Received: 7 July 2021 | Revised: 3 February 2022 | Accepted: 5 February 2022

DOI: 10.1111/jfpp.16466

Journal of Food Processing and Preservation | Institute of Food Science + Technology | ifst | WILEY

ORIGINAL ARTICLE

Effects of a_w storage condition on quality deterioration of dried cabbages

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Funding information
National Key Research and Development Program of China, Grant/Award Number: 2017YFD0400903

Abstract

Quality deterioration of dried vegetables often occurs during storage, and there is limited information about the quality and microbiota of dried cabbages during storage. In the present study, the appearance, physical and flavor properties, water status and mobility, and bacterial composition of dried cabbages stored at different water activity (a_w, 0.33, 0.43, 0.67, 0.78, and 0.84) conditions for 50 days were analyzed. The results showed that the content and molecular mobility of bound water, the dominant water status, increased with increasing storage a_w condition in dried cabbage samples. Dried cabbages stored at higher a_w conditions (a_w = 0.67, 0.76, and 0.84) showed less attractive appearance, poor hardness, and less integral microstructure. The deterioration of typical flavor properties, especially the loss of 2-butenenitrile, 4-methylthiobutyronitrile, and dimethyl disulfide, was the main characteristic of flavor changes. Higher a_w of storage condition notably increased the relative abundance of *Leuconostoc* after storage.

Novelty impact statement

1. Higher storage a_w condition led to the worse appearance, hardness, and integral microstructure of dried cabbages.
2. Typical flavor properties deteriorated including loss of 2-butenenitrile, 4-methylthiobutyronitrile, and dimethyl disulfide.
3. Higher a_w of storage condition notably increased the relative abundance of *Leuconostoc*.

1 | INTRODUCTION

Cabbage, a rich source of micronutrients and phytochemicals, is a worldwide popular and most consumed vegetable belonging to the family of *Brassicaceae* (Seong et al., 2016; Wang et al., 2015). Fresh cabbage, however, is highly perishable and not recommended for long-time storage (Sagar & Kumar, 2010; Sow et al., 2017). Drying is often used to prolong the shelf-life of cabbages due to its efficacy and simplicity (Xu et al., 2020), and it benefits storage stability, packaging requirements, and transport loading (Jin et al., 2014). Furthermore, there is a large export market for dried cabbage in China (Xu et al., 2004).

The drying technology, methods, and mechanism of cabbages, and their effects on the physical, chemical, and bioactive properties of cabbages have been reported (Phungamngoen et al., 2013; Rajkumar et al., 2017; Sarkar et al., 2021; Tao et al., 2019; Xu et al., 2004). The quality deteriorations of dehydrated cabbages, however, have seldom been studied. Quality deteriorations of dried agro-products often occur during shelf-life, and the undesirable changes include discoloration, texture softening, off-flavors, and nutritional value loss (Acevedo et al., 2008). Consequently, the deteriorations affect consumer acceptability and lead to devaluation (Bourdoux et al., 2016). The water activities (a_w) of storage condition plays a crucial role in the quality stabilization of dehydrated vegetables. The moisture content and mobility

of bound water increase in dried vegetables during storage, and they have an impact on the chemical stability and microbial diversity and composition (Yang et al., 2019). Drying is usually mildly performed to minimize sensory changes for dehydrating vegetables, and human pathogens, and spoilage microorganisms could survive the drying process and remain viable as a result (Beuchat et al., 2013; Bourdoux et al., 2016; Mujumdar, 2014). The microbial growth and proliferation are closely associated with a_w in food systems. For example, a_w had a positive effect on the metabolic activity of the epiphytic microbial community, cultivable population, and microbial diversity of grape skins (Martins et al., 2020). The a_w of storage condition could also affect the flavor of dehydrated foods. High a_w storage condition led to the loss of volatile characteristics and flavor deterioration (Yang et al., 2020), and water migration during the storage of sea cucumber peptide powders induced the formation of off-flavor compounds (Wang et al., 2019).

To the best of our knowledge, limited data have been reported about the quality and microbial composition of dried cabbages during storage. Herein, the physical, flavor qualities, and bacterial profiles of dried cabbages stored at different a_w conditions for 50 days were systematically investigated. It provided a comprehensive evaluation for deterioration and fundamental information for quality control of dried cabbage during storage.

2 | MATERIALS AND METHODS

2.1 | Dried cabbage samples and storage conditions

Dried cabbages were purchased from Xinghua Dehydrated Foods Group Co., Ltd. (Taizhou, Jiangsu Province, China). They were placed into sealed desiccators with saturated salt solutions for a 50-day storage period. Five saturated salt solutions were used to achieve different water activities namely, $MgCl_2$, K_2CO_3, $NaNO_2$, NaCl, and KCl, corresponding to a_w values of 0.33, 0.43, 0.67, 0.76, and 0.84 respectively at 25°C (Wang et al., 2013). Physical, and flavor properties were analyzed every 10 days of the storage period.

