Food Chemistry: X 18 (2023) 100702

Contents lists available at ScienceDirect

Food Chemistry: X

journal homepage: www.sciencedirect.com/journal/food-chemistry-x

Edible gum addition improves the quality of freeze-dried restructured strawberry blocks

Feifei Yang [a,b], Xiyun Sun [a], Jiaqi Hu [a,b], Honghong Cai [b,c], Hongwei Xiao [d], Xianghua Wu [b], Chunju Liu [e], Haiou Wang [b,*]

[a] College of Food Science, Shenyang Agricultural University, Shenyang 100866, China
[b] School of Food Science, Nanjing Xiaozhuang University, Nanjing 211171, China
[c] College of Biological Science and Technology, Beijing Forestry University, Beijing 100083, China
[d] College of Engineering, China Agricultural University, Beijing 100083, China
[e] Institute of Agro-product Processing, Jiangsu Academy of Agricultural Sciences, Nanjing 210014, China

ARTICLE INFO

Keywords:
Edible gum
Freeze-dried restructured strawberry block
Vacuum freeze-drying
Quality
Hygroscopicity
Texture

ABSTRACT

Freeze-dried restructured strawberry blocks (FRSB) have become an increasingly popular product. In this study, the effects of six edible gums (guar gum, gelatin, xanthan gum, pectin, konjac gum, and carrageenan) on the FRSB quality were investigated. For FRSBs, compared with those in untreated samples, the 0.6 % guar gum addition increased texture profile analysis (TPA) hardness, chewiness, and puncture hardness by 29.59%, 174.86%, and 25.34%, respectively; after the 0.6% gelatin addition, the sensory evaluation sourness was reduced by 8.58%, whereas yield, TPA chewiness, and puncture hardness were increased by 3.40%, 28.62%, and 92.12%, respectively; with the 0.9% gelatin addition, the sensory evaluation sourness was reduced by 8.58%; with the 0.9% pectin addition, the yield, TPA hardness, chewiness, and puncture hardness were increased by 4.55%, 5.94%, 77.49%, and 103.62%, respectively. In summary, 0.6–0.9% pectin, gelatin, and guar gum addition are recommended to improve the main qualities of FRSBs.

1. Introduction

Strawberries (*Fragaria ananassa Duch.*) are highly sought-after fruits owing to their appetizing taste, pleasant flavor, nutrient richness and derived functional ingredients (Fan & Zhang, 2022; Frabetti, Porto, Simao, & Laurindo, 2021; Kosińska-Cagnazzo, Diering, Prim, & Andlauer, 2015). As an extremely perishable fruit, strawberries are easily infected by microorganisms during storage and are rattled during transportation, thereby reducing their quality and edible value (Cybulska et al., 2022); therefore, strawberries must be processed immediately to ensure a longer shelf life (Shehata et al., 2020), for which drying is regarded as an appropriate method (Calín-Sánchez et al., 2020; Karam, Petit, Zimmer, Djantou, & Scher, 2016). Drying of fresh fruits and vegetables refers to the use of drying techniques to reduce water content until the water activity is <0.4 for long-term preservation (Wu, Zhang, & Fan, 2022; Ghinea, Prisacaru, & Leahu, 2022).

Vacuum freeze-drying (VFD) is an excellent method for foods because its high-vacuum and low-temperature processes preserve the shape, flavor, color, and original nutrients of raw fruits and vegetables (Bailón-Moreno, Olivares-Arias, Vicaria, & Chiadmi-García, 2018; Zhang et al., 2020). Recently, restructured fruit and vegetable products have attracted the attention of researchers because of their increasing appearance in the market and their popularity with customers. (Hnin, Zhang, Wang, & Devahastin, 2019; Liu, Zhang, & Hu, 2022). Leverrier, Almeida, & Cuvelier (2016) found that particle size and shape play a key role in the rheological behavior of reconstructed apple purees. Shittu & Olaitan (2014) found that the inclusion of okra (*Abelmoschus esculentus*) powder substantially increased the viscosity and dispersibility of restructured yam flour.

Compared with fruit and vegetable crisps processed using traditional methods, freeze-dried restructured product has several advantages (Egas-Astudillo, Martínez-Navarrete, & Camacho, 2020). First, it can be used as a personalized food that satisfies the needs of different consumers and can be rationally combined with different raw materials of fruits and vegetables (Escalante-Aburto, Trujillo-deSantiago, Álvarez, & Chuck-Hernández, 2021). Second, the original fruit and vegetable tissues are crushed to form a homogeneous pulp, which can inhibit the adverse effects of epidermal waxes and cellular tissue barriers on water

* Corresponding author.
E-mail address: who1978@163.com (H. Wang).

https://doi.org/10.1016/j.fochx.2023.100702
Received 11 September 2022; Received in revised form 25 April 2023; Accepted 1 May 2023
Available online 3 May 2023

sublimation during freeze-drying, thereby reducing the drying time and improving the quality of the freeze-dried product (Bhatta, Stevanovic Janezic, & Ratti, 2020). Finally, the microstructure and texture of the product can be precisely adjusted using the ratios of different raw materials and ingredients.

Edible gum is a popular food additive in the food industry for frozen foods, beverages, and dairy products because of its thickening, gelling, emulsifying, stabilizing, and clarifying properties (Sulieman, 2018; Milani & Maleki, 2012; Li & Nie, 2016). In recent years, research on edible gums has gained increasing popularity. Bai et al. (2017) investigated the effects of pectin on the molecular structural changes in starch during digestion. Lin et al. (2021) demonstrated that the K values, dynamic modulus, and inhibition of starch pasting improved as the concentration of xanthan and konjac gum increased. However, no reports are present on the effects of edible gum addition on the quality of freeze-dried restructured strawberry blocks (FRSB).

In this study, six types of edible gum (xanthan, gelatin, pectin, carrageenan, konjac, and guar gums) were used as food additives to investigate their effects on the quality of FRSB. The yield, sensory, color, textural properties, volatile compounds, water status, and hygroscopicity of the dried products were analyzed. This study aimed to provide practical implications for improving the quality of freeze-dried restructured fruit and vegetable products.

2. Materials and methods

2.1. Materials

Strawberries (*Fragaria* × *ananassa 'Red Face'*) were purchased from Lai-yang Haitel Food in Qingdao City, Shandong Province, China. Sucrose, sodium caseinate, and maltodextrin were purchased from Henan Wan-bang Chemical Technology in Zhengzhou City, Henan Province, China.

2.2. Sample preparation of restructured strawberry pulp

Freeze-dried pure strawberry pulp is extremely sour and easily crumbles and does not easily form bulk samples after dying. Sucrose addition can change the sugar-acid ratio, reduce the taste of the acid, and make it easier for consumers to accept. The FRSB can be easily cured and formed with the addition of maltodextrin and sodium caseinate. Strawberries were prepared into strawberry pulp using a pulper (JYZ-D51, Jinan, China) thrice for 40 s each. Based on a previous study by Hu et al. (2022), 9% sucrose, 2% maltodextrin, and 1% sodium caseinate (percentage by mass) were added in sequence and mixed, which was used as the control group. Based on the control group, pectin, gelatin, xanthan gum, konjac gum, guar gum, and carrageenan (with mass percentages of 0.3%, 0.6%, 0.9%, and 1.2% for each edible gum) were individually added and mixed for 90 s at 65 000 r/min using a homogenizer (FJ200-SH, Shanghai, China), which were used as the treatment groups with the addition of edible gum.

2.3. Freeze-drying of restructured strawberry blocks

The prepared strawberry pulp was injected into 2 × 2 × 1 cm molds, and placed in a vacuum freeze-dryer (SCIENTZ-50F, Ningbo, China) to perform freezing at 101 000 Pa for 4 h. After the temperatures of the strawberry material and the cold trap had dropped to −40 °C, the vacuum pump was started and the drying process began with heating at −30 °C for 2 h, −20 °C for 2 h, −10 °C for 2 h, 0 °C for 2 h, 10 °C for 2 h, 20 °C for 2 h, 30 °C for 2 h, 40 °C for 2 h, and 50 °C for 4 h, during which the vacuum pressure was maintained below 50 Pa. At the end of the procedure, the equipment was stopped and the samples in each group were demolded, placed in separate bags with desiccants, and placed in a −18 °C fridge for subsequent measurement of the indicators.

2.4. Determination of yield

Strawberry pulp was weighed prior to being placed in a mold, and the dried samples were weighed after demolding. The yields were calculated using Eq. (1).

$$y = \frac{x_1}{x_2} \times 100 \tag{1}$$

where y is the yield (%);x_1 is the mass of the strawberry pulp sample before VFD (g); and x_2 is the mass of the FRSB sample after VFD (g).

2.5. Determination of sensory evaluation

Sensory evaluation of the FRSB samples was performed according to the method described by Morais, Cruz, & Bolini (2014), with minor modifications. Ten students majoring in food science from Nanjing Xiaozhuang University were invited to conduct random sensory evaluations. They were well trained in basic sensory evaluation skills. Their mouths were rinsed with water before evaluation, and the samples were evaluated on a 9-point intensity scale. Not intense corresponded with "1," and the strongest intensity corresponded with "9." The scale indicated the intensity of the corresponding indicator of the samples in order from lowest to highest (Hu et al., 2022; Guo et al., 2022; Ayhan, & Eştürk, 2009).

