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Compatibility characterization and storage stability of *Ficus hirta Vahl.* chicken soup powder during storage

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Abstract

Ficus hirta Vahl. chicken soup (FHV+C-S) powder is one of the most popular Chinese-style soup powders due to its high nutritional value and special flavor. In this study, infrared spectroscopy was used to investigate the compatibility between FHV and chicken after decoction, and result showed new absorption peaks (1871 and 1522 cm^{-1}) generated in the mixed soup of FHV-chicken, indicating the interaction between FHV and chicken. The storage stability and shelf life of FHV+C-S powder were also estimated, and results indicated that storage temperature and time greatly influenced the acid value (AV) and peroxide value (POV) of FHV+C-S powder. The regression equations of FHV+C-S powder simulated by the first-order kinetic equation and the Arrhenius equation showed a high fit coefficient ($R^2 > 0.9$), and the shelf-life of the powder was predicted to be 568 days. Gas chromatography-ion mobility spectrometry (GC-IMS) was employed to analyze the changes in volatile compounds in FHV+C-S powder during storage, and results indicated the fluctuation of flavor compounds, with some decreased with storage time prolonged, such as 2-phenylethanol, hexanal, butanone, butyraldehyde, while some other increased, such as amyl alcohol, valeraldehyde, 2-octanone, 2-heptanone. This demonstrated GC-IMS as a visualized tool for flavor compounds and stability analysis.

Keywords: *Ficus hirta Vahl*; chicken soup powder; infrared spectra; shelf life; GC-IMS.

Practical Application: The compatibility characterization and storage stability of FHV+C-S powder were investigated and the shelf-life of the powder was predicted to be 568 days. This study provides a methodology basis for predicting the shelf-life of soup powders.

1 Introduction

Recently, global chicken consumption has grown rapidly (Ghollasi-Mood et al., 2017; Grau et al., 2011). Due to its advantages of high protein, low cholesterol and low-fat, chicken is one of the most traded and consumed meats worldwide. Consumption of chicken provides important nutrients to a large number of people worldwide (Jayasena et al., 2013; Patsias et al., 2008; Sallam, 2007). However, chicken is prone to deterioration during storage or transportation. It must be consumed immediately or manufacture stable products for future consumption. In Chinese culture, chicken is frequently served roasted or braised with edible functional ingredients or in soups of different types. Chicken soup (C-S) is an excellent food for convalescent patients primarily attributed to its high digestibility and nutritive values including low fat content (Gadekar et al., 2009). Soup can boost the appetite by stimulating the secretion of saliva, accelerate peristalsis of the stomach, which assists food intake and promotes nutrient delivery easily (Chiang et al., 2007; Ke et al., 2011).

FHV, an edible functional material with the restorative effect, belongs to the Moraceae family (Tripathi et al., 2017). Some pharmacological researches have shown that FHV possessed immune-regulatory, anti-inflammatory bioactivities (Cheng et al., 2017), antibacterial (Zeng et al., 2012), and improved memory function of Alzheimer's disease (AD) mice (Au et al., 2008). Over the centuries, FHV has been widely used in the preparation of healthy foods and for multiple medicinal purposes. The roots of FHV have been used for soup cooking by Chinese Hakka for a long history (Liu et al., 2017). It has been reported that FHV soup (FHV-S) has a clear protective effect against dimethylformamide- and cocaine-induced acute liver injury in mice via inhibition of free radical reactions (Achour, 2006; Patsias et al., 2008). Lots of meat-based soups found in China, FHV+C-S is well-known traditional stews prepared using young and mature native chickens, respectively (Feng et al., 2018), and has a great vogue because of the characteristic flavor as well as consumers health benefits. The content of some components of FHV and chicken decoction changed obviously after its compatibility. The composition changes of decoction after compatibility were complicated. To understand the changes after the compatibility of the soups and elucidate its compatibility mechanism, both microanalysis and macro comparison should be carried out. However, it was reported that Fourier transform infrared spectroscopy could enable the rapid differentiation of

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fresh and frozen/thawed chicken (Grunert et al., 2016). To our best knowledge, there are few reports on the overall composition change of the soup by using infrared spectroscopy.

There is an increasing demand for ready to cook or serve convenience chicken products throughout the world due to their health benefits. FHV+C-S powders are convenience foods catering to current needs at room temperature, which are sensitive to environmental conditions during the storage. Lipid oxidation is a major form of deterioration in soup powder products, which can cause quality losses, including flavor, function, nutritive value and color (Jouki et al., 2020; Soyer et al., 2010). Furthermore, it influences the quality and acceptability of C-S powder (Nollet, 2012). To solve these problems, we need to predict the shelf life (Ramos et al., 2021).

Shelf life, an important feature of food, can be defined as the length of time that a food product could be stored without its quality becoming unacceptable by consumers (Calligaris et al., 2016). The ability to predict the shelf life of a product is a complex proposition. Depending on the product nature, various properties or quality indices must be experimentally followed as a function of time to evaluate the degradation of the product quality (Achour, 2006). Generally, for real-time storage, it will take a long time to determine the shelf life of food, but the accelerated storage coupled with the Arrhenius modelling can easily shorten the experimental period (Afifah & Ratnawati, 2021).

According to the State Food and Drug Administration of China, AV and POV are selected as the indicator to predict the shelf life of dried C-S powders, and the acceptability limits are 2.5 mg/g and 0.20 g/100 g, respectively (GB 10146-2015). However, to the best of our knowledge, no research has been conducted on the shelf-life prediction of FHV+C-S powder through accelerated storage coupled with first-order and Arrhenius equation modelling.