2.2 | Measurement of texture and microstructure

A texture analyzer (TA-XT2i plus, Stable Micro Systems, Ltd., Surrey, UK) was used to analyze the texture of dried cabbages. Samples were compressed by a P/25 probe at a pre-speed, test speed, and post-speed of 2.0 mm/s, 1.5 mm/s, and 5.0 mm/s, respectively, and 10% strain (Wang et al., 2018). Hardness was evaluated in terms of maximum force (rupture force in N) recorded in a typical force-distance diagram.

To observe microstructure of dried cabbages, samples were soaked in 4% glutaraldehyde for 1 hr and rinsed three times with 0.1 mol/L phosphate buffer (pH 7.4). After freeze drying, the samples were kept on aluminum base and coated with a gold layer by a sputter coater (BAL-TEC AG, Balzers, Liechtenstein). The samples were then photographed using an H-7650 scanning electron microscope (Hitachi High Technologies Corporation, Tokyo, Japan) at an accelerating voltage of 80 kV (Yang et al., 2017).

2.3 | Detection of flavor properties

FOX 3000 electronic nose was used to analyze the flavor of the dried cabbages. The gas analyzer array detector of electronic nose (LY/LG, LY/G, LY/AA, LY/Gh, LY/gCTI, LY/gCT, T30/1, P10/1, P10/2, P40/1, T70/2, and PA2) was applied to distinguish odor patterns of different aroma models. The test parameters followed the method described by Yang et al. (2016) with modification.

Volatile compounds in dried cabbages were analyzed by solid-phase micro-extraction combined with gas chromatography–mass spectrometry (HS-SPME-GC–MS) according to our previous study (Pu et al., 2019). Dried cabbages (1 g) were weighed in a sealed 20-ml headspace vial. The fiber holder (DVB/CAR/PDMS, 50/30 mm) (Supelco Ltd., Bellefonte, PA, USA) was used to extract the volatile compounds at 60°C for 40 min, which were then analyzed by GC–MS (7890A/5975C, Agilent Technologies, Santa Clara, CA, USA). The volatile compounds were desorbed at 250°C for 5 min in the GC injector in splitless mode, and separated on a DB-5MS capillary column (30 m × 0.25 mm, 0.25 mm) (J&W Scientific, Folsom, CA, United States). The column temperature was initially kept at 40°C for 3 min, raised to 80°C at 5°C/min and maintained for 3 min, then increased to 220°C by 10°C/min for 2 min and to 240°C by 5°C/min for 2 min finally. The carrier gas helium ran at a flow rate of 0.8 ml/min. Mass spectra were obtained in an electron impact mode and were taken at 70 eV ionization energy in the 35–550 amu mass range with the ion source temperature set at 230°C. The retention index was calculated for each volatile compound using the retention times of a homologous series of C7-C30 *n*-alkanes (Sigma-Aldrich, St. Louis, MO, USA) and by comparing the retention times with those of authentic compounds analyzed under similar conditions.

2.4 | Determination of moisture content and water status

Moisture content was determined according to our previous study (Yang et al., 2017). Low-field nuclear magnetic resonance (LF-NMR) was used to detect water status and molecular mobility in dried cabbages. Transverse relaxation time curves were generated using the Carr-Purcell-Meiboom-Gill pulse sequence. Pulse parameters were set according to our previous study (Pu et al., 2019).

2.5 | Amplicon sequencing of microbiota in dried cabbages

16S rDNA sequencing was used to analyze the bacterial composition of dried cabbages on days 0 and 50 at different a_w conditions.

The total bacterial suspension was obtained according to the protocol (National Health Commission of the People's Republic of China & State Food and Drug Administration, 2017). The cabbages samples were homogenized with phosphate buffer solution (PBS, 10 mmol/L, pH = 7.2, 1:10, w/v) in the stomacher bag, and mixed using a Stomacher 400 (International P. B. I., Milano, Italy) at 300 rpm for 2 min. The total genomic DNA was extracted using a TIANamp Bacteria DNA Kit (TIANGEN Biotech, Beijing, China) according to the instruction manual. A high-fidelity polymerase chain reaction (PCR) was utilized to amplify bacterial 16S rDNA hypervariable region 4 (V4) with the primers (Primer 341F: CCTACGGGNGGCWGCAG, and Primer 805R: GACTACHVGGGTATCTAATCC), and specific sequencing labels were added to the library. High-throughput sequencing was performed on an Illumina Miseq platform using a 2 × 250 bp paired-end method after the library was quantified, mixed, and quality checked. The raw data were filtered by several steps to remove low-quality reads. Operational taxonomic units (OTUs) were clustered with a similarity of 97% by UPARSE (Edgar, 2013). The OTUs were then subsampled randomly. After quality cleaning, filtering, and dereplication, the input sequences were ordered according to their abundances, considering the high abundance reads. Mothur was used for taxonomical assignments at an 80% confidence level based on the Ribosomal Database Project database (Cole et al., 2014). R software packages (V2.15.3, http://www.r-project.org/) were used for calculation of alpha and beta diversities. Cluster analysis and Venn diagram were used to reveal the difference in microbial profiles (Xie et al., 2017). The statistical difference of relative abundances of bacterial communities was identified by Matastats (White et al., 2009).