2.6. Determination of color

The color of the samples was determined using a colorimeter (NH310, Shenzhen, China). For the initial strawberry pulp, $L_0* = 55.43$, $a_0* = 10.99$, $b_0* = 7.39$, and the total color difference (ΔE) was calculated using Eq. (2).

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \tag{2}$$

where ΔE is the total color difference of the sample; L^*, a^*, and b^* are lightness, red, and yellow value of the FRSB samples, respectively; and L_0*, a_0*, and b_0* are the color values of the fresh strawberry pulp.

2.7. Determination of texture profile analysis

The FRSB samples were performed with texture profile analysis (TPA) using a TMS-PRO texture analyzer (Sterling, VA, USA), based on the parameter settings of that in Hu et al. (2022). Texture-related parameters (hardness, cohesiveness, elasticity, adhesiveness, and chewiness) were obtained by mechanically compressing the sample twice.

2.8. Determination of puncture

The FRSB samples were performed with a puncture test using the TMS-PRO texture analyzer, based on the parameter settings of that in Hu et al. (2022), after which parameters of hardness and penetration work were obtained.

2.9. Determination of volatile compounds

A PEN3 electronic nose (Airsense, Schwerin, Germany) was used to determine the volatile compounds in the FRSB samples according to the method described by Hu et al. (2022). The PEN3 electronic nose simulates the olfactory system of the human body and includes 10 metal-oxide sensors. The specific names and performance descriptions of the sensors are listed in Table S1.

2.10. Determination of water status

The water status of the samples was determined using a MesoMR23-060 V-I low-field nuclear magnetic resonance (LF-NMR) analyzer

Table 1
Comparison of yield and sensory evaluation for the freeze-dried restructured strawberry blocks with six edible gum additions.

Type of edible gum	Concentration (%)	Yield (%)	Sensory evaluation				
			Astringency	Sourness	Sweetness	Crispness	Stickiness
Guar gum	0	19.12 ± 0.19^{B}	0.00 ± 0.00	5.83 ± 0.29^{A}	5.33 ± 0.29^{A}	5.67 ± 0.58^{C}	4.33 ± 0.58^{A}
	0.3	19.71 ± 0.10^{Ba}	0.00 ± 0.00^{d}	3.83 ± 0.29^{Bd}	3.00 ± 0.00^{Cd}	4.67 ± 0.29^{Dd}	2.50 ± 0.50^{Bb}
	0.6	19.59 ± 0.33^{Ba}	0.00 ± 0.00^{d}	3.83 ± 0.29^{Bd}	4.33 ± 0.59^{Bd}	6.50 ± 0.50^{Bab}	4.83 ± 0.29^{Aa}
	0.9	19.86 ± 0.16^{Bb}	0.00 ± 0.00^{d}	3.33 ± 0.29^{Bc}	3.17 ± 0.29^{Ce}	7.83 ± 0.29^{Aa}	4.33 ± 0.29^{Ac}
	1.2	20.66 ± 0.34^{Aab}	0.00 ± 0.00^{d}	2.33 ± 0.58^{Ce}	2.67 ± 0.29^{Cd}	7.50 ± 0.50^{Abc}	5.00 ± 1.00^{Ab}
Gelatin	0	19.12 ± 0.19^{B}	0.00 ± 0.00	5.83 ± 0.29^{A}	5.33 ± 0.29^{AB}	5.83 ± 0.29^{BC}	4.33 ± 0.58^{C}
	0.3	19.05 ± 0.13^{Bbc}	0.00 ± 0.00^{d}	4.83 ± 0.29^{Bc}	4.00 ± 0.00^{Cc}	3.83 ± 0.29^{De}	4.33 ± 0.29^{Ca}
	0.6	19.77 ± 0.04^{Aa}	0.00 ± 0.00^{d}	5.33 ± 0.29^{Bc}	5.83 ± 0.29^{Ab}	4.83 ± 0.76^{Cc}	5.33 ± 0.29^{Ba}
	0.9	19.07 ± 0.18^{Bc}	0.00 ± 0.00^{d}	5.33 ± 0.29^{Ba}	4.67 ± 0.29^{BCc}	6.17 ± 0.29^{ABc}	5.50 ± 0.50^{Bb}
	1.2	18.36 ± 0.14^{Cd}	0.00 ± 0.00^{d}	5.00 ± 0.00^{Bb}	5.17 ± 0.76^{ABab}	6.83 ± 0.29^{Acd}	6.33 ± 0.29^{Aa}
Xanthan gum	0	19.12 ± 0.19^{C}	0.00 ± 0.00^{C}	5.83 ± 0.29^{A}	5.33 ± 0.29^{A}	5.83 ± 0.29^{C}	4.33 ± 0.58^{B}
	0.3	19.08 ± 0.08^{Cabc}	0.83 ± 0.29^{Bc}	4.50 ± 0.00^{Bc}	4.17 ± 0.29^{BCc}	6.83 ± 0.76^{Bb}	4.50 ± 0.50^{Ba}
	0.6	20.02 ± 0.34^{Ba}	1.17 ± 0.29^{Bc}	6.17 ± 0.29^{Ab}	4.83 ± 0.29^{ABcd}	7.17 ± 0.29^{ABa}	4.83 ± 0.29^{Ba}
	0.9	21.33 ± 0.58^{Aa}	2.00 ± 0.00^{Ab}	4.67 ± 0.29^{Bb}	4.50 ± 0.50^{Bcd}	7.83 ± 0.29^{ABa}	5.83 ± 0.29^{Aab}
	1.2	21.00 ± 0.00^{Aa}	1.17 ± 0.29^{Bc}	3.50 ± 0.00^{Cd}	3.50 ± 0.50^{Cc}	8.17 ± 0.76^{Aab}	5.83 ± 0.76^{Aab}
Pectin	0	19.12 ± 0.19^{B}	0.00 ± 0.00^{B}	5.83 ± 0.29^{A}	5.33 ± 0.29^{B}	5.83 ± 0.29^{C}	4.33 ± 0.58^{CD}
	0.3	19.68 ± 0.61^{ABab}	0.00 ± 0.00^{Bd}	2.67 ± 0.29^{Be}	6.33 ± 0.29^{Aa}	7.83 ± 0.29^{Aa}	3.83 ± 0.29^{Da}
	0.6	19.90 ± 0.36^{ABa}	0.00 ± 0.00^{Bd}	2.83 ± 0.29^{Be}	5.50 ± 0.50^{Bbc}	7.00 ± 0.00^{Ba}	4.83 ± 0.29^{BCa}
	0.9	19.99 ± 0.35^{Ab}	0.00 ± 0.00^{Bd}	1.83 ± 0.29^{Cd}	4.00 ± 0.00^{Cd}	7.83 ± 0.29^{Aa}	5.33 ± 0.29^{Bb}
	1.2	19.34 ± 0.64^{ABc}	1.83 ± 0.29^{Ab}	1.00 ± 0.00^{Df}	2.83 ± 0.29^{Dcd}	8.50 ± 0.50^{Aa}	6.17 ± 0.29^{Aab}
Konjac gum	0	19.12 ± 0.19^{A}	0.00 ± 0.00^{E}	5.83 ± 0.29^{B}	5.33 ± 0.29^{A}	5.83 ± 0.29^{B}	4.33 ± 0.58^{B}
	0.3	18.87 ± 0.47^{Abc}	1.83 ± 0.29^{Db}	7.33 ± 0.58^{Aa}	4.83 ± 0.29^{Ab}	5.67 ± 0.58^{Bc}	3.83 ± 0.29^{Ba}
	0.6	19.47 ± 0.13^{Aab}	2.83 ± 0.29^{Ca}	7.17 ± 0.29^{Aa}	5.17 ± 0.76^{Abcd}	5.83 ± 0.29^{Bb}	4.67 ± 0.58^{Ba}
	0.9	18.81 ± 0.32^{Ac}	4.50 ± 0.50^{Aa}	5.83 ± 0.29^{Ba}	5.33 ± 0.29^{Ab}	6.83 ± 0.29^{Ab}	6.33 ± 0.58^{Aa}
	1.2	19.94 ± 0.22^{Aabc}	5.83 ± 0.29^{Aa}	6.00 ± 0.00^{Ba}	5.67 ± 0.29^{Aa}	6.00 ± 0.50^{ABde}	6.50 ± 0.87^{Aa}
Carrageenan	0	19.12 ± 0.19^{A}	0.00 ± 0.00^{E}	5.83 ± 0.29^{A}	5.33 ± 0.29^{B}	5.83 ± 0.29^{A}	4.33 ± 0.58^{A}
	0.3	18.01 ± 0.04^{Bc}	2.83 ± 0.29^{Aa}	5.67 ± 0.29^{Ab}	6.33 ± 0.58^{Aa}	5.83 ± 0.29^{Ac}	2.50 ± 0.50^{Bb}
	0.6	18.39 ± 0.14^{Bb}	2.33 ± 0.29^{Bb}	3.83 ± 0.29^{Bd}	6.83 ± 0.29^{Aa}	5.67 ± 0.58^{ABc}	3.50 ± 0.50^{Ab}
	0.9	18.58 ± 0.33^{Bc}	1.17 ± 0.29^{Dc}	4.33 ± 0.58^{Bb}	7.00 ± 0.00^{Aa}	5.00 ± 0.50^{ABd}	4.00 ± 0.00^{Ac}
	1.2	19.58 ± 0.73^{Abc}	1.83 ± 0.29^{Cb}	4.00 ± 0.00^{Bc}	4.83 ± 0.29^{Bb}	5.83 ± 0.29^{Ae}	3.67 ± 0.58^{Ac}

Note: Values are means ± SD of three repetitions. In the same column, capital letters indicate the significant difference between different addition concentrations in the same edible gum group, and lowercase letters indicate the significant difference between the different edible gums with same addition concentration ($P < 0.05$).