The objective was to investigate the interaction of FHV-chicken decoction for exploring a rapid and effective method to study the compatibility mechanism. Shelf-life of FHV+C-S powder during accelerated storage was predicted and volatile compounds in the powder also were investigated.

2 Materials and methods

2.1 Materials and reagents

Fresh, domesticated, yellow-feather female chickens that had been fed for 183 d were purchased from the local market (Wanshou Road, Haizhu District, Guangzhou, China). The average weight of the chicken was approximately 1.0 kg. FHV was purchased from Heyuan city, Guangdong, China. Flavor proteases and complex proteases were obtained from Novozymes. Total antioxidant capacity kits were purchased from Nanjing Jiancheng Bioengineering Research Institute (Zhonghua Road, Qinhuai District, Nanjing, China). All other reagents used are of analytical grade, purchased from Guangzhou Chemical Reagent Factory.

2.2 Preparation of FHV+C-S powders

Preparation of FHV+C-S was modified slightly according to our previous study (Zeng et al., 2019). The chicken meat was evenly cut into small pieces by using a chopper (SL1020-A, Yangjiang SHIBAZI Group Co., Ltd, Yangjiang, Guangdong, China). Unheated distilled water (the meat-to-water ratio was 1:2) and flavor protease and complex protease (1:1, w/w, substrate concentration 2‰) were carried out by enzymatic hydrolysis in water bath for 4 hr (HHS-11-2, Shanghai Boyuan Industrial Co., Shanghai, China). Then, FHV (8%, chicken meat basis, w/w) and other ingredients were added to a stew pot (0.45 L, Guangdong Skyline Electric Co., Guangdong, China) and stewed for 3 hr. Finally, a chicken carcass was filtered after stewing. The FHV+C-S powder was prepared by the spray dryer (FD-1D-50, Beijing Boyikang Experimental Instrument Co., Beijing, China). The inlet air temperature was set at 170 °C and kept constant throughout the process. The feed speed was 16 mL/min. The powders were packed in a vacuum plastic bag. These were stored at different constant temperature and avoid light for 50 days. Every 10 days, ten packages were randomly selected and tested.

2.3 Fourier transform infrared spectroscopy (FTIR)

The FTIR spectroscopy (Thermo Scientific Nicolet iS5, America) analysis was used to characterize the chemical structure interactions in the different soup samples. The spectra were obtained over the wavenumber range of 4000-400 cm^{-1}. The spectral resolution was 4 cm^{-1} and 32 scans per sample. Samples were mixed with powdered potassium bromide (KBr) and ground gently and then pressed to form a pellet.

2.4 Color measurements

The detection method was consistent with the report of Yu et al. (2020). Determination of whiteness was carried out using a Spectrophotometer (NS-A-1608, Shenzhen Sanenshi Technology Co., Shenzhen, China) and parameters obtained were L*, b* and a*, respectively. Three measurements were performed, and the average values were calculated and adopted for each sample. The value of whiteness was calculated using the following Equation 1:

$$W = 100 - \sqrt{\left(100 - L^{*}\right)^{2} + b^{*2} + a^{*2}} \tag{1}$$

Where the L* indicates transparency (L* is equal to zero and represent black, L* is equal to hundred and represent white), and the larger the value of L*, the whiter the color of powder. The b* and a* represent the level of red and yellow, respectively.

2.5 Lipid extraction

A modified method was investigated for the total lipid extraction from powder (Li et al., 2019a). Briefly, approximately 40 g of the samples were poured into an Erlenmeyer flask, together with 200 mL petroleum ether. After soaking at room temperature for 12 hr, the organic layer was collected and combined, then filtered through filter paper. The collected solvent was mostly removed by a rotary evaporator (RE-52A, Yarong Biochemical Instrument Factory, Shanghai, China), and dried with nitrogen at 35 °C to obtain lipids. Lipid samples were placed in a vial, flushed with nitrogen gas, sealed tightly and kept at - 80 °C for further analysis within one week.

2.6 Lipid oxidation indexes

The AV reflects the free fatty acid content. The AV of the sample was determined according to the National Standard of China (2016a - GB 5009.229). The POV is expressed as meq oxygen/kg in the lipid sample. The POV was determined by a standard iodometric titration procedure following the method of the National Standard of China (2016b - GB 5009.227). This experiment was carried out in triplicate.

2.7 Developing the accelerated shelf-life test (ASLT) model for soup powders

To the accelerated shelf-life model, a single accelerating factor approach was selected, and the principles of chemical kinetics were applied to quantify the effects of temperature on the rate of deteriorative reactions (Afifah & Ratnawati, 2021; Wenjiao et al., 2014).

The effect of the chosen extrinsic factor on the deterioration of FHV+C-S powder was quantified by monitoring lipid oxidation reactions. The oxidation kinetics model analysis and shelf-life prediction were carried out by using the following equations (Xie et al., 2018). For the accelerated storage experiment, the samples were stored for 50 days at 30 °C, 40 °C and 50 °C, respectively. During storage, the samples were collected at regular intervals of 10 days. These samples were used to determine AV and POV to fit the shelf-life prediction equation.

Arrhenius Equation 2:

$$k = k_0 exp\left(-Ea / RT\right) \tag{2}$$

Where k is the reaction rate constant as an absolute temperature in s^{-1}, k_0 is frequency factor in s^{-1}, Ea is the activation energy in $Jmol^{-1}$, R is the universal gas constant equal to 8.3144 $Jmol^{-1}$, T is the absolute temperature in K.