3 | RESULTS AND DISCUSSION

3.1 | Physical properties

The physical deteriorations of dried cabbages during storage at different a_w were shown in Figure 1, including the appearance changes, microstructure, and hardness of samples during 50 days of storage. For the dried cabbages stored at low a_w conditions (a_w = 0.33 and 0.43), no notable appearance change was detected as the color (yellow and green) was almost maintained through the entire storage time (Figure 1a). However, discoloration and microorganism growth were observed in the cabbage samples stored at high a_w conditions (a_w = 0.67, 0.76, and 0.84) at the later period of storage. The samples lost the characteristic yellow and green color and turned white and gray on day 10, and visible microbial growth was observed at a_w = 0.76 and 0.84 on days 40 and 30, respectively. The destruction of pigments and antioxidants, including chlorophylls, due to oxidation, contributes to the discoloration in dehydrated green vegetables (Sturm & Hensel, 2017). A_w could facilitate the extent of browning in dehydrated cabbages (Mizrahi et al., 1970).

Similar tendencies were also observed in microstructure (Figure 1b) and hardness (Figure 1c) of the dried cabbages. At the beginning of storage, cross section of dried cabbages was composed of erect and turgid cells. Distribution of sample cells was orderly and did not change remarkably at a_w = 0.33 and 0.43 conditions as the storage period progressed. However, gradual fold and adhesion of the tissues were observed at a_w = 0.76 and 0.84 conditions after 30 days. At the end of storage, a complete

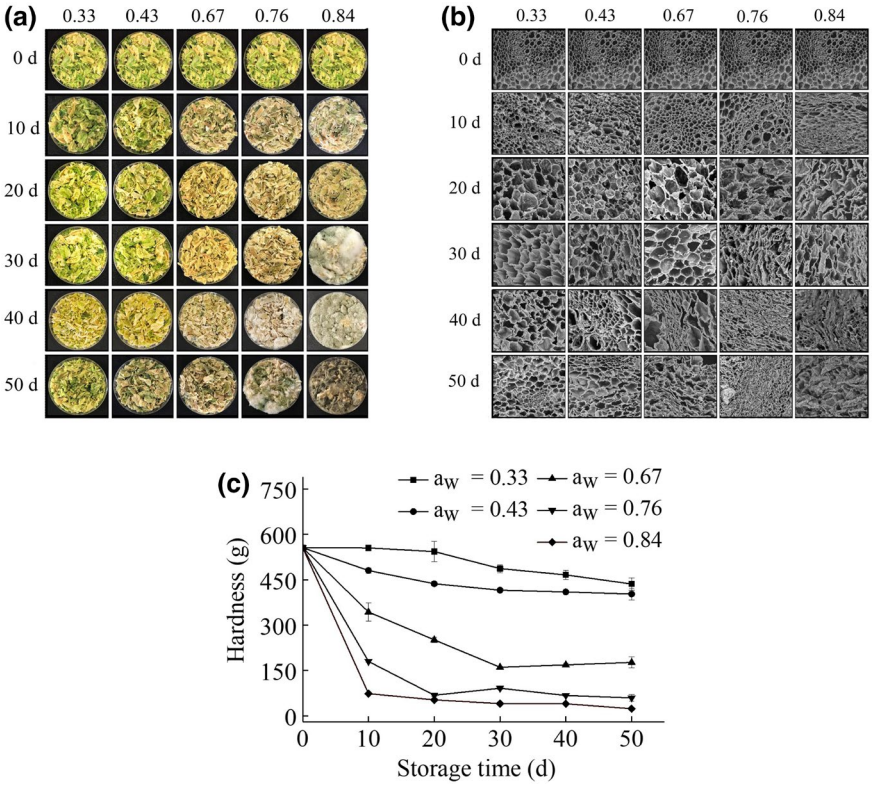

FIGURE 1 Appearance changes (a), microstructure (b), and hardness (c) of dried cabbages stored at different a_w conditions

collapse of the microstructure was observed at a_w = 0.84 condition. The results indicated that storage conditions lead to microstructural changes of dried products. Consequently, microstructural changes affected their macroscopic physical properties. At high a_w conditions (a_w = 0.67, 0.78, and 0.84), hardness of the dried cabbages decreased more rapidly on the first 10 days of storage, and they were significantly lower ($p < .05$) than the other samples. At the end of storage, hardness of dried cabbages stored at a_w = 0.33 and 0.43 conditions was >400 g, and that of the dried cabbages stored at higher a_w conditions was <300 g. Dried cabbages stored at lower a_w conditions showed a more attractive appearance, integral microstructure, and maintained a better hardness during storage.

3.2 | Flavor properties analysis

Electronic nose analysis provides a comprehensive evaluation of the overall information on flavor, and principle component analysis (PCA) is used to explain variance in the experimental data (Wang et al., 2018). Figure 2a showed the radar fingerprint chart of the flavor properties of the dried cabbages before and after storage. Generally, the similar shape of these radar graphs implied some similarities among the samples. Compared with other sensors, the values of PA/2, T70/2, P40/1, P10/2, P10/1, and T30/1 were positive. With the increasing a_w, values of the six sensors increased at first, reached a peak value at a_w = 0.67, and then decreased. These sensors were positively correlated with sulfur compounds and acids, alcoholic vapors, freon oxidative molecules, methane, and aliphatic nonpopular molecule, hydrocarbons, and acids, respectively (Pei et al., 2016; Yao et al., 2015). The radar fingerprint charts of the dried cabbages stored at a_w = 0.33 condition for 50 days almost overlapped with that on day 0, indicating that the overall flavor characteristics did not change much after 50 days storage. The result exhibited that lower a_w was a more promising storage condition for maintaining flavor for dried cabbages.