(Niumag, Suzhou, China) based on Wang et al. (2022) with minor modifications. The typical pulse parameters in the test included the following experimental parameters: 200 000 sampling points, 8 repeated scans, 5 000 ms interval time, 8 000 echoes, and 0.25 ms echo time. After the scanning test, the T_2 inversion fitting software was used to fit the T_2 value to obtain the T_2 spectrum.

2.11. Determination of hygroscopicity

The hygroscopicity of the samples was determined according to the method described by Feng et al. (2022), with minor modifications. Before moisture absorption, the dried samples were weighed to determine the initial mass, and the hygroscopic samples were weighed according to the absorption time (10 min, 20 min, 0.5 h, 1 h, 1.5 h, 2 h, 3 h, 4 h, 6 h, 9 h, 21 h, 24 h, 2 d, 3 d, 4 d, and 5 d). The hygroscopicity was calculated using Eq. (3).

$$HR = \frac{m1 - m0}{m0} \times 100 \quad (3)$$

where HR is the hygroscopicity of the dried samples (%), and m_0 and m_1 are the masses of the initial dried(g) and the hygroscopic samples at the corresponding absorption time (g), respectively.

2.12. Statistical analysis

Each sample was measured in triplicate, and the results were averaged. ANOVA and Tukey's HSD tests of SPSS 19.0 statistics software (IBM, Chicago, IL, USA) were used for data analysis, with statistical significance defined as $p < 0.05$. Volatile compounds were analyzed using the Winmuster software (Schwerin, Germany) with an electronic nose system. Other data were analyzed using OriginPro9 (Origin Lab, Northampton, MA, USA).

3. Results and discussion

3.1. Influence of different edible gum additions on the yield and sensory evaluation

Yield is an important indicator of production quantity and is directly related to economic benefits. Yield differences compared with those in the control group were as follows: the 1.2% guar gum addition increased the yield of the dried sample by 8.05%; the 0.6% gelatin addition increased the yield by 3.40%; the 0.9% xanthan gum and pectin additions increased the yield by 11.56% and 4.55% respectively; and 1.2% konjac gum and carrageenan additions increased the yield by 4.29% and 2.41%, respectively (Table 1). By comparing the yields of the six edible gums with the same amount of addition, we found that guar and xanthan gums resulted in relatively higher yields than those of the other gums. This high yeild may be because that guar and xanthan gums increased the bonding activity with water in the tissues of the samples owing to their relatively higher hydrophilicity and thickening ability (Barak & Mudgil, 2014).

Sensory evaluation is the most intuitive and important indicator for evaluating food and can directly reflect consumer acceptance of food (Singh-Ackbarali & Maharaj, 2014). The effects of the addition of different edible gums on the sensory perception of the dried samples are shown in Table 1. The effects of edible gum addition on the sourness, sweetness, astringency, crispness, and stickiness of the dried samples depend on the type and concentration of the gum.

The results of comparing the sourness among the six edible gums at the same amount of addition are as follows: guar gum and gelatin addition in FRSB presented no apparent astringency; the addition of 0.9% and 1.2% guar gum reduced sourness by 42.88% and 60.03%, respectively; the addition of 0.9% and 1.2% of pectin reduced sourness by 68.61% and 82.85%, respectively; the addition of 0.9% gelatin reduced sourness by 8.58%; the addition of 0.9% carrageenan increased

Table 2
Comparison texture properties for the freeze-dried restructured strawberry blocks with six edible gum additions.

Type of edible gum	Concentration (%)	TPA					Puncture	
		Hardness (N)	Cohesiveness (N)	Elasticity	Adhesiveness (N)	Chewiness (N·mm)	Hardness (N)	Penetration work (N·mm)
Guar gum	0	161.63 ± 2.23^{D}	0.10 ± 0.00^{A}	1.08 ± 0.05^{A}	16.48 ± 1.00^{D}	17.68 ± 0.46^{B}	10.78 ± 0.44^{C}	8.40 ± 0.76^{C}
	0.3	127.60 ± 0.35^{Ee}	0.13 ± 0.02^{Aa}	0.80 ± 0.08^{Bc}	18.59 ± 0.78^{Cb}	13.82 ± 0.81^{Cc}	27.95 ± 2.83^{Aa}	14.90 ± 0.82^{Bab}
	0.6	209.46 ± 1.04^{Ba}	0.13 ± 0.00^{Aa}	0.83 ± 0.07^{Bbc}	30.85 ± 1.54^{Aa}	22.16 ± 1.31^{Ac}	29.63 ± 2.78^{Aa}	20.27 ± 2.05^{Aa}
	0.9	201.25 ± 2.54^{Ca}	0.12 ± 0.02^{Aa}	0.80 ± 0.06^{Bc}	20.81 ± 0.63^{Bc}	16.63 ± 0.75^{Be}	20.59 ± 1.40^{Bbc}	8.68 ± 0.67^{Cc}
	1.2	242.67 ± 2.26^{Aa}	0.12 ± 0.02^{Ab}	0.89 ± 0.14^{Bab}	30.64 ± 0.46^{Ab}	23.67 ± 1.32^{Ad}	14.14 ± 1.69^{BCe}	2.69 ± 0.35^{Dc}
Gelatin	0	161.63 ± 2.23^{B}	0.10 ± 0.00^{A}	1.08 ± 0.05^{A}	16.48 ± 1.00^{C}	17.68 ± 0.46^{B}	10.78 ± 0.44^{B}	8.40 ± 0.76^{B}
	0.3	147.72 ± 2.26^{Cc}	0.28 ± 0.26^{Aa}	0.74 ± 0.05^{Bc}	18.79 ± 2.44^{Cb}	13.29 ± 2.39^{Cc}	17.77 ± 2.34^{Ac}	8.37 ± 0.82^{Bc}
	0.6	141.56 ± 2.58^{De}	0.16 ± 0.04^{Aa}	0.87 ± 0.18^{ABbc}	23.82 ± 2.23^{Bb}	22.74 ± 2.44^{Acd}	20.71 ± 2.39^{Ac}	19.03 ± 1.65^{Aab}
	0.9	123.15 ± 2.59^{Ee}	0.12 ± 0.01^{Aa}	0.86 ± 0.16^{ABc}	15.34 ± 1.62^{Cc}	11.66 ± 1.10^{Df}	19.34 ± 1.91^{Abc}	10.90 ± 1.23^{Bb}
	1.2	177.72 ± 2.61^{Ae}	0.15 ± 0.06^{Aab}	0.85 ± 0.17^{ABab}	27.65 ± 2.27^{Ab}	22.25 ± 2.06^{Ae}	17.89 ± 0.30^{Acd}	10.16 ± 1.89^{Bb}
Xanthan gum	0	161.63 ± 2.23^{E}	0.10 ± 0.00^{A}	1.08 ± 0.05^{A}	16.48 ± 1.00^{D}	17.68 ± 0.46^{D}	10.78 ± 0.44^{D}	8.40 ± 0.76^{C}
	0.3	199.84 ± 2.42^{Ca}	0.16 ± 0.06^{Aa}	1.11 ± 0.13^{Aa}	25.85 ± 2.51^{BCa}	37.81 ± 1.48^{Aa}	20.42 ± 2.09^{Cbc}	6.74 ± 1.40^{Cc}
	0.6	209.15 ± 1.85^{Aa}	0.14 ± 0.04^{Aa}	1.12 ± 0.05^{Aa}	23.30 ± 2.74^{Cb}	34.00 ± 1.24^{Ba}	22.13 ± 2.41^{Cbc}	15.44 ± 2.72^{ABab}
	0.9	180.86 ± 1.95^{Db}	0.18 ± 0.04^{Aa}	1.10 ± 0.10^{Aab}	34.77 ± 2.80^{Aa}	35.04 ± 1.07^{Ba}	28.23 ± 1.92^{Ba}	13.70 ± 0.79^{Ba}
	1.2	204.89 ± 2.65^{Bc}	0.20 ± 0.11^{Aab}	0.89 ± 0.09^{Bab}	28.24 ± 2.40^{Bb}	26.61 ± 1.35^{Cc}	37.89 ± 1.75^{Aa}	16.69 ± 1.27^{Aa}
Pectin	0	161.63 ± 2.23^{C}	0.10 ± 0.00^{B}	1.08 ± 0.05^{B}	16.48 ± 1.00^{CD}	17.68 ± 0.46^{C}	10.78 ± 0.44^{D}	8.40 ± 0.76^{B}
	0.3	133.75 ± 1.73^{Dd}	0.11 ± 0.05^{Ba}	1.00 ± 0.05^{BCab}	12.88 ± 2.20^{Dc}	12.79 ± 1.97^{Dc}	17.65 ± 1.71^{Cc}	6.89 ± 1.23^{Bc}
	0.6	163.47 ± 2.75^{Cc}	0.13 ± 0.01^{Ba}	1.00 ± 0.06^{BCab}	18.39 ± 2.81^{Cc}	19.84 ± 1.18^{Cd}	18.77 ± 0.39^{Ccd}	7.95 ± 1.58^{Bc}
	0.9	170.96 ± 2.01^{Bc}	0.16 ± 0.04^{Ba}	1.22 ± 0.12^{Aa}	22.86 ± 2.86^{Bc}	31.38 ± 1.86^{Bb}	21.95 ± 0.80^{Bb}	6.98 ± 0.44^{Bcd}
	1.2	212.46 ± 2.77^{Ab}	0.24 ± 0.03^{Aa}	0.91 ± 0.06^{Cab}	51.81 ± 1.40^{Aa}	50.19 ± 1.53^{Aa}	24.08 ± 0.90^{Ab}	11.64 ± 1.60^{Ab}
Konjac gum	0	161.63 ± 2.23^{B}	0.10 ± 0.00^{A}	1.08 ± 0.05^{A}	16.48 ± 1.00^{B}	17.68 ± 0.46^{B}	10.78 ± 0.44^{D}	8.40 ± 0.76^{C}
	0.3	178.29 ± 2.37^{Ab}	0.10 ± 0.03^{Aa}	0.94 ± 0.06^{ABb}	17.53 ± 2.54^{ABb}	13.29 ± 1.15^{Dc}	22.01 ± 1.95^{Bb}	15.79 ± 1.72^{Aa}
	0.6	149.51 ± 1.82^{Cd}	0.11 ± 0.02^{Aa}	0.80 ± 0.10^{BCc}	15.98 ± 2.14^{Bc}	12.70 ± 0.16^{De}	16.44 ± 0.64^{Cd}	10.10 ± 1.82^{Bc}
	0.9	108.25 ± 2.75^{Df}	0.15 ± 0.05^{Aa}	0.89 ± 0.10^{BCc}	20.86 ± 1.17^{Ac}	19.86 ± 0.74^{Ad}	26.14 ± 2.54^{Aa}	11.87 ± 1.43^{Bab}
	1.2	165.53 ± 2.72^{Bf}	0.12 ± 0.02^{Ab}	0.75 ± 0.08^{Cb}	19.43 ± 2.54^{AB}	15.69 ± 0.84^{Cf}	19.30 ± 1.22^{BCc}	17.41 ± 1.58^{Aa}
Carrageenan	0	161.63 ± 2.23^{B}	0.10 ± 0.00^{B}	1.08 ± 0.05^{A}	16.48 ± 1.00^{Cc}	17.68 ± 0.46^{E}	10.78 ± 0.44^{C}	8.40 ± 0.76^{B}
	0.3	181.28 ± 1.91^{Ab}	0.13 ± 0.03^{ABa}	1.10 ± 0.04^{Aa}	18.23 ± 0.36^{Cb}	20.84 ± 1.01^{Db}	28.05 ± 1.39^{Aa}	13.15 ± 1.76^{Ab}
	0.6	174.38 ± 1.73^{Cb}	0.14 ± 0.02^{ABa}	1.05 ± 0.02^{Aa}	24.64 ± 2.92^{Bb}	27.35 ± 1.48^{Bb}	24.64 ± 1.51^{ABb}	16.12 ± 2.58^{Ab}
	0.9	166.19 ± 2.73^{Dd}	0.16 ± 0.03^{Aa}	1.00 ± 0.09^{Abc}	27.60 ± 2.66^{ABb}	24.44 ± 1.35^{Cc}	17.12 ± 2.31^{BCc}	5.77 ± 1.99^{BCd}
	1.2	197.72 ± 3.09^{Bd}	0.16 ± 0.01^{Aab}	1.03 ± 0.10^{Aa}	31.00 ± 2.36^{Ab}	36.30 ± 0.49^{Ab}	15.54 ± 1.71^{Cde}	3.50 ± 1.08^{Cc}