The modified Logistic Arrhenius Equation 3 is given by :

$$lnk = lnk_0\left(-Ea / RT\right) \tag{3}$$

2.8 GC-IMS analysis

Volatile substances of FHV+C-S powders were determined according to the procedure of LI (Li et al., 2019b) and ZENG (Zeng et al., 2019) with some modifications. The GC-IMS instrument (FlavourSpec® G.A.S. Dortmund Co., Dortmund, Germany) was equipped with an auto-sampler unit (CTC Analytics AG, Switzerland) and a syringe for headspace analysis. 2 g FHV+C-S powders were selected, transferred to 20 mL headspace solid flask immediately sealed with blue PTFE / white silicone septa (Supelco, Bellefonte, PA, USA), and heated at 80 °C for 20 min in the incubating box to generate volatile compounds from the sample. 500 μL of headspace was automatically injected into the injector (80 °C, splitless mode) utilizing a heated syringe at 85 °C. The chromatographic separation was performed using a SE-54 capillary column (15 m, ID:0.53 mm) maintained at 40 °C, with nitrogen as the carrier gas. The syringe temperature was 85 °C and the transfer tube temperature was set at 45 °C. The total analysis time was 30 minutes. The differences of volatile flavor compounds between samples were identified by Laboratory Analytical Viewer, Three plug-ins (Reporter Plug-in, Gallery Plot Plug-in and Dynamic PCA Plug-in) and GC × IMS library search software.

2.9 Statistical analysis

Statistical analyses and mapping were performed using SPSS 24.0 (version 12, SPSS Inc.) and Origin 9.0, respectively. All data were expressed as means ± SDs of triplicate determinations and were analyzed by analysis of variance followed by Duncan's multiple comparison test at a significance level of $p < 0.05$.

3 Results and discussion

3.1 Infrared spectra on the compatibility of FHV+C-S

FTIR spectroscopy was used to investigate the intensity and shape of absorption peaks as the result of the interaction of various functional groups. As shown in Figure 1, it was clear that three different soups had similar spectral profiles, with little difference in absorption intensity at 4000-1500 cm^{-1}. Similar spectral lines testify to the similarity of their chemical constituents. There were stretching vibrations of O-H of hydroxyl groups in the range of 3750-3000 cm^{-1} and C = C of olefin groups in the range of 1675-1640 cm^{-1} for three different soups. Compared FHV+C-S with C-S, FHV-S, red shifts were observed from C-S 3303 to FHV+C-S 3315 cm^{-1} and FHV-S 3311 to FHV+C-S 3315 cm^{-1}. The infrared absorption spectra of three groups of soups at 1500-400 cm^{-1} had obvious fingerprint characteristics, indicating that the compatibility of soups had changed. There were two weaker peaks at 628 cm^{-1} of FHV-S and 590 cm^{-1} of FHV+C-S, which indicated the existence of C-H bending vibration in the molecule. It was shown that FHV+C-S contained the distinctive chemical constituents of FHV-S. FHV+C-S retained some absorption peaks of C-S and FHV-S, such as the spectrum of 3745 cm^{-1},

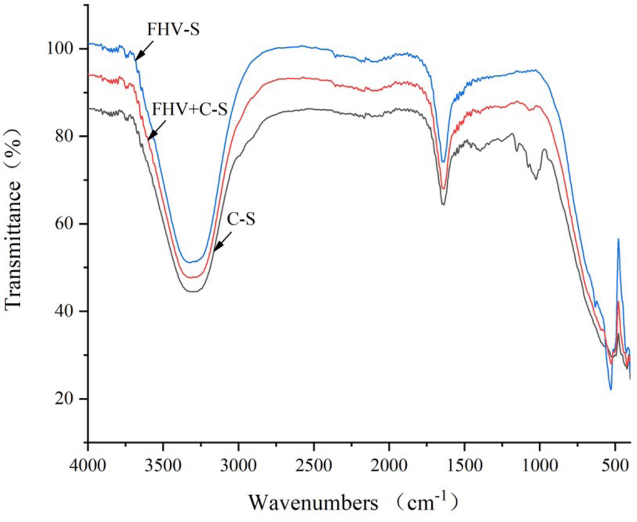

Figure 1. Fourier transforms infrared spectra of soup powders.

3315 cm^{-1} and 1635 cm^{-1}. Some absorption peaks in the spectrum of FHV+C-S disappeared, including 1396 cm^{-1}, 1255 cm^{-1}, 1151 cm^{-1}, 1022 cm^{-1}, 528 cm^{-1}, 416 cm^{-1} of C-S and 628 cm^{-1}, 503 cm^{-1}, 428 $cm^{-1}$of FHV-S, etc. The absorption peak of the FHV+C-S was observed at 1066 cm^{-1}, which was related to the bending vibration absorption peak of C-H aromatic hydrocarbons. This may be attributed to the existence of the new group caused by the interaction of components during stewing. It has been reported that infrared spectroscopy could quickly reflect the superposed spectrum of the complex components of the sample, reflect the overall effect of the sample and the changes in various chemical components, and reveal the interaction and mutual influence of the components of the sample, as well as the possible new components and changes (Grunert et al., 2016; Wenning & Scherer, 2013). The characteristic absorption peak position and peak shape and peak intensity were also different in the infrared spectrum, which constituted the entire infrared spectrum of the decoction and had the characteristics of macroscopic fingerprints. The change of the entire infrared spectrum would reflect the difference in the chemical composition of the complex system, and the newly adsorption peak presented at 1066 cm^{-1} indicated the component interaction between FHV and chicken, which made them compatible in the soup.