PCA analysis in Figure 2b displayed the differences in the volatile profiles. The accumulative variance contribution rate of the first two principal components accounted for 95.4% (more than 85%), indicating that most flavor information could be determined (Yang et al., 2016). The points presenting the volatile profiles of dried cabbages stored for 50 days were completely separated from the original ones. In addition, the points of the dried cabbages stored at a_w = 0.33 condition located the closest to the points of the sample on day 0, and the results indicated that lower a_w contributed to preservation of volatile compounds in dried cabbages, which was in agreement with the results shown in Figure 2a.

3.3 | Moisture content and water status

Moisture content and water status are critical parameters to evaluate the stability of dried products (Xu et al., 2017). Generally, the moisture contents of the dried cabbages stored at different a_w conditions were all increased, but the increase was more rapid with growing a_w (Figure 3a). At the end of storage, moisture content of the cabbage samples stored at a_w = 0.76 and 0.84 conditions exceeded safe moisture level (15%) for dried foods (Afzal et al., 1999).

Figure 3b-f showed the distribution of LF-NMR T_2 relaxation times of dried cabbages at different a_w conditions. Three relaxation times and their corresponding peak areas were recorded. For the samples before storage, the signals in the range between 0 and 10 ms (T_{21}) represented bound water, between 10 and 100 ms (T_{22}) represented the immobilized water and those between 100 and 1000 ms (T_{23}) represented the free water (Yang et al., 2017). The transverse relaxation time of bound water increased for samples at all treatments during storage.

The T_{21} peak area in all samples changed significantly ($p < .05$), whereas that of T_{22} and T_{23} showed insignificant changes ($p > .05$). Compared with samples at a_w = 0.33 condition, the T_{21} peak area in other samples increased during storage, suggesting that mobility of bound water increased (Pitombo & Lima, 2003). These results indicated that more bound water could participate in chemical reactions and affect the quality stability of dried cabbages at the same time. In addition, the transverse relaxation time of bound water increased for samples at a_w = 0.76 and 0.84 conditions during storage and located in the range between 10 and 100 ms at the end of storage. These results indicated that molecular mobility of bound water increased at higher a_w and could be utilized by microorganisms to reactivate their growth and propagation (Li et al., 2015).

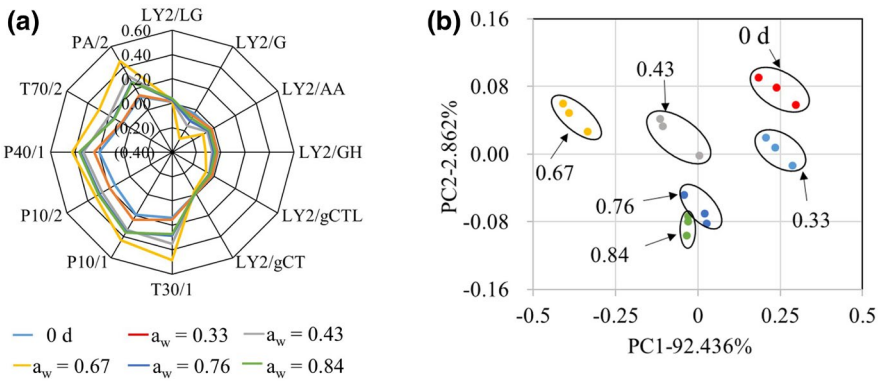

FIGURE 2 E-nose analysis (a) and PCA analysis of E-nose data (b) of dried cabbages stored at different a_w conditions