Note: Values are means ± SD of three repetitions. In the same column, capital letters indicate the significant difference between different addition concentrations in the same edible gum group, and lowercase letters indicate the significant difference between the different edible gums with same addition concentration ($P < 0.05$).

the sweetness by 31.33%; 1.2% pectin and konjac gum increased stickiness by 42.49% and 50.12%, respectively; the addition of 0.9% guar gum and gelatin increased the crispness by 38.10% and 5.83%, respectively; the addition of 0.9% and 1.2% pectin increased crispness by 34.30% and 45.80%, respectively; and the addition of 1.2 xanthan gum increased crispness by 40.13%. These findings could be a result of altered FRSB porous structure and increased porosity of the samples with the addition of edible gum, which lead to a crisper product (Waldron, Parker, & Smith, 2006).

3.2. Influence of different edible gum additions on color

Color is closely related to acceptance by the market and consumers (Huang & Hsieh, 2005). *ΔE* quantified the accuracy of color

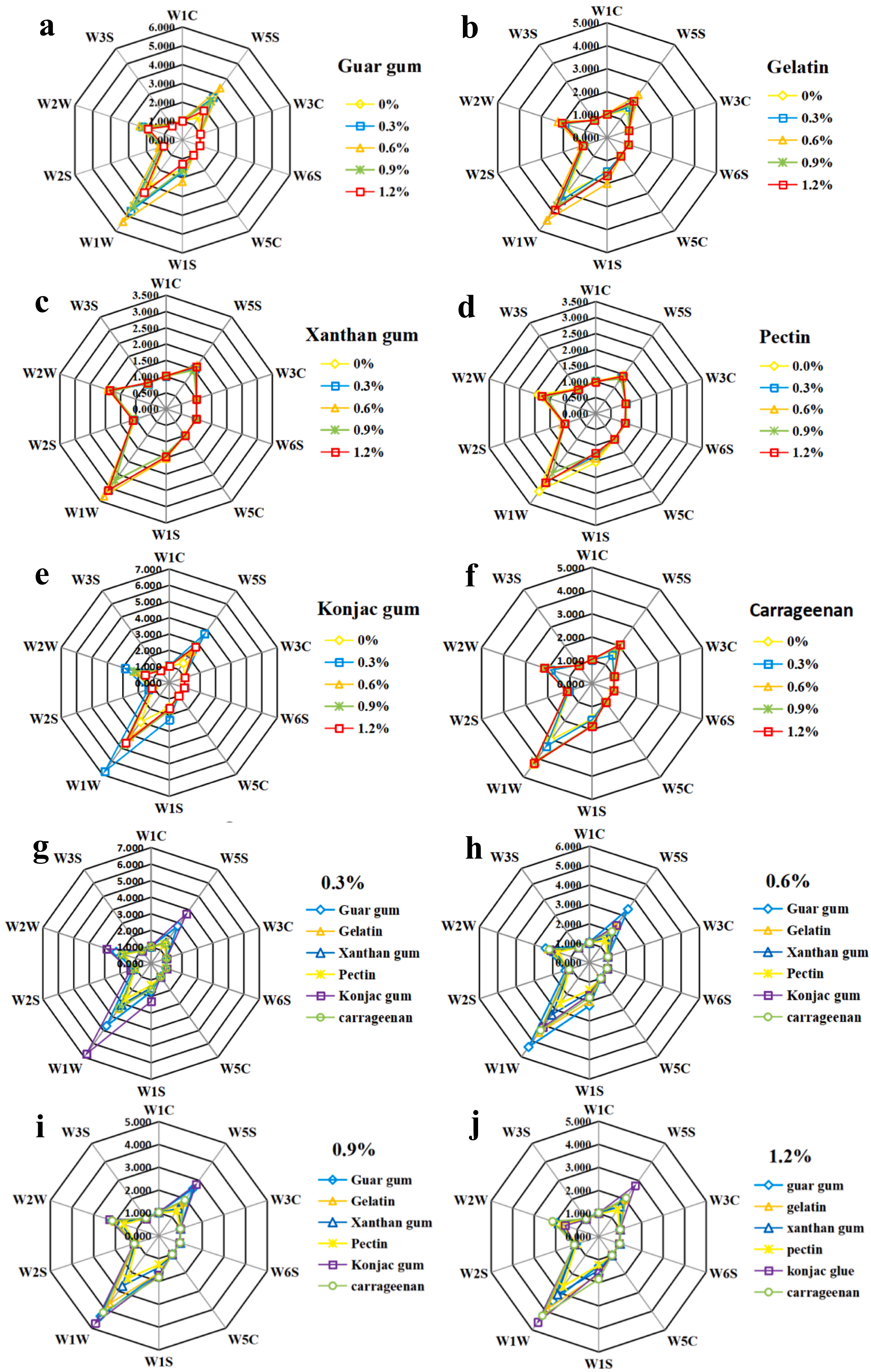

Fig. 1. The radar map analysis of volatile compounds in the freeze-dried restructured strawberry blocks with gum additions, including guar gum(a), gelatin(b), xanthan gum(c), pectin(d), konjac gum(e), and carrageenan(f), and the six edible gums at the same addition concentration (i.e, 0.3%(g), 0.6%(h), 0.9%(i), 1.2%(j)).