3.2 Color changes of FHV+C-S powders during accelerated storage

Color is a key index for food sensory analysis because it informs consumers of their assessment of product quality and overall acceptability. The changes of L*, a* and b* of the powders during accelerated storage are shown in Figure 2A. The L* values of powders decreased during storage, but the a* and b* values increased. The storage temperature had a significant effect on the change of the color parameters of powders ($p < 0.05$). Compared with the samples stored at 30 °C and 40 °C, there was no significant difference in their color values during storage, although a minor decrease or increase of the color parameters were observed. The higher temperature (50 °C) had a negative effect on the color of the powder. It may be attributed to high temperature accelerates the lipid oxidation of powders. Color parameters of powders before accelerated storage were determined as L* value of 78.09±0.43, a* value of 5.83±0.25 and b* value of 23.53±1.03. After accelerated storage for 50 days, the corresponding L* values decreased to 73.99±0.68 and a*, b* increased to 7.14±0.18 and 26.54±1.07, respectively, at 50 °C. Moreover, L* value of powder stored at 30 °C was highest among all the samples, while a* and b* value of powder at 50 °C were lowest. There was no significant difference in L*, a* and b* values of the powder stored at 30 °C for 50 days ($p > 0.05$). Color is one of the most important quality indicators of the dried sample, affecting the marketability of the final product. Previous studies reported that the average L* values of lard and butter were 72.69 and 82.35, respectively, and the b* values raised with the degree of fat oxidation (Méndez-Cid et al., 2017). Figure 2A showed the loss rate of whiteness of soup powder in different storage conditions, which was highly correlated with the storage time at each temperate. At 50 °C, the loss rate was significantly ($p < 0.05$) higher than those at lower temperatures. There was no significant difference in the loss rates of the soup powders stored at 30 °C and 40 °C ($p > 0.05$). It was reported a relationship between the depth of sardine yellowness and accumulation of lipid oxidation products such as hydroperoxides and aldehydes (Cyprian et al., 2016). Therefore, the redness and yellowness of soup powder increased significantly during accelerated storage, which may be related to the lipid oxidation and Maillard reaction.

3.3 Oxidative stability

The oxidative stability of powder was investigated by determining the POV and AV after incubation at three different storage temperatures for 50 days. Figure 2B showed the formation of hydroperoxides in powder at 30, 40 and 50 °C. As illustrated in Figure 2B(a), the AV of powder raised significantly during storage ($p < 0.05$). The result was in agreement with a study in which the content of AV from soybean oil at 25 °C was lower than 55 °C (Eshghi et al., 2014). Thus, oxidative changes in the different storage conditions were greatly affected by their chemical composition. As for the minor degradation compounds, it was observed that they varied with the storage temperature and time.

POV is regarded as an indicator of the primary lipid oxidation product, which can directly characterize the degree of lipid oxidation over time (Park & Kim, 2016; Manzoor et al., 2022). Figure 2B(b) showed the POV of powder at 30, 40 and 50 °C. In general, the higher POV , the worse the quality of sample. The result showed that temperature variations had an influence on POV. With the increase of temperature, the POV of all sample increased, but the degree of increment was different at different temperature. At the same time, the lipid peroxidation rate raised with increasing storage temperature. This result was in agreement with a study that phospholipid content in fat from leg and breast chicken meat decreased during frozen storage because lipid oxidation caused peroxides (Soyer et al., 2010). It may be attributed to high temperature accelerated the process of breaking the fat chain and promoted the hydrolysis of enzymes into more free fatty acids, which led to an increment of POV. These results indicated that low temperature could retard lipid oxidation in soup powders. Xie et al. (2018) also reported the difference in POV of lipids extracted from two clam species became more significant during accelerated storage. Autoxidation was the most common form of lipid oxidation, which was a complex free radical chain reaction process. Free radicals could be formed through the dehydrogenation of C-H bonds in lipid molecules, which promoted the oxidation of lipid (Yin et al., 2011).

3.4 Shelf-life prediction

Table 1 contained the equation for the linear regression analysis, the coefficient of determination (R^2), and the kinetic constant (k) for the AV and POV increase at different temperatures of incubation for soup powder. The oxidation kinetics model analysis was carried out by using the first-order kinetic equation. Regression coefficients of the first-order kinetic equations for AV and POV values of powders at different temperatures were all higher than 0.98, the highest value of AV and POV were 0.9923 and 0.9932, respectively. These high regression coefficient values indicated the acceptability of the first-order reaction (Wang et al., et al., 2017). The first order kinetic model is often