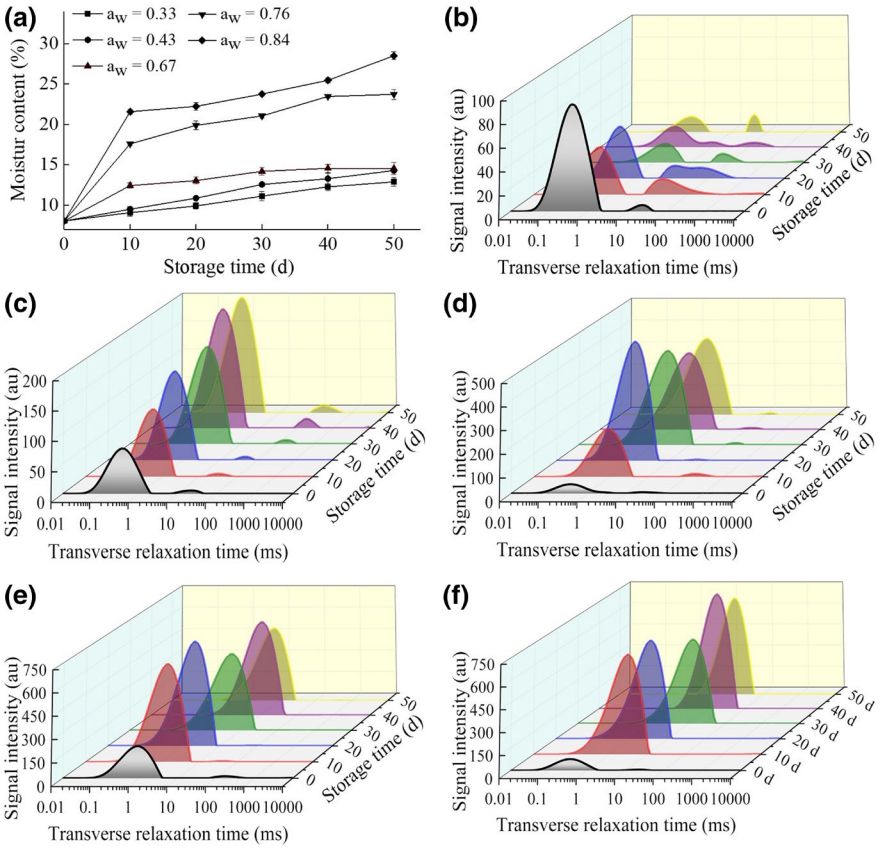

FIGURE 3 Moisture content (a) and moisture signal intensity of dried cabbages stored at a_w of 0.33 (b), 0.43 (c), 0.67 (d), 0.76 (e), and 0.84 (f) conditions

3.4 | Volatile compounds analysis

Change in volatile compounds is a critical parameter to evaluate quality of dried cabbages during the market circulation. The volatile compounds in dried cabbages on 0 days and after 50 days of storage at different a_w conditions were shown in Table 1, and there were 46 volatile compounds detected in total, including 3 hydrocarbons, 7 alcohols, 5 aldehydes, 2 esters, 1 acid, 5 ketones, 8 terpenes, and 15 heterocyclic and aromatic compounds.

As exhibited in Tables 1, 14 volatile compounds in the list were detected at the beginning of storage. Heterocyclic and aromatic compounds were the predominant compounds, especially 2-butenenitrile and 4-methylthiobutyronitrile, with a relative content of 58.22 and 16.97%, respectively. Cabbage contains enzyme myrosinase which hydrolyzes glucosinolates and leads to the formation of flavor compounds, mainly nitriles (Rajkumar et al., 2017). Moreover, many sulfides also contribute to the sulfurous aroma, typical of the cabbages flavor (Rajkumar et al., 2017). In this study, three sulfides were detected, including dimethyl sulfide, dimethyl disulfide, and dimethyl trisulfide in samples on Day 0. In previous publication, some volatile compounds were also detected in newly hot-air or freeze-dried cabbages, such as dimethyl sulfide, dimethyl disulfide, benzenepropanenitrile, hexanal, and nonanal (Rajkumar et al., 2017). After being stored for 50 days, hydrocarbons and alcohols were detected in all the cabbage samples stored at different a_w conditions, and the relative contents of aldehydes in the dried cabbages increased. Furthermore, heterocyclic, and aromatic compounds decreased with the increasing a_w of storage condition. The lowest relative contents were found in the dried cabbages stored at a_w = 0.76 and 0.84 conditions, and they were 22.04 and 22.80%, respectively. A series of aldehydes constituting pentanal, hexanal, and nonanal were found to be the major aldehydes after 50 days. They were considered to constitute pungent odors in dried cabbages (Rajkumar et al., 2017). As typical flavor compounds in dried cabbages, relative content of 2-butenenitrile decreased with increasing a_w of storage condition, while dimethyl disulfide was lost in samples stored at higher a_w (0.67, 0.78, and 0.84) conditions. The results indicated that the typical flavors of dried cabbages stored at higher a_w conditions were lost after storage for 50 days.

3.5 | Diversity of microbiota in the dried cabbages

There were 2226 different OTUs detected in total, and each sample consisted of 417 ± 296 OTUs, and the refraction and Shannon index curves of the microbiota in dried cabbages were shown in Figure 4a-b. Although refraction curves increased with the sequencing depth, the Shannon index curves of all the samples reached a plateau. Coverage index (99.91 ± 0.01%) suggested that most species were captured, indicating that the results were valid as derived from data.

Among these groups, the microbiota of the dried cabbages stored at a_w = 0.84 condition showed the highest alpha-diversity after 50 days of storage, whereas those of the samples stored at the other a_w conditions were close to those of the samples on day 0. The cluster

TABLE 1 Volatile compounds content of dried cabbages on day 0 and day 50 stored at different a_w conditions