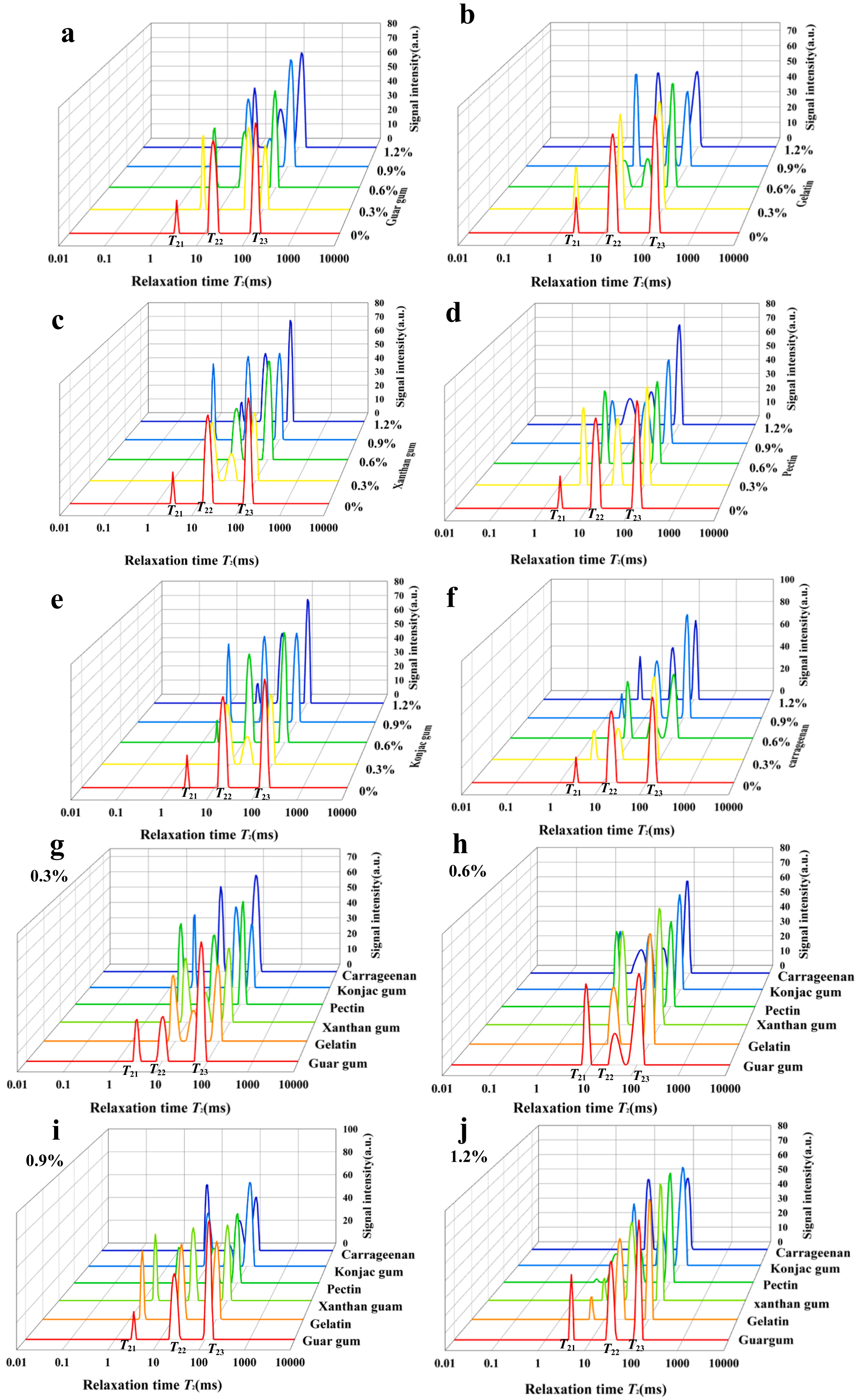

Fig. 2. The Low-field NMR analysis of water status in the freeze-dried restructured strawberry blocks with gum additions, including guar gum(a), gelatin(b), xanthan gum(c), pectin(d), konjac gum(e), and carrageenan(f), and the six edible gums at the same addition concentration (i.e, 0.3%(g), 0.6%(h), 0.9%(i), 1.2%(j)).

reproduction into a numerical value, which reflected the accuracy of the color performance of the samples. The higher the score, the more distorted the color; therefore, the smaller the value, the higher the probability that the product will be obtained. From Table S2, compared with that in the control group, the addition of 0.3% gelatin, 0.6% xanthan gum, 1.2% pectin, and 1.2% konjac gum all contributed to a significantly ($p < 0.05$) higher L^* value in FRSB, indicating that these products had a brighter appearance; a significantly ($p < 0.05$) lower ΔE occurred in the samples with the addition of 0.6% guar gum, 0.9% gelatin, 0.9% and 1.2% xanthan gum; 0.3%, 0.6%, and 0.9% pectin; 0.6% and 0.9% konjac gum; and 0.3%, 0.6%, 0.9%, and 1.2% carrageenan, indicating that these gum additions can maintain a better appearance for the dried samples. This phenomenon may be related to the Maillard reaction and degradation of anthocyanins. The samples with the above concentrations of edible gum possibly exhibited a slighter Maillard browning reaction, less anthocyanin degradation, and maintained a good apparent color (Frabetti et al., 2021; Manzocco, Calligaris, Mastrocola, Nicoli, & Lerici, 2000).

3.3. Influence of different edible gum additions on the texture properties

When the TPA test was performed, the samples were compressed twice to simulate mastication and evaluate their textural properties. Hardness is the resistance of a sample to compression at a certain deformation rate (Tireki, Sumnu, & Sahin, 2021). Cohesiveness refers to mutual attraction within a product when simulating mastication (Xie et al., 2017). Elasticity is the degree to which a sample can recover after the deformation force is removed following the first compressive deformation (Fox, Guinee, Cogan, & McSweeney, 2017). Adhesiveness is a measure of the energy required to overcome the surface attraction of FRSB when masticated (Ansari, Maftoon-Azad, Farahnaky, Hosseini, & Badii, 2014). Chewiness is the product of hardness, cohesiveness, and elasticity and is a comprehensive indicator of product quality.

The TPA test results are listed in Table 2. Comparison of the TPA hardness among the six edible gums with the same amount of added guar gum revealed a higher TPA hardness than those in the other gums.

Compared with that of the control group, the addition of 1.2% guar gum, 0.6% xanthan gum, and 0.9%, and 1.2% pectin increased TPA hardness by 50.13%, 29.40%, 5.94%, and 22.33%, respectively. The addition of guar gum, gelatin, xanthan gum, or konjac gum had no significant effect on the cohesiveness ($p > 0.05$) as the cohesiveness increased with the addition of pectin and carrageenan. The addition of 0.9% pectin increased elasticity and chewiness by 12.96% and 77.49%, respectively; 0.6% guar gum and gelatin addition contributed to 25.34% and 28.62% increase in chewiness of the TPA, respectively; the addition of 1.2% pectin increased chewiness of the TPA by 183.88%; the addition of 0.6% guar gum, gelatin, and carrageenan increased the puncture hardness by 174.86%, 92.12%, and 128.57%, respectively. These results are likely due to the adhesion behavior of edible gum, whose branched arabinose and galactose can be well cross-linked with the hemicellulose and cellulose in the sample to form a rigid network structure, thus increasing their resistance to the damaging effects of mechanical forces (Broxterman & Schols, 2018).

Compared with the TPA, the puncture test is generally performed at a local point on the sample, with fewer requirements for the shape and size of the test samples. The puncture penetration work was increased by 141.31% and 126.55% with the addition of 0.6% guar gum and gelatin, respectively, compared with that of the control group. The addition of 0.9% pectin and 0.3% and 0.6% guar gum increased puncture hardness by 103.62%, 159.28%, and 174.86%, respectively; the addition of 0.9% xanthan gum and konjac gum increased the puncture hardness by 161.87% and 142.48%, respectively. The above results demonstrate that the addition of edible gum could improve the textural properties of FRSB, which is largely consistent with the previous TPA results, where the edible gum was cross-linked with polysaccharides or cellulose in the strawberries during processing, resulting in a tighter porous network structure of the sample, leading to higher rigidity and elasticity (Zhao, Malfait, Guerrero-Alburquerque, Koebel, & Nyström, 2018).

3.4. Influence of different edible gum additions on the volatile compounds

The radar diagrams of the sensor response values for the FRSB are shown in Fig. 1. For the FRSB with all six edible gum additions, sensors W1W, W2W, W1S, and W5S had higher response values, indicating that the FRSB contained higher contents of sulfides, aromatics, methyl compounds, and aromatic components of short-chain alkanes. The samples with the 0.6% guar gum (Fig. 1a) and 0.6% gelatin (Fig. 1b) addition had substantially higher response values in the W1W, W2W, W1S, and W5S sensors than other samples in the same group. The profiles of the response values in the sensors nearly overlapped in the radar diagrams of the xanthan gum (Fig. 1c) and pectin groups (Fig. 1d), indicating that the concentration of xanthan gum and pectin had no significant ($p > 0.05$) effect on the flavor of volatile compounds in the samples.

Compared with other samples in the same group, higher response values of theW1W, W2W, W1S, and W5S sensors were observed in the FRSB samples with the addition of 0.3 % konjac gum (Fig. 1e) and 1.2% carrageenan gum (Fig. 1f). By comparing the six edible gums with the same amount of addition, the addition of 0.3% konjac gum (Fig. 1g), 0.9% konjac gum (Fig. 1i), and 0.6% guar gum (Fig. 1h) all contributed to significantly ($p < 0.05$) higher sensor response values of W1W, W2W, and W5S than those of other gums, demonstrating that the addition of konjac gum and guar gum resulted in a relatively higher content of volatile compounds than that of other gums. The reason for the higher flavor achieved by the addition of gum may be the gradual sublimation of the ice crystals during processing, which are constantly cross-linking with some of the substances in the strawberries, creating microzones that form a physical barrier to prevent the diffusion of volatile compounds (Nijhuis et al., 1998; Mui, Durance, & Scaman, 2002; Krokida & Philippopoulos, 2006).