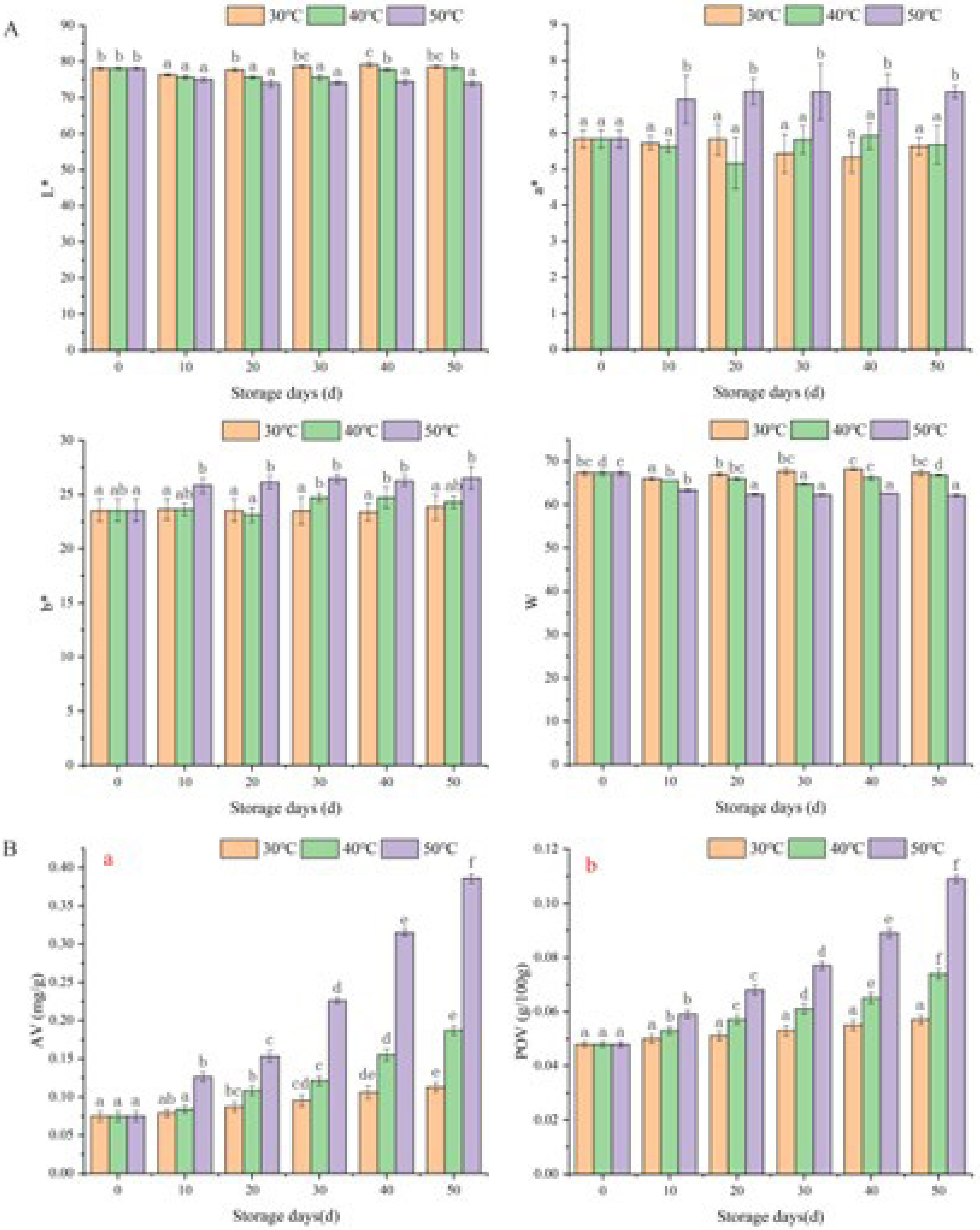

Figure 2. Effects of storage temperatures on color, AV and POV of FHV+C-S powders. (A) Color changes of samples during accelerated storage; (B) AV and POV changes of samples during accelerated storage. For each temperature, different superscript letters indicate statistically significant differences at $p < 0.05$.

used to construct food quality reaction kinetics model, and it reflects the relationship between the storage quality index and time (Rajchl et al., 2010).

The Arrhenius equation is widely used to describe the temperature dependence of kinetic constants (Schwaab & Pinto, 2007). Arrhenius Equation reflects the relationship between the reaction rate constant and the absolute temperature. The reaction rate constant and shelf-life at room temperature can be obtained by calculating the data collected from high temperature to room temperature. The AVs and POVs of powders at 30, 40 and 50 °C were obtained to fit the kinetic model. The oxidation kinetics model analysis and shelf-life prediction were carried out by using the following equations.

The First-order Kinetic Equation 4:

$$y = y_0 e^{kt} \tag{4}$$

Where y is the value of AV and POV indicators, y_0 is the initial AV and POV value, and k is the rate constant at a given temperature.

The values of k were obtained from the slope of the regression of ln $[y/y_0]$ versus time. Plotting the lnk versus 1/T in degrees Kelvin, a straight line (Arrhenius plot) was obtained, and it was possible to calculate the Ea of the degradation reaction from the relative slope. Figure 3 showed the Arrhenius plots for the formation of AV and POV. In the calculated rate constants at different temperatures, the slope of the regression line (-Ea/R) was obtained through the use of ln k on the reciprocal (T^{-1}) plot. The activation energy (Ea) was obtained through the slope of the regression line, k_0 was obtained through the intercept of the regression line (Wenjiao et al., 2014). The temperature dependence of rates on AV and POV changes was described adequately by Arrhenius kinetics at the studied temperature (Figure 3). The results from Figure 3 showed that the slope of the regression line was 6499.7, so the values of Ea and rate constant (k_0) for the powder in AV were 54.041 kJmol^{-1} and 1.8311×10^{10} respectively, and the corresponding R^2 in AV was 0.9943. The slope of the regression line was 7322.9, so the values of Ea and rate constant (k_0) for the powder in POV were 60.885 kJmol^{-1} and 1.1301×10^{8} respectively, and the corresponding R^2 in POV was 0.9949. The greater the Ea value, the slower the oxidation rate, indicating higher oxidation stability of the sample (Radha krishnan et al., 2015).

Accelerated oxidation experiments were carried out to obtain the degradation rate of lipid at 30, 40 and 50 °C. The calculated parameter and the shelf life at 50 °C were used to estimate the shelf life of samples under normal conditions utilizing the formula. The Equation 5 of the AV predictive model :

$$y = 0.075\times exp\left(1.8311\times10^{7} texp\left(-54041 / RT\right)\right) \tag{5}$$

The Equation 6 of the POV predictive model :

$$y = 0.048\times exp\left(1.1301\times10^{8} texp\left(-60885 / RT\right)\right) \tag{6}$$

Table 1. Reaction rate constant k and determination coefficient R_2 for first order regression.

