 0.6^{b}	4.3 ± 0.3^{b}	6.4 ± 0.7^{b}	8.7 ± 1.4^{b}
	S_A	ND	1.5 ± 0.3^{b}	2.5 ± 0.3^{bc}	3.6 ± 0.2^{c}	4.9 ± 0.5^{c}	7.6 ± 0.6^{c}
	S_N	ND	1.3 ± 0.1^{b}	2.1 ± 0.1^{c}	3.3 ± 0.0^{c}	5.2 ± 0.4^{c}	6.9 ± 0.4^{c}
	S_F	ND	1.4 ± 0.1^{b}	2.9 ± 0.4^{b}	5.2 ± 1.1^{b}	7.0 ± 0.6^{b}	9.2 ± 1.4^{b}
PUT	Control	ND	2.4 ± 0.6^{a}	6.5 ± 1.3^{a}	15.7 ± 2.9^{a}	28.7 ± 3.4^{a}	43.9 ± 5.5^{a}
	S_M	ND	2.2 ± 0.2^{a}	3.9 ± 0.6^{b}	6.5 ± 1.1^{b}	8.2 ± 0.5^{bc}	11.0 ± 1.6^{b}
	S_A	ND	2.0 ± 0.4^{a}	4.0 ± 0.4^{b}	5.1 ± 0.2^{bc}	7.4 ± 1.3^{bc}	10.6 ± 1.9^{b}
	S_N	ND	1.9 ± 0.1^{a}	3.6 ± 0.3^{b}	4.9 ± 0.3^{c}	7.1 ± 0.2^{c}	9.9 ± 2.9^{b}
	S_F	ND	2.3 ± 0.4^{a}	3.7 ± 0.2^{b}	6.1 ± 0.9^{bc}	8.6 ± 0.7^{b}	11.7 ± 0.6^{b}
CAD	Control	ND	2.5 ± 0.4^{a}	6.9 ± 1.4^{a}	13.8 ± 1.5^{a}	16.8 ± 2.7^{a}	23.8 ± 3.9^{a}
	S_M	ND	ND	1.5 ± 0.3^{b}	4.5 ± 0.5^{b}	7.3 ± 0.6^{b}	11.6 ± 1.1^{b}
	S_A	ND	ND	1.6 ± 0.2^{b}	4.2 ± 0.2^{b}	6.9 ± 0.4^{b}	11.9 ± 0.8^{b}
	S_N	ND	ND	1.8 ± 0.0^{b}	4.2 ± 0.3^{b}	6.7 ± 1.1^{b}	12.7 ± 1.3^{b}
	S_F	ND	ND	2.0 ± 0.4^{b}	3.9 ± 0.7^{b}	7.4 ± 0.8^{b}	12.2 ± 0.6^{b}
SPM	Control	15.3 ± 2.0^{a}	18.6 ± 0.8^{b}	14.7 ± 1.3^{b}	12.4 ± 2.5^{a}	11.3 ± 0.9^{a}	9.7 ± 0.6^{a}
	S_M	13.9 ± 1.7^{a}	21.7 ± 0.6^{a}	20.4 ± 3.6^{a}	11.3 ± 1.8^{a}	10.3 ± 0.8^{a}	8.1 ± 0.4^{b}
	S_A	14.2 ± 0.4^{a}	22.9 ± 2.4^{a}	19.5 ± 1.1^{a}	11.9 ± 0.6^{a}	10.5 ± 2.1^{a}	9.0 ± 0.3^{ab}
	S_N	13.7 ± 1.3^{a}	19.7 ± 1.1^{ab}	18.3 ± 0.8^{a}	12.1 ± 1.2^{a}	10.7 ± 1.13^{a}	9.1 ± 1.3^{ab}
	S_F	15.1 ± 0.2^{a}	21.8 ± 0.9^{a}	19.7 ± 2.4^{a}	12.4 ± 0.7^{a}	9.9 ± 1.8^{a}	8.6 ± 0.6^{ab}

(Continued)