3.5. Influence of different edible gum additions on the water status

LF-NMR can provide direct information on the water state of the samples in a system by measuring the transverse relaxation time (T_2) of hydrogen protons (Sun, Zhang, & Yang, 2019). The longer the peak time of T_2, the more intense the peak position in the T_2 spectrum, the stronger the mobility of the water phase, and the weaker the degree of binding. Water status in the dried samples generally exists in three forms: free water T_{23}, which is free of cells and tissues and has high mobility; uneasily flowing water $T_{22,}$ which is subject to certain restraints; and bound water T_{21}, which binds tightly to cells and tissues. The wet-base moisture content of FRSB was approximately 5%. As shown in Fig. 2, FRSB in all groups of the six edible gum additions showed three T_2 peaks, in which free water T_{23} appeared around 100 ms, uneasily flowing water T_{22} appeared around 10 ms, and bound water T_{21} appeared around 0.1 ms. By comparing the T_2 peaks, the proportion of free water in FRSB in each group was relatively higher than those of uneasily flowing and bound water. By comparing the influence of the addition concentration in the same edible gum group, 0.9% guar gum addition resulted in a smaller T_{22} peak (lower content of uneasily flowing water) in the FRSB (Fig. 2a), whereas 0.9 % gelatin (Fig. 2b) and 0.9% carrageenan addition (Fig. 2f) resulted in a smaller T_{23} peak (lower content of free water) in the FRSB. In addition, 0.6% pectin addition contributed to a similar proportion of free water and bound water and lower content of uneasily flowing water in the FRSB. A reason for these results may be that the addition of edible gum can change the microstructure of FRSB, and the added edible gum can bond with water, which can influence the dehydration behavior of the three forms of water during VFD.

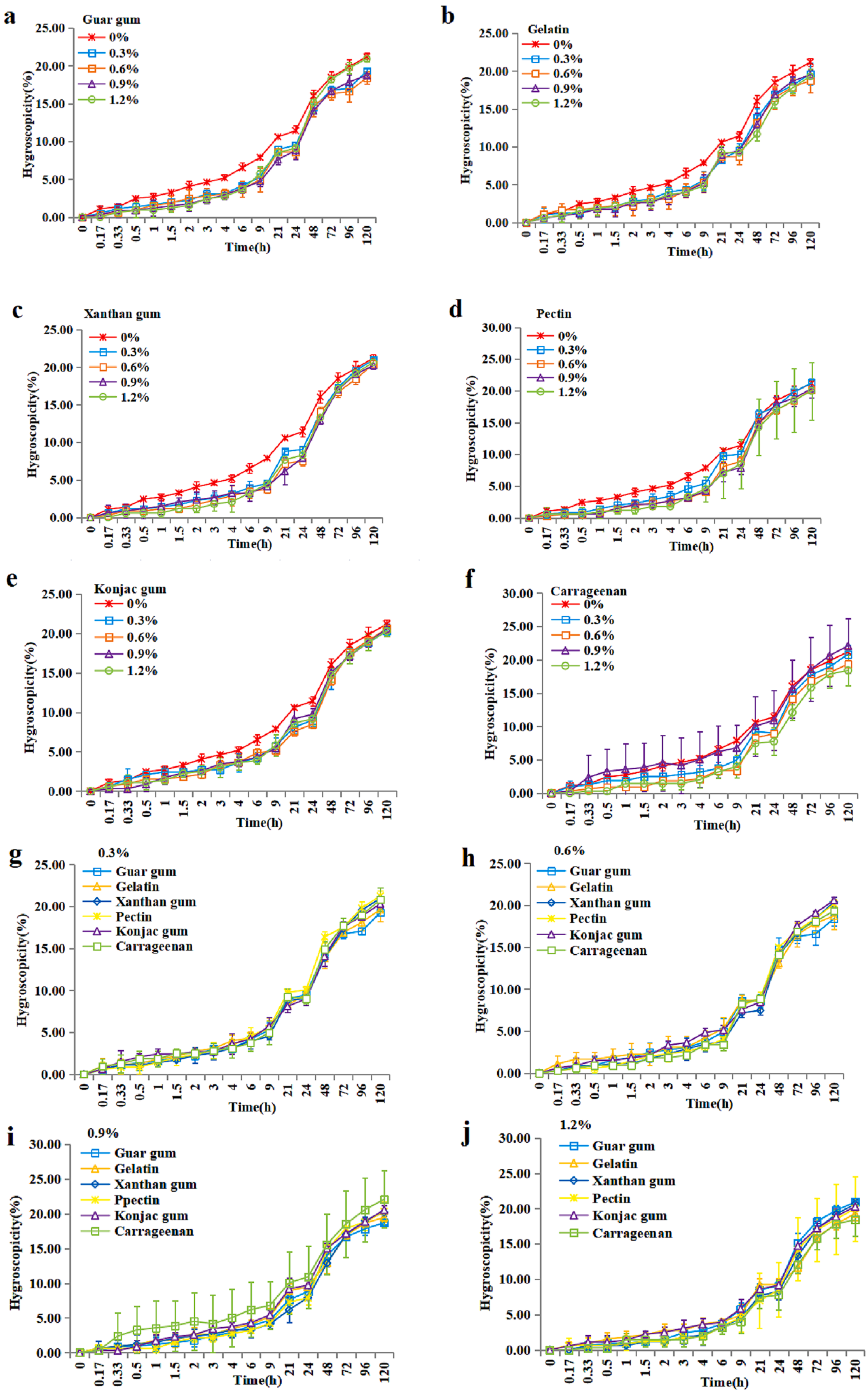

Fig. 3. The hygroscopicity analysis of the freeze-dried restructured strawberry blocks with gum additions, including guar gum(a), gelatin(b), xanthan gum(c), pectin (d), konjac gum(e), and carrageenan(f), and the six edible gums at the same addition concentration (i.e, 0.3%(g), 0.6%(h), 0.9%(i), 1.2%(j)).

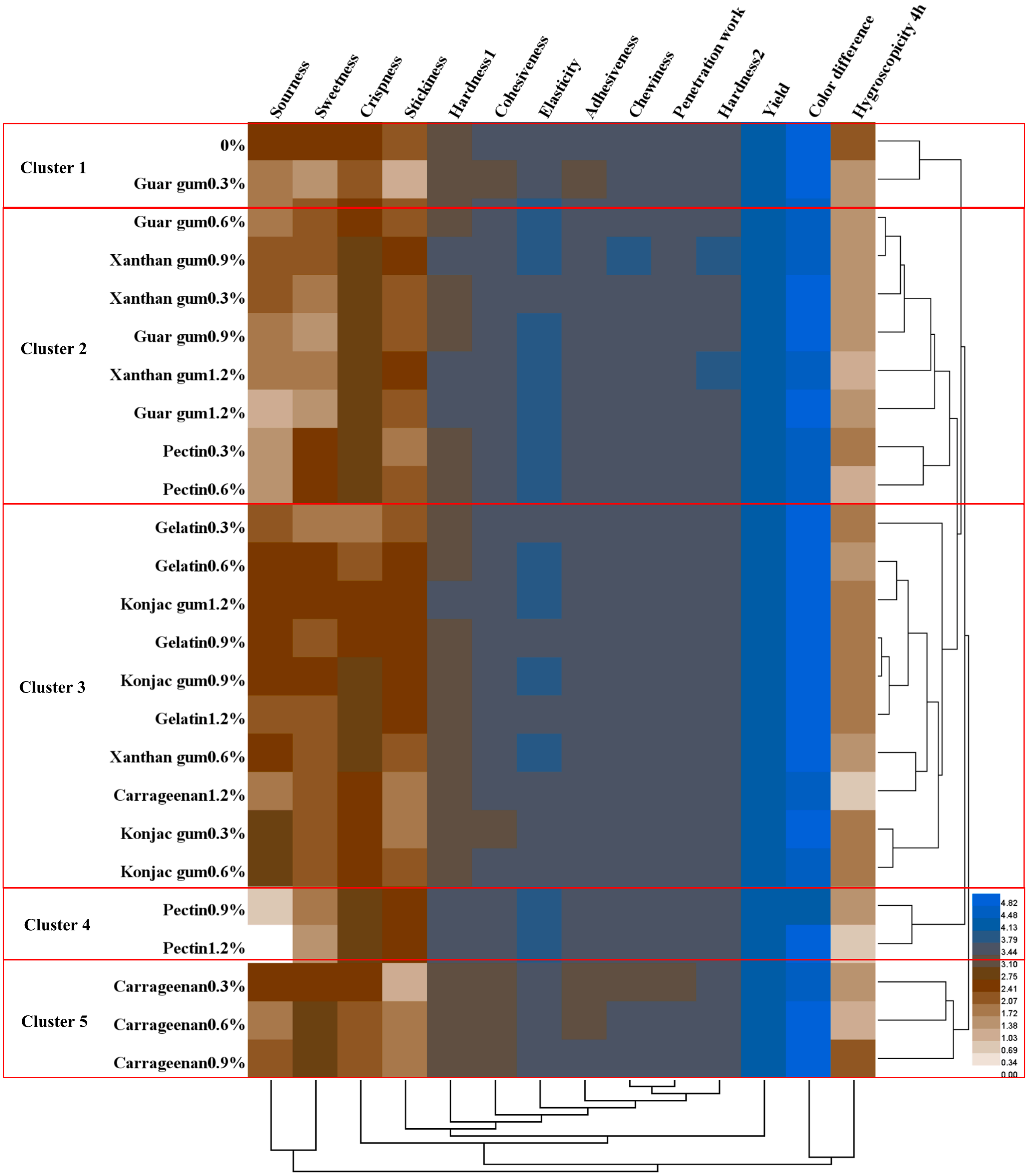

Fig. 4. Hierarchical cluster analysis of the qualities of the freeze-dried restructured strawberry blocks with different edible gum additions.