Index	Temperature(°C)	Regression equation	R^2	K Value
AV (mg/g)	30	0.0737exp(0.0086t)	0.9923	0.0086
	40	0.0726exp(0.0186t)	0.9902	0.0186
	50	0.0822exp(0.0324t)	0.9845	0.0324
POV (g/100g)	30	0.0478exp(0.0035t)	0.9927	0.0035
	40	0.0480exp(0.0083t)	0.9867	0.0083
	50	0.0490exp(0.0156t)	0.9932	0.0156

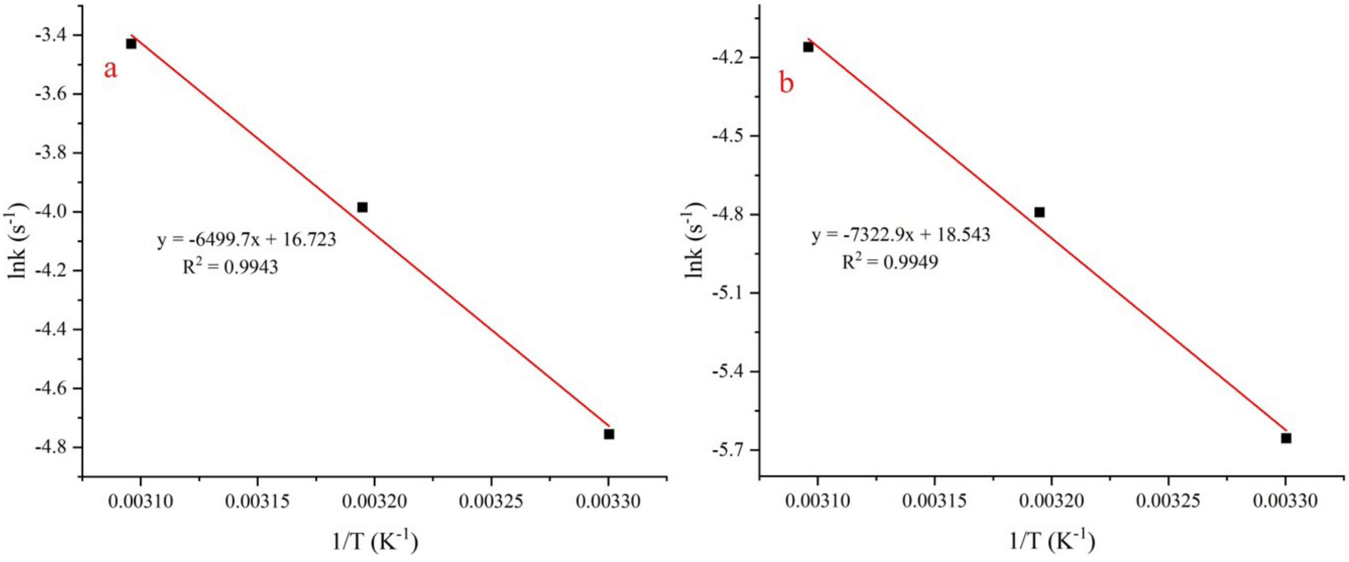

Figure 3. The value calculated of lnk versus 1/T in AV (a) and POV (b).

According to GB 10146-2015 (National Standard of China, 2015) National Food Safety Standard for Edible Animal Fats and Oils were described as follow AV ≤ 2.5 mg/g and POV ≤ 0.2 g/100g. The specific levels of Chinese standard were lower than the quality standards of the Global Organization for EPA and DHA Omega-3s (GOED) (AV ≤ 3 mg/g, POV ≤15.76 g/100 g) (Yang & Chiang, 2017). The shelf life prediction of the FHV+C-S powders stored at room temperature were 568 days and 593 days, respectively, When T = 298.15 K (25 °C).

3.5 GC-IMS analysis

The differences of volatile compounds in powders from different storage were analyzed by GC-IMS. Figure 4A showed a topographical view of FHV+C-S powders during storage. Different color was associated with the volatile compounds obtained from the analyzed samples. The topographical map indicated that the powder components were well-separated under the proposed GC-IMS conditions. The combined information from the representative signal peaks selected from the topographic map was used to distinguish the samples at different storage periods, as shown in Figure 4B.

The results of the gallery plot were shown in Figure 4C. Concentrations of some volatile substances decreased with the prolonged storage period, such as 2-phenylethanol, hexanal, butanone, butanal, 2-pentanone, 2,3-butanedione, α-pinene, 2-propanone, 2,3-pentanedione and ethylpropanoate. This indicated that lipid oxidation and carbonyl reaction might promote the volatilisation of some flavour compounds (Herianto et al., 2022). However, some volatile substances in powders increased with the prolonged storage periods, such as pentanol, pentanal, 2-octanone, 2-heptanone, isoamyl acetate, linalool, 1-hexanol, 1,8-cineole and cis-3-hexenol, indicating that alcohols were the main products of fat oxidation and their flavor threshold was higher than aldehydes.

Principal component analysis (PCA) was a multivariate statistical analysis technique and was established using signal intensity to highlight the differences in volatile compounds (Li et al., 2019c; Wang et al., 2022). PCA of volatile compounds in FHV+C-S powders was shown in Figure 4D. The volatile organic compounds varied with the storage time, and the PCA of the sample was different when stored at different temperatures. The accumulative variance contribution rate of the first two PCs were 92%, indicating that the two principal components included most information of the volatile compounds. As shown in Figure 4D, the fresh sample tended to cluster on the left, the sample points moved right along the PC1 axis and the distribution of the samples on the PCA gradually changed over time. This behavior could be accounted for by the difference in the flavor compound compositions of powders stored at different periods. The PCA results showed that the samples of 5# and 6# were the closest, indicating that the variations of flavor substance of the powder stored for a certain period may tend to stabilize. Through the PCA, it could be seen that the PCA could make a good distinction between the flavor compounds of powders stored at different storage times.