No.	Compounds name	Retention index	Volatile compounds content (%)					
			0 day	$a_w = 0.33$	$a_w = 0.43$	$a_w = 0.67$	$a_w = 0.76$	$a_w = 0.84$
	Hydrocarbons		**0.00%**	**6.14%**	**2.15%**	**2.19%**	**5.30%**	**1.41%**
1	Dodecane	1200		3.18%	1.36%	0.46%	5.30%	
2	Tetradecane	1400		1.88%	0.79%	1.09%		1.41%
3	Tridecane	1300		1.08%		0.64%		
	Alcohols		**0.00%**	**1.40%**	**11.39%**	**24.24%**	**18.24%**	**15.83%**
4	Ethanol	428			5.75%	4.57%		
5	1-pentanol	764			3.74%	2.37%	3.35%	8.08%
6	1-hexanol, 2-ethyl-	1030		1.40%	1.90%	2.92%	2.65%	0.76%
7	1-hexanol	865				5.33%		
8	Benzyl alcohol	1032				1.78%		
9	1-octen-3-ol	1011					6.54%	6.99%
10	1-butanol, 2-methyl-, (.+/−.)-	730				7.27%	5.70%	
	Aldehydes		**2.17%**	**6.88%**	**5.76%**	**17.25%**	**4.26%**	**15.88%**
11	Hexanal	805	0.88%	3.03%	2.84%	7.72%	1.01%	0.49%
12	Nonanal	1105	1.29%	2.50%		1.03%	0.54%	
13	Benzaldehyde	978		1.35%	2.92%	6.61%	0.97%	
14	2-heptenal, (E)-	951				0.86%	1.74%	2.14%
15	Pentanal	705						13.25%
	Esters		**0%**	**0%**	**0%**	**2.50%**	**4.50%**	**6.09%**
16	Isoamyl acetate	864				2.50%	4.03%	5.66%
17	Bornyl acetate	1289					0.47%	0.43%
	Acid		**8.22**	**9.66%**	**16.18%**	**17.06%**	**14.31%**	**8.30%**
18	Acetic acid	625	8.22	9.66%	16.18%	17.06%	14.31%	8.30%
	Ketones		**0.60%**	**0.77%**	**0.56%**	**1.27%**	**9.32%**	**0.49%**
19	3(2H)-furanone, dihydro-2-methyl-	808	0.60%	0.77%	0.56%	0.62%		
20	2-heptanone	885				0.65%		
21	2-methylcyclohexanone	928					1.05%	
22	3-octanone	984					7.37%	
23	Cyclohexanone, 2,2,6-trimethyl-	1056					0.90%	0.49%
	Terpenes		**0.80%**	**11.41%**	**6.51%**	**1.96%**	**18.35%**	**29.02%**
24	Longifolene	1405	0.80%	0.95%				
25	o-cymene	1034		2.37%	1.62%	1.96%	8.28%	8.55%
26	α-terpinene	1015					1.40%	
27	γ-terpinene	1050		2.83%	2.02%		4.28%	9.87%
28	Terpinolene	1085		3.52%	2.36%		2.08%	4.75%
29	α-pinene	917		0.63%	0.51%		1.04%	2.35%
30	β-pinene	981		0.76%			1.27%	2.79%
31	D-limonene	1028		0.35%				0.71%
	Heterocyclic and aromatic compounds		**88.24%**	**61.50%**	**57.96%**	**34.56%**	**22.04%**	**22.80%**
32	Dimethyl sulfide	530	2.80%	12.42%	12.57%	3.83%		2.37%
33	Dimethyl trisulfide	974	0.38%	0.60%	0.92%		1.84%	0.89%
34	Dimethyl disulfide	750	2.01%	2.07%	4.46%			
35	2-butenenitrile	697	58.22%	14.60%	12.44%	11.78%	10.65%	6.37%
36	3-butenenitrile	656	2.17%	1.93%				

TABLE 1 (Continued)

No.	Compounds name	Retention index	0 day	Volatile compounds content (%) $a_w = 0.33$	$a_w = 0.43$	$a_w = 0.67$	$a_w = 0.76$	$a_w = 0.84$
37	Naphthalene	1160	0.94%	0.41%				
38	Dibutylbenzene	1294		22.57%	22.28%	9.72%	5.38%	7.62%
39	Caryophyllene	1416		0.24%	0.85%		0.54%	0.77%
40	2,6-dimethylstyrene	1054					0.26%	
41	Pyrazine, 2,6-dimethyl-	914	0.99%	1.77%	1.87%	1.62%		0.35%
42	Pyridine, 2,3-dimethyl-	932			0.88%	1.21%		
43	Benzenepropanenitrile	1259	3.76%			2.76%	2.81%	4.43%
44	4-methylthiobutyronitrile	1494	16.97%					
45	Phenol, 2,4-bis(1,1-dimethylethyl)-	1503		2.12%	1.69%	0.75%	0.56%	
46	3,4-dimethylthiophene	901		2.77%		2.89%		