3.6. *Influence of different edible gum additions on the hygroscopicity*

Hygroscopicity is an important indicator for measuring VFD products and is closely related to the composition and microstructure of FRSB. The higher the porosity, the higher the hygroscopic ability of the product. The influence of the addition of different edible gums on the hygroscopicity of FRSB is shown in Fig. 3. Notably, the hygroscopicity in each gum addition group increased gradually over time, whereas a rapid increase occurred after 9 h of storage. Compared with that of the control group, the addition of guar gum, gelatin, xanthan gum, pectin, and konjac gum (Fig. 3a–e) all resulted in lower FRSB hygroscopicity during most of the storage period ($p < 0.05$), and the differences tended to disappear after 24 h ($p > 0.05$). However, 0.6% guar gum addition (Fig. 3a) resulted in lower hygroscopicity on the fifth day of storage. As shown in Fig. 3g–j, no differences in the hygroscopicity of FRSB with different edible gum additions ($p > 0.05$) were observed. We deduce that the addition of edible gum facilitates the formation of a film barrier on the surface of the FRSB, which can effectively prevent ambient water vapor from entering the interior of the samples in the early stage of hygroscopicity and rusting in lower hygroscopicity. After 24 h of storage, the thin-film barrier was gradually destroyed by the adsorbed water vapor, increasing the permeability of the water vapor. The hygroscopicity gradually increased until it was very close to that in the control group after five days of storage.

3.7. Cluster analysis

Cluster analysis was used to analyze the differences between the different FRSBs. As shown in Fig. 4, according to the vertical dendrogram, all treatments with the six edible gum additions could be classified into five main clusters. The first cluster included the control group and 0.3% guar gum group. The second cluster included the 0.3%, 0.9%, and 1.2% xanthan gum; 0.6%, 0.9%, and 1.2% guar gum; and 0.3% and 0.6% pectin additions. The third cluster included 0.3%, 0.6%, 0.9%, and 1.2% gelatin; 0.3%, 0.6%, 0.9%, and 1.2% konjac gum; 0.6% xanthan gum, and 1.2% carrageenan additions. The fourth cluster included 0.9% and 1.2% pectin additions, and the fifth cluster included 0.3%, 0.6%, and 0.9% carrageenan additions. Three main clusters were identified for the 14 indicators according to the horizontal dendrogram: sourness and sweetness fell into the first cluster, color difference and hygroscopicity (4 h) fell into the third cluster, and all other indicators fell into the second cluster.

4. Conclusion

In this study, we investigated the effects of six edible gums (gelatin, pectin, carrageenan, and xanthan, konjac, and guar gums) on the quality of FRSB. Compared with that of the control group, the results showed no significant ($p > 0.05$) astringency in FRSB with the addition of guar gum and gelatin; the addition of guar gum, gelatin, xanthan gum, and konjac gum had no significant difference on cohesiveness ($p > 0.05$). After a gelatin addition of 0.6%, the yield was increased by 3.40%, sensory evaluation sourness was reduced by 8.58%, TPA chewiness was increased by 28.62%, and puncture hardness and penetration work were increased by 92.12% and 126.55%, respectively; the addition of 0.6% guar gum increased TPA hardness and chewiness by 29.59% and 25.34%, respectively, and increased puncture hardness and penetration work by 174.86% and 141.31%, respectively; the addition of 0.9% gelatin decreased the sensory evaluation sourness by 8.58% and increased the crispness by 5.83%; the addition of 0.9% pectin increased yield, TPA hardness, elasticity, chewiness puncture hardness, and sensory evaluation crispness by 4.55%, 5.94%, 12.96%, 77.49%, 103.62% and 34.31%, respectively. All five gum additions, except for carrageenan, resulted in lower hygroscopicity than that in the control group during mid-storage. The addition of konjac gum resulted in a higher content of volatile compounds, whereas the addition of carrageenan resulted in a lower total color difference. In summary, gelatin, pectin, and guar gum can individually improve the quality of FRSB and are recommended as edible gum additives for FRSB. This study provides a theoretical basis for improving the quality of freeze-dried restructured products and serves as a reference for the strawberry processing industry.

CRediT authorship contribution statement

Feifei Yang: Methodology, Writing – original draft, Investigation. **Xiyun Sun:** Conceptualization, Methodology, Funding acquisition. **Jiaqi Hu:** Methodology, Writing – review & editing. **Honghong Cai:** Methodology, Writing – original draft, Investigation. **Hongwei Xiao:** Conceptualization, Writing – review & editing. **Xianghua Wu:** Resources, Methodology. **Chunju Liu:** Data curation, Methodology. **Haiou Wang:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This work was supported by the National Natural Science Foundations of China (No. 31872901), the Agricultural Key Research and Industrialization Projects in Liaoning Province (2020JH2/10200036), and Excellent Scientific and Technological Innovation Team of Colleges and Universities of Jiangsu Province (SUJIAOKE〔2021〕No.1). The authors would like to thank Editage (www.editage.cn) for English language editing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2023.100702.

References

Ansari, S., Maftoon-Azad, N., Farahnaky, A., Hosseini, E., & Badii, F. (2014). Effect of moisture content on textural attributes of dried figs. *International Agrophysics, 28*(4), 403–412. https://doi.org/10.2478/intag-2014-0031

Ayhan, Z., & Eştürk, O. (2009). Overall quality and shelf life of minimally processed and modified atmosphere packaged "ready-to-eat" pomegranate arils. *Journal of Food Science, 74*(5), C399–C405. https://doi.org/10.1111/j.1750-3841.2009.01184.x

Bai, Y., Wu, P., Wang, K., Li, C., Li, E., & Gilbert, R. G. (2017). Effects of pectin on molecular structural changes in starch during digestion. *Food Hydrocolloids, 69*, 10–18. https://doi.org/10.1016/j.foodhyd.2017.01.021

Bailón-Moreno, R., Olivares-Arias, V., Vicaria, J. M., & Chiadmi-García, L. (2018). Shelf-life kinetic model for freeze-dried oranges using sensory analysis and luminance determination. *Journal of Food Science and Technology, 55*(10), 4013–4019. https://doi.org/10.1007/s13197-018-3326-4

Barak, S., & Mudgil, D. (2014). Locust bean gum: Processing, properties and food applications—a review. *International Journal of Biological Macromolecules, 66*, 74–80. https://doi.org/10.1016/j.ijbiomac.2014.02.017

Bhatta, S., Stevanovic Janezic, T., & Ratti, C. (2020). *Freeze-drying of plant-based foods. Foods, 9*(1), 87. https://doi.org/10.3390/foods9010087

Broxterman, S. E., & Schols, H. A. (2018). Interactions between pectin and cellulose in primary plant cell walls. *Carbohydrate Polymers, 192*, 263–272. https://doi.org/10.1016/j.carbpol.2018.03.070

Calín-Sánchez, Á., Lipan, L., Cano-Lamadrid, M., Kharaghani, A., Masztalerz, K., Carbonell-Barrachina, Á. A., & Figiel, A. (2020). Comparison of traditional and novel drying techniques and its effect on quality of fruits, vegetables and aromatic herbs. *Foods, 9*(9), 1261. https://doi.org/10.3390/foods9091261

Cybulska, J., Drobek, M., Panek, J., Cruz-Rubio, J. M., Kurzyna-Szklarek, M., Zdunek, A., & Frąc, M. (2022). Changes of pectin structure and microbial community composition in strawberry fruit (*Fragaria× ananassa Duch.*) during cold storage. *Food Chemistry, 381*, Article 132151. https://doi.org/10.1016/j.foodchem.2022.132151

Xie, D., Liu, X., Zhang, H., Xia, W., Huang, X., Bi, D., & Pan, S. (2017). Textural properties and morphology of soy 7S globulin-corn starch(amylose, amylopectin). *International Journal of Food Properties, 20*(10), 2197–2205. https://doi.org/10.1080/10942912.2016.1233430

Egas-Astudillo, L. A., Martínez-Navarrete, N., & Camacho, M. M. (2020). Impact of biopolymers added to a grapefruit puree and freeze-drying shelf temperature on process time reduction and product quality. *Food and Bioproducts Processing, 120*, 143–150. https://doi.org/10.1016/j.fbp.2020.01.004

Escalante-Aburto, A., Trujillo-de Santiago, G., Álvarez, M. M., & Chuck-Hernández, C. (2021). Advances and prospective applications of 3D food printing for health improvement and personalized nutrition. *Comprehensive Reviews in Food Science and Food Safety, 20*(6), 5722–5741. https://doi.org/10.1111/1541-4337.12849

Fan, T. T., & Zhang, J. (2022). Effects of resveratrol treatment on quality and antioxidant properties of postharvest strawberry fruit. *Journal of Food Biochemistry, 46*(8). https://doi.org/10.1111/jfbc.14176

Feng, S., Bi, J., Yi, J., Li, X., Li, J., & Ma, Y. (2022). Cell wall polysaccharides and mono-/disaccharides as chemical determinants for the texture and hygroscopicity of freeze-dried fruit and vegetable cubes. *Food Chemistry, 395*(30), Article 133574. https://doi.org/10.1016/j.foodchem.2022.133574

Fox, P. F., Guinee, T. P., Cogan, T. M., & McSweeney, P. L. (2017). Cheese: Structure, rheology and texture. In *Fundamentals of Cheese Science* (pp. 475-532). Springer, Boston, MA. doi: 10.1007/978-1-4899-7681-9-14.