The substances with clear odor characteristics of FHV+C-S powders stored at different temperatures and times were shown in Table 2. Qualitative analysis of each type of flavor material was shown in Figure 4E; the serial numbers in this figure correspond

Table 2. Volatile compounds identified with GC-IMS.

Chemical group	Number	Analyte	CAS Number	Formula	Weight	Retention index	Retention time
Aldehydes	1	Butyraldehyde	C123728	C_4H_8O	72.1	566.7	158.00
	2	Propionaldehyde	C123386	C_3H_6O	58.1	507.9	136.58
	3	Valeraldehyde	C110623	$C_5H_{10}O$	86.1	743.8	256.31
	4	Hexanal	C66251	$C_6H_{12}O$	100.2	789.8	303.03
Alcohols	5	Amyl alcohol	C71410	$C_5H_{12}O$	88.1	763.3	275.48
	6	1-octen-3-ol	C3391864	$C_8H_{16}O$	128.2	1012.9	700.66
	7	Propanol	C71238	C_3H_8O	60.1	587.7	165.62
	8	Linalool	C78706	$C_{10}H_{18}O$	154.3	1082.6	888.88
	9	2-phenylethanol	C60128	$C_8H_{10}O$	122.2	1105.3	951.91
	10	2-ethyl-1-hexanol	C104767	$C_8H_{18}O$	130.2	1044.2	783.58
	11	Cis-3-hexanol	C928961	$C_6H_{12}O$	100.2	876.3	409.97
	12	1-hexanol	C111273	$C_6H_{14}O$	102.2	825.1	342.12
Ketones	13	Butanone	C78933	C_4H_8O	72.1	549.9	151.88
	14	Acetone	C67641	C_3H_6O	58.1	504.2	135.23
	15	2,3-butanedione	C431038	$C_4H_6O_2$	86.1	624.4	179.33
	16	2-pentanone	C107879	$C_5H_{10}O$	86.1	678.7	205.28
	17	Cyclohexanone	C108941	$C_6H_{10}O$	98.1	890.9	432.86
	18	2-heptanone	C110430	$C_7H_{14}O$	114.2	883.2	420.56
	19	2,3pentanedione	C600146	$C_5H_8O_2$	100.1	694.6	215.53
	20	2-octanone	C111137	$C_8H_{16}O$	128.2	990.8	644.50
Olefins	21	α-pinene	C80568	$C_{10}H_{16}$	136.2	904.4	456.25
	22	Limonene	C138863	$C_{10}H_{16}$	136.2	1004.7	679.44
Esters	23	Propyl acetate	C105373	$C_5H_{10}O_2$	102.1	713.9	229.98
	24	Isoamyl acetate	C123922	$C_7H_{14}O_2$	130.2	874.1	406.64
Others	25	Amyl alcohol dimer	C71410	$C_5H_{12}O$	88.1	739.2	252.01
	26	2-methylpyrazine	C109080	$C_5H_6N_2$	94.1	856	380.90
	27	1,8-eucalyptus brain	C470826	$C_{10}H_{18}O$	154.3	1057.8	820.59