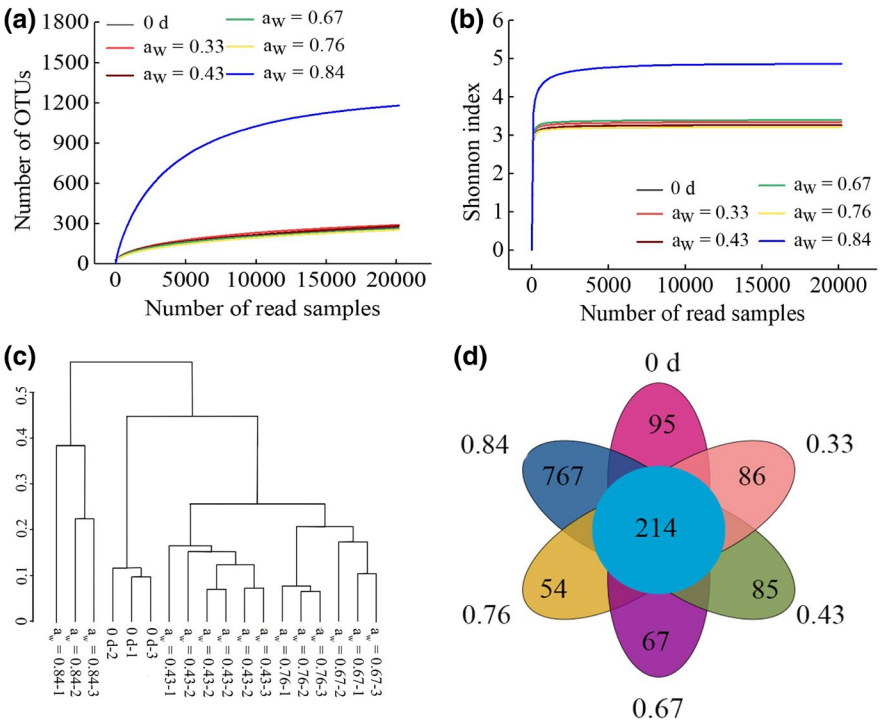

FIGURE 4 Rarefaction curve (a) and Shannon index curves (b), cluster analysis (c), and Venn diagram (d) of the microbiota (OTU level) in dried cabbages stored at different a_w conditions

analysis and Venn diagram were used to compare the bacterial community of all samples at the OTU level. As shown in Figure 4c, cluster analysis indicated that the microbiota of the dried cabbage samples was divided into two main clusters, one of which was those of the dried cabbages stored at $a_w = 0.84$ condition for 50 days and the other consisted of those of the samples on day 0 and stored at the other a_w conditions. The results indicated that the dried cabbages stored at $a_w = 0.84$ condition for 50 days had significantly different bacterial profiles from the other groups. Venn diagram was used to find the number of unique and shared OTUs among all the samples. As shown in Figure 4d, 214 OTUs were shared by all the samples. There were 767 unique OTUs detected in the dried cabbages stored at $a_w = 0.84$ condition, and all the other samples had only <100 unique OTUs. The results indicated that lower a_w storage condition was a promising candidate to maintain the initial bacterial profile in dried cabbages.

3.6 | Bacterial composition at genus level

The bacterial composition at genus level was shown in Figure 5. The most abundant genera included *Leuconostoc*, *Streptococcus*, *Lactococcus*, and *Lactobacillus*, and three of them were classified into lactic acid bacteria (LAB), a gram-positive bacterial group (Alvarez-Sieiro et al., 2016). They dominate fermentation microbiota in many fermented foods, but they are also relevant as food spoilage organisms. In most cases, the spoilage LABs originate from the production line or raw materials and are resistant to environmental stresses (Kubota et al., 2008). *Streptococcus* infection is among the important problems facing contemporary medicine (Krzyściak et al., 2013). Numerous streptococci occur as opportunistic pathogens and cause health problems, including pharyngitis, pneumonia among other infections (Krzyściak et al., 2013). It was observed that the relative