Frabetti, A. C. C., Porto, A. S., Simao, R. D., & Laurindo, J. B. (2021). Strawberry-hydrocolloids dried by continuous cast-tape drying to produce leather and powder. *Food Hydrocolloids, 121*, 107041. https://doi.org/10.1016/j.foodhyd.2021.107041

Ghinea, C., Prisacaru, A. E., & Leahu, A. (2022). Physico-chemical and sensory quality of oven-dried and dehydrator-dried apples of the starkrimson, golden delicious and florina cultivars. *Applied Sciences, 12*(5), 2350. https://doi.org/10.3390/app12052350

Guo, J., Liu, C. J., Li, Y., Liu, J. X., Jiang, S., Li, D. J., … Zhang, M. (2022). Effect of sucrose and citric acid on the quality of explosion puffing dried yellow peach slices. *Drying Technology, 40*(13), 2783–2793. https://doi.org/10.1080/07373937.2021.1965161

Hnin, K. K., Zhang, M., Wang, B., & Devahastin, S. (2019). Different drying methods effect on quality attributes of restructured rose powder-yam snack chips. *Food Bioscience, 32*, Article 100486. https://doi.org/10.1016/j.fbio.2019.100486

Huang, X., & Hsieh, F. H. (2005). Physical properties, sensory attributes, and consumer preference of pear fruit leather. *Journal of Food Science, 70*(3), E177–E186. https://doi.org/10.1111/j.1365-2621.2005.tb07133.x

Hu, J., Sun, X., Xiao, H., Yang, F., Liu, C., Wang, H., … Zhang, W. (2022). Optimization of conditions for a freeze-dried restructured strawberry block by adding guar gum, pectin and gelatin. *Plants, 11*(21), 2809. https://doi.org/10.3390/plants11192500

Wu, J., Zhang, L., & Fan, K. (2022). Recent advances in ultrasound-coupled drying for improving the quality of fruits and vegetables: A review. *International Journal of Food Science and Technology, 57*(9), 5722–5731. https://doi.org/10.1111/ijfs.15935

Karam, M. C., Petit, J., Zimmer, D., Djantou, E. B., & Scher, J. (2016). Effects of drying and grinding in production of fruit and vegetable powders: A review. *Journal of Food Engineering, 188*, 32–49. https://doi.org/10.1016/j.jfoodeng.2016.05.001

Kosińska-Cagnazzo, A., Diering, S., Prim, D., & Andlauer, W. (2015). Identification of bioaccessible and uptaken phenolic compounds from strawberry fruits in *in vitro* digestion/Caco-2 absorption model. *Food Chemistry, 170*, 288–294. https://doi.org/10.1016/j.foodchem.2014.08.070

Krokida, M. K., & Philippopoulos, C. (2006). Volatility of apples during air and freeze drying. *Journal of Food Engineering, 73*(2), 135–141. https://doi.org/10.1016/j.jfoodeng.2005.01.012

Leverrier, C., Almeida, G., & Cuvelier, G. (2016). Influence of particle size and concentration on rheological behaviour of reconstituted apple purees. *Food Biophysics, 11*(3), 235–247. https://doi.org/10.1007/s11483-016-9434-7

Li, J. M., & Nie, S. P. (2016). The functional and nutritional aspects of hydrocolloids in foods. *Food Hydrocolloids, 53*, 46–61. https://doi.org/10.1016/j.foodhyd.2015.01.035

Lin, S., Liu, X., Cao, Y., Liu, S., Deng, D., Zhang, J., & Huang, G. (2021). Effects of xanthan and konjac gums on pasting, rheology, microstructure, crystallinity and *in vitro* digestibility of mung bean resistant starch. *Food Chemistry, 339*(1), Article 128001. https://doi.org/10.1016/j.foodchem.2020.128001

Liu, Y., Zhang, Z., & Hu, L. (2022). High efficient freeze-drying technology in food industry. *Critical Reviews in Food Science and Nutrition, 62*, 3370–3388. https://doi.org/10.1080/10408398.2020.1865261

Manzocco, L., Calligaris, S., Mastrocola, D., Nicoli, M. C., & Lerici, C. R. (2000). Review of non-enzymatic browning and antioxidant capacity in processed foods. *Trends in Food Science & Technology, 11*(9–10), 340–346. https://doi.org/10.1016/S0924-2244(01)00014-0

Milani, J., & Maleki, G. (2012). Hydrocolloids in food industry. *Food Industrial Processes-Methods and Equipment, 2*, 2–37. https://doi.org/10.5772/32358

Morais, E. C., Morais, A. R., Cruz, A. G., & Bolini, H. M. A. (2014). Development of chocolate dairy dessert with addition of prebiotics and replacement of sucrose with different high-intensity sweeteners. *Journal of Dairy Science, 97*(5), 2600–2609. https://doi.org/10.3168/jds.2013-7603

Mui, W. W., Durance, T. D., & Scaman, C. H. (2002). Flavor and texture of banana chips dried by combinations of hot air, vacuum, and microwave processing. *Journal of Agricultural and Food Chemistry, 50*(7), 1883–1889. https://doi.org/10.1021/jf011218n

Nijhuis, H. H., Torringa, H. M., Muresan, S., Yuksel, D., Leguijt, C., & Kloek, W. (1998). Approaches to improving the quality of dried fruit and vegetables. *Trends in Food Science & Technology, 9*(1), 13–20. https://doi.org/10.1016/S0924-2244(97)00007-1

Shehata, S. A., Abdeldaym, E. A., Ali, M. R., Mohamed, R. M., Bob, R. I., & Abdelgawad, K. F. (2020). Effect of some citrus essential oils on post-harvest shelf life and physicochemical quality of strawberries during cold storage. *Agronomy, 10*(10), 1466. https://doi.org/10.3390/agronomy10101466

Shittu, T. A., & Olaitan, O. F. (2014). Functional effects of dried okra powder on reconstituted dried yam flake and sensory properties of ojojo-a fried yam (*Dioscorea alata L.*) snack. *Journal of Food Science and Technology, 51*(2), 359–364. https://doi.org/10.1007/s13197-011-0513-y

Singh-Ackbarali, D., & Maharaj, R. (2014). Sensory evaluation as a tool in determining acceptability of innovative products developed by undergraduate students in food science and technology at the University of Trinidad and Tobago. *Journal of Curriculum and Teaching, 3*(1), 10–27. https://doi.org/10.5430/jct.v3n1p10

Sulieman, A. M. E. H. (2018). Gum arabic as thickener and stabilizing agents in dairy products. *Gum Arabic, 151–165*. https://doi.org/10.1016/j.fbio.2019.100486

Sun, Q., Zhang, M., & Yang, P. (2019). Combination of LF-NMR and BP-ANN to monitor water states of typical fruits and vegetables during microwave vacuum drying. *LWT, 116*, e108548.

Tireki, S., Sumnu, G., & Sahin, S. (2021). Correlation between physical and sensorial properties of gummy confections with different formulations during storage. *Journal Food Science Technology, 58*, 3397–3408. https://doi.org/10.1007/s13197-020-04923-3

Waldron, K. W., Parker, M. L., & Smith, A. C. (2006). Plant cell walls and food quality. *Comprehensive Reviews in Food Science and Food Safety, 2*(4), 128–146. https://doi.org/10.1111/j.1541-4337.2003.tb00019.x

Wang, H., Li, X., Wang, J., Vidyarthi, S. K., Wang, H., Zhang, X. G., … Xiao, H. W. (2022). Effects of postharvest ripening on water status and distribution, drying characteristics, volatile profiles, phytochemical contents, antioxidant capacity and microstructure of kiwifruit (*Actinidia deliciosa*). *Food Control, 139*, Article 109062. https://doi.org/10.1016/j.foodcont.2022.109062

Zhang, L., Liao, L., Qiao, Y., Wang, C., Shi, D., An, K., & Hu, J. (2020). Effects of ultrahigh pressure and ultrasound pretreatments on properties of strawberry chips prepared by vacuum-freeze drying. *Food Chemistry, 303*(15), Article 125386. https://doi.org/10.1016/j.foodchem.2019.125386

Zhao, S., Malfait, W. J., Guerrero-Alburquerque, N., Koebel, M. M., & Nyström, G. (2018). Biopolymer aerogels and foams: Chemistry, properties, and applications. *Angewandte Chemie International Edition, 57*(26), 7580–7608. https://doi.org/10.1002/anie.201709014