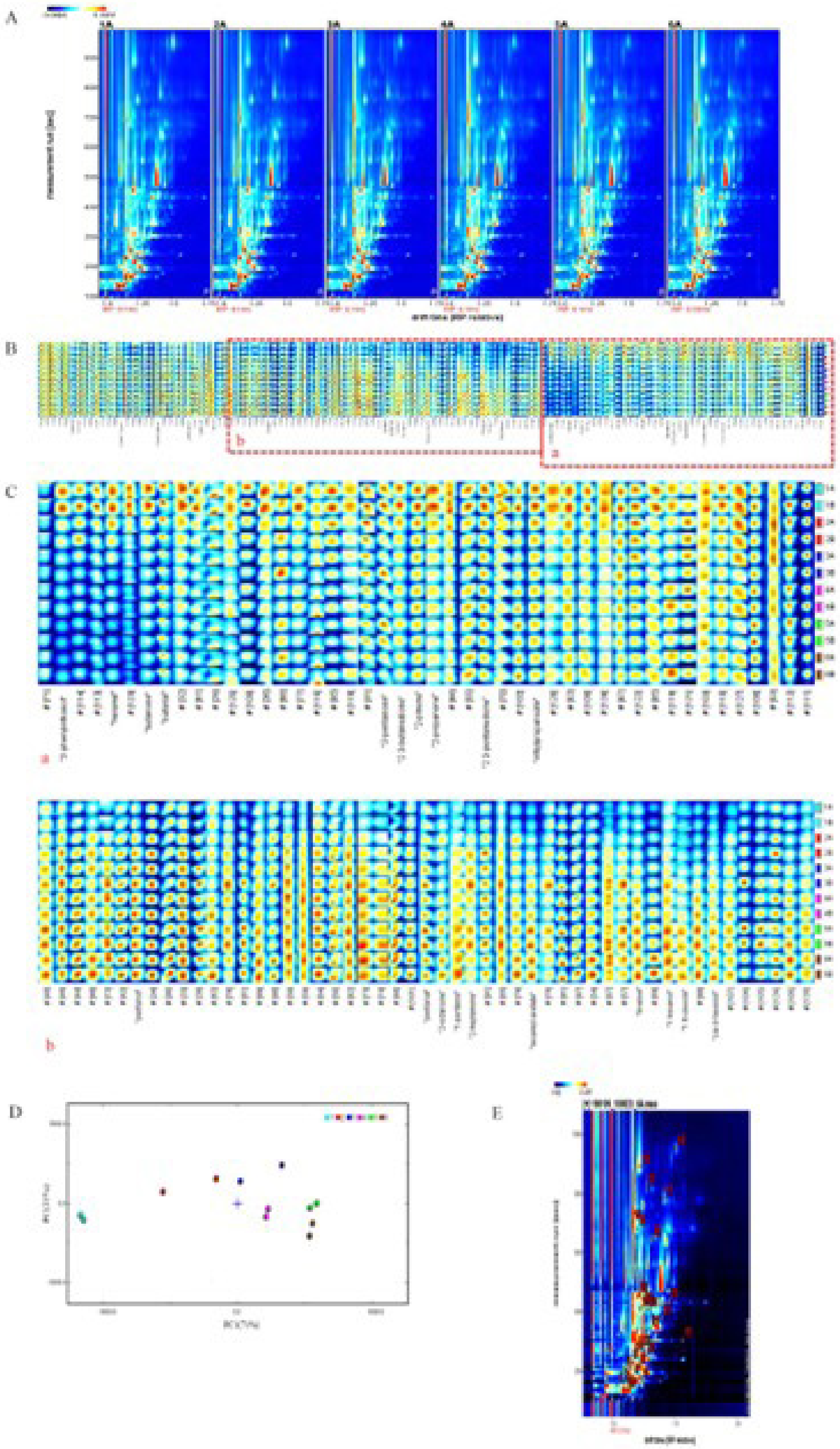

Figure 4. Identification of compounds in FHV+C-S powders by GC–IMS. (A) GC-IMS topographic plots of FHV+C-S powders; (B) Fingerprint of volatile compounds of FHV+C-S powders; (C) Ca correspond to Ba, C_b correspond to B_b; (D) PCA scatter plot of FHV+C-S powders; (E) Qualitative results of the sample.

to those in Table 2. Figure 4E showed that the volatile components of samples at different storage periods could be separated well by GC-IMS technology, and the differences of volatile substances could be seen intuitively. Identification was based on retention time in the GC column and the drift time of each analyte. A total of 66 volatile substances were detected in powders.

According to the built-in NIST 2014 gas phase retention index database and G.A.S IMS migration time database, 27 specific volatile substance components were determined by two-dimensional qualitative. Table 2 showed that some volatile compounds were studied, including aldehydes, alcohols, ketones, olefins, esters and others. The abundant aldehydes and ketones were arisen from unsaturated fatty acid oxidation, while saturated fatty acids did not oxidise (Li et al., 2022; He et al., 2022). Limonene, α-pinene, propionaldehyde, hexanal and linalool contributes to "citrus", "pine", "fragrance" and "fatty" flavors profiles, respectively, whereas eucalyptus brain has similar flavor profiles of camphor by consulting literature. In short, 2-phenylethanol, hexanal, butanone, butyraldehyde, 2-pentanone, 2,3-butanedione, α-pinene, acetone, 2,3-pentanedione, and propyl acetate were the main aroma contributing substances in the sample.

Previous research had revealed that the main aroma substances in C-S were mepyrazine, 2-ethyl-4-methylthiazole, 3-(methylthio) propanal, (E,E)-2,4-decadienal (Feng et al., 2018; Takakura et al., 2014). Qi et al. found that the umami-causing substances in C-S were mainly inosine 5-monophosphate and chloride, and the flavor and volatile substances of C-S increased for 2 hr (Qi et al., 2017). The aroma substances in C-S powders were different from other studies. It could be hypothesized that the breeds of chicken used for stewing soup were not indicated. There was a significant difference in the preparation of C-S during stewing.

4 Conclusion

The compatibility between FHV and chicken after decoction were investigated by infrared spectra. The changes of the whole infrared spectrum could reflect the changes in the chemical composition of the complex system, and the newly adsorption peak presented at 1066 cm^{-1} indicated the component interaction between FHV and chicken meat, which made them compatible in the powder. The storage stability and shelf life of the powder were estimated by the accelerated test. Results suggested that the higher temperature had a significant influence on AV and POV of samples ($p < 0.05$). The shelf life of powders stored at room temperature we predicted were 568 days according to the first-order kinetic equation and the Arrhenius equation. 27 kinds of volatile compounds were identified in the powder by GC-IMS. The content of five ketones compounds decreased with the prolonged storage time, and the content of four alcohols compounds increased, indicating that alcohols were the main products of fat oxidation. It demonstrated that GC-IMS could be a visualized tool for the analysis of flavour compounds and stability.

Ethical approval

This article does not contain any studies with human or animal subjects.

Conflict of interest

The authors have no conflict of interest to declare.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author contribution

Minhua Tan: Conceptualization (equal); Methodology (equal); Resources (equal); Formal ananlysis (equal); Supervision (equal); Writing-original draft (equal); **Biying Wang:** Methodology (equal); Software (equal) Data curation (equal); Validation (equal); **Wei Liu:** Investigation (equal); Methodology (equal); Resources (equal); Data curation (equal); Writing-review & editing (equal); **Xiaofang Zeng:** Funding acquisition (equal); Conceptualization (equal); Data curation (equal); Software (equal); **Yuanhong Zhang:** Supervision (equal); Visualization (equal); Writing-review & editing (equal); **Limei Yu:** Funding acquisition (equal); Supervision (equal); Formal analysis (equal); Writing-review & editing (equal).

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