BAs	Sample	Concentration of BAs (mg/kg)					
		0th day	2nd day	4th day	6th day	8th day	10th day
SPD	Control	8.5 ± 0.4[a]	15.7 ± 1.3[a]	25.8 ± 1.3[a]	22.6 ± 1.4[a]	16.9 ± 0.3[a]	6.8 ± 2.5[a]
	S_M	8.6 ± 0.4[a]	14.8 ± 2.1[a]	22.8 ± 1.6[a]	21.1 ± 1.9[a]	15.7 ± 0.9[a]	8.2 ± 1.1[ab]
	S_A	8.3 ± 0.7[a]	13.9 ± 1.5[a]	23.7 ± 1.0[a]	19.8 ± 0.4[a]	16.7 ± 1.4[a]	8.9 ± 0.5[a]
	S_N	7.9 ± 1.5[a]	14.0 ± 0.7[a]	23.1 ± 0.6[a]	18.8 ± 2.4[a]	15.9 ± 0.6[a]	7.7 ± 0.3[b]
	S_F	7.7 ± 0.7[a]	14.4 ± 0.5[a]	24.8 ± 0.8[a]	20.4 ± 0.6[a]	16.4 ± 1.8[a]	8.6 ± 0.7[ab]
TYM	Control	0.7 ± 0.1[a]	0.6 ± 0.1[a]	1.3 ± 0.1[a]	1.4 ± 0.0[a]	1.1 ± 0.2[a]	1.1 ± 0.2[a]
	S_M	0.7 ± 0.0[a]	0.6 ± 0.0[a]	0.8 ± 0.2[b]	0.9 ± 0.1[b]	0.7 ± 0.1[b]	0.6 ± 0.1[b]
	S_A	0.6 ± 0.1[a]	0.6 ± 0.1[a]	0.7 ± 0.1[b]	1.1 ± 0.2[b]	0.8 ± 0.2[b]	0.7 ± 0.1[b]
	S_N	0.6 ± 0[a]	0.5 ± 0.1[a]	0.7 ± 0.1[b]	0.9 ± 0.0[b]	0.6 ± 0.1[b]	0.7 ± 0.0[b]
	S_F	0.6 ± 0.2[a]	0.6 ± 0.1[a]	0.8 ± 0.0[b]	1.0 ± 0.1[b]	0.7 ± 0.0[b]	0.7 ± 0.1[b]
TRM	Control	ND	ND	ND	0.4 ± 0.0[a]	0.4 ± 0.1[a]	0.5 ± 0.1[a]
	S_M	ND	ND	ND	ND	ND	0.2 ± 0.1[b]
	S_A	ND	ND	ND	ND	ND	0.2 ± 0.0[b]
	S_N	ND	ND	ND	ND	ND	0.2 ± 0.0[b]
	S_F	ND	ND	ND	ND	ND	0.2 ± 0.1[b]

[a] HIM: histamine, PUT: putrescine, CAD: cadaverine, SPM: spermine, SPD: spermidine, TYM: tyramine, TRM: tryptamine, ND: not detected.
[b] Values are the mean of three replications ± standard deviation.
[c] Means in the same column with different letters are significantly different ($P < 0.05$).

concentrations exhibit an unstable fluctuation trend throughout the entire storage period. This may be due to the phenomenon of transformation between spermine and spermidine and other biogenic amines, where spermine can be converted into putrescine under the action of spermine synthase[46]. The mutual transformation pathway of polyamine metabolism allows for the sequential transfer of amino propyl groups in reactions catalyzed by spermidine and spermine synthase, resulting in an increase in molecular size from putrescine to spermidine and then to spermine[47]. Compared with other biogenic amines, the overall content of tryptame is lower. Similarly, the detection content of tryptophan is relatively low, and there is basically no detection in the early stage of storage, which may be due to the fact that low-temperature storage can effectively inhibit the formation of tryptophan. In our study, due to the broad-spectrum antibacterial activity and antioxidant capacity of AFEOs, the biological transformation of BAs was significantly inhibited.