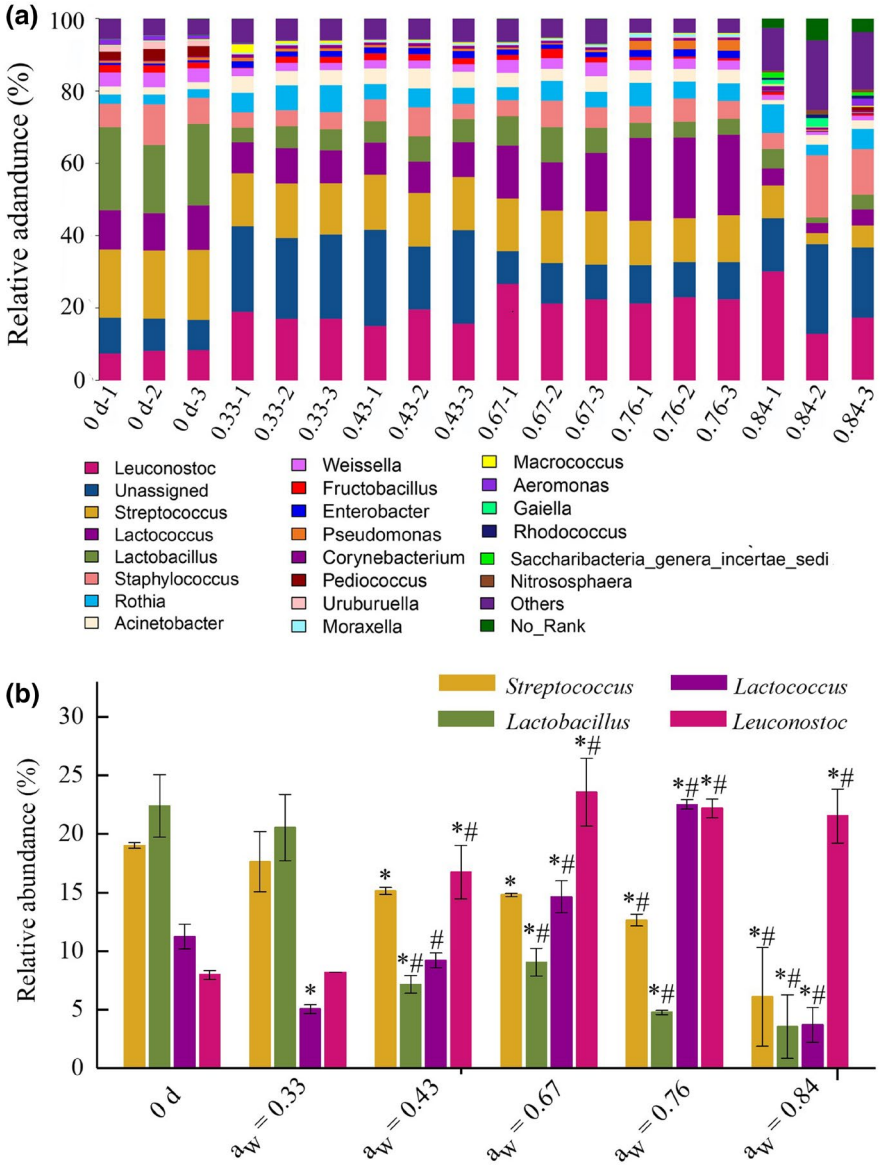

FIGURE 5 Bacterial composition at genus level (a) and the relative abundance of *Lactobacillus*, *Lactococcus*, *Leuconostoc*, and *Streptococcus* (b) on day 0 and day 50 in dried cabbages stored at different a_w conditions. (* meant the relative abundance was significantly different from that of the group 0 day, and # meant the relative abundance was significantly different from that of the group $a_w = 0.33$ ($p < .05$))

abundance of *Streptococcus* decreased rapidly with increasing a_w after being stored for 50 days. In addition, a significant increase was observed in the relative abundance of *Leuconostoc* in the dried cabbages stored at high a_w (0.67, 0.76, and 0.84) conditions for 50 days, whereas the relative abundance of *Lactobacillus* decreased in the samples stored at the same conditions. *Leuconostoc* spp. are environmental organisms generally found in fresh plants, such as cabbages. Some species could utilize sugar in cabbages for growth. However, in many foods, *Leuconostoc* spp. has been found to be the most predominant species, that also belongs to the predominant microbiota at the late shelf-life stage (Andreevskaya et al., 2018). The documented spoilage activities for both bacteria include the excessive formation of buttery and sour off-odors (Rahkila et al., 2012). In addition, some *Leuconostoc* spp. spoilage has been associated with discoloration and the production of gas and slime (Johansson et al., 2011). It was reported that there were foodborne pathogens, including *Salmonella* spp., *Cronobacter* spp., *Staphylococcus* spp., and *E. coli*, in dehydrated foods in many cases (Chitrakar et al., 2019). *Staphylococcus* also accounted for a portion of relative abundance in the present study of dried cabbages. In the previous publication, the effects of a_w of storage conditions on dried vegetables. In the dried carrot samples, the relative abundances of *Weissella*, *Leuconostoc*, and *Lactobacillus* were decreased after storage, and the relative abundance of *Pediococcus* was increased leading to the generation of volatile γ-terpinene (Pu et al., 2019). The relative abundances of *Weissella*, *Erwinia*, *Rosenbergiella*, and *Ewingella* were increased in dehydrated chives after storage, and high a_w of storage condition significantly raise the relative abundances of *Kocuria*, *Streptococcus*, and *Bacillus*, which were associated with the various detected volatile compounds (Xie et al., 2022).

4 | CONCLUSIONS

In the present study, the effects of a_w storage conditions on quality deterioration of dried cabbages were systematically evaluated.

Dried cabbages stored at lower a_w condition maintained initial color and hardness, better microstructure, and less adhesion of tissues. At higher a_w conditions, molecular mobility of bound water increased, and microorganism could utilize it for growth. Meanwhile, high a_w aggravated flavor deterioration and increased the diversity of microbiota after 50 days of storage. It also contributed to the relative abundance increase of *Leuconostoc*, a spoiling bacterial community. In summary, the study provided systematic information for quality monitoring of dried cabbages and may contribute to further preservation strategies for dried foods.

ACKNOWLEDGMENTS

This work is financially supported by the foundation of National Key Research and Development Program of China (2017YFD0400903), the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD).

AUTHOR CONTRIBUTIONS

minhao xie: Conceptualization; investigation; writing – review and editing. **Haoliang Pu:** Investigation; writing – original draft. **Qiuhui Hu:** Resources; supervision. **Anxiang Su:** Project administration; validation. **Alfred Mugambi Mariga:** Writing – review and editing. **Xiuting Li:** Supervision. **Wenjian Yang:** Conceptualization; funding acquisition; methodology; supervision; writing – review and editing.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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How to cite this article: Xie, M., Pu, H., Hu, Q., Su, A., Mariga, A. M., Li, X. & Yang, W. (2022). Effects of a_w storage condition on quality deterioration of dried cabbages. *Journal of Food Processing and Preservation*, *00*, *1–10*. https://doi.org/10.1111/jfpp.16466