3.7 Comparison with other essential oil treatments for fish products

In this section, the effects of AFEOs treatment on raw fish fillets are compared with those of other essential oils, as shown in Table 5. AFEOs treatment exhibits several unique advantages. Firstly, AFEOs demonstrate superior antioxidant and antibacterial properties without significant concentration limitations. Additionally, the treatment process is simple, requiring only the immersion of fish samples, which enhances utilization and reduces waste. Secondly, AFEOs significantly inhibit the formation of biogenic amines, effectively preventing spoilage and its adverse

Table 5 Comparison of the effect of plant essential oils on maintaining the quality of fish products

Plant Sources	Active ingredients	Processing method	Tested food	Effectiveness	Ref.
Lemongrass, cinnamon	neral, isoneral, geranial	immersion	Fish flesh (Dusky Spinefoot)	Inhibited the biogenic amine production during seafood preservation with reducing the microbial contamination about 0.3 log CFU/g	[48]
Bitter orange	dietary phenolics, vitamin C	immersion	Carp Fillet	On the 12th day of storage, the TVB-N content in fish meat exceeded 40 mg/100 g	[49]
Citrus	lemonene, γ-terpinene, β-laurylene	nanoemulsions	Rainbow trout fillets	TVB-N values were 18.10 mg/100 g (Day 10). Determine positive effects on fish by removing fishy odor	[50]
Ocimum basilicum	methylchavicol, linalool	immersion	Nile tilapia	Sedation and anesthesia and reduces stress in fish to achieve better taste	[51]
Orange peel	imone, α-pinene, sabine, β-myrcene	edible coatings	Rainbow trout fillets	The shelf life of fillets can be increased to at least 12 days by coating them with the salep containing 0.5% orange peel essential oil	[38]
Cinnamomum camphora, Citrus lemon	α-limonene, β-pinene, γ-terpinene	infiltration	Rainbow trout meat	Has a certain antibacterial effect, on the seventh day of storage, there was a significant difference between the control group and the treatment group	[52]
Marjoram	terpinen-4-ol, cinnamaldehyde, eugenol	nanocomposite films	Rainbow trout slice	Significantly delayed the growth of *Listeria monocytogenes* during the 15-day storage	[53]
Artemisia dracunculus	α-Pinene, anethole	composite edible coating	Nemipterus japonicus fillets	Promising antimicrobial inhibition activity against TMC and PTC bacteria during storage at refrigerator for 16 days	[54]
Zanthoxylum	eucalyptol, linalool	coating protective	Sashimi fillets	The TVB-N value of the control group is~20 mg/100 g, while the TVB-N value of the treated group is ~10 mg/100 g (Day 10).	[11]

effects on human health. Moreover, AFEOs treatment imparts a distinctive natural flavor to the raw fish fillets, offering an enhanced sensory experience for consumers, and having the low residual concentration on the fish surface. Then, widespread availability of raw materials across various regions ensures a year-round supply of effective plant materials. Overall, the prominent advantages of AFEOs in treating raw fish fillets include their efficacy, ease of processing, high utilization efficiency, broad applicability, and long history of use, making them one of the best choices among various essential oils.

4 Conclusion

Arisaema fargesii from different seasons shows variation in composition, antibacterial and antioxidant properties, but all have achieved good effects on sashimi. The research results indicate that it can maximize the sensory quality of sashimi and inhibit the growth of microbial populations, which is conducive to solving the problem of continuous decline in major freshness indicators such as lipid oxidation, protein degradation, and biogenic amine accumulation, significantly delaying the decay process of sashimi products. Therefore, *Arisaema fargesii*, as a naturally occurring herbal medicine already utilized in food, exhibits certain efficacy in the storage of sashimi through its essential oil extracts. In the future, other potential bioactive compounds of *Arisaema fargesii* and their applications in the preservation of other foods can be explored, holding significant potential and prospects for industrial development.

Conflicts of interest

The authors declare that there are no conflicts of interest in this work.

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