



Quality characteristics of sponge cakes made of rice flour under different preservation conditions

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Abstract

In this study, indica rice flour was used as raw material to substitute 100% (w/w) of low-gluten flour to make sponge cake (IRSC). The effect of different packaging atmospheres and temperatures on the characteristics of IRSC quality was investigated in a series of storage tests for six weeks. Quality prediction models were built based on Pearson correlation analysis and stepwise regression analysis on quality indicators of IRSC. Results showed that in the process of preservation, the moisture content, water activity (*A_w*), springiness and resilience evidently decreased, but the hardness and adhesiveness significantly increased. The aging and degradation rate of IRSCs stored at 37 °C was notably faster than when stored at 25 °C, where it had a higher *A_w*, a lower hardness, a better springiness and resilience of more than 14 days. Nitrogen-filled packaging and a 25 °C storage had a synergizing effect on maintaining good quality and extending the shelf-life of IRSCs for nearly 10 days.

Keywords: preservation method; indica rice flour; sponge cake; quality prediction model; synergistic effect.

Practical Application: This study is of reference value to increasing the added value for rice via the transformation into bakery products like sponge cake. In addition, the establishment of quality prediction models contributes to predict the edible quality and shelf-life of the cakes at the stage of storage.

1 Introduction

Globally, 0.6~1% of the population suffers from celiac disease or some other type of gluten intolerance (Nespeca et al., 2021), and they need strict gluten-free diet throughout their lifetime due to gluten intolerance. Rice is naturally gluten-free and is a preferred carbohydrate by majority of the world population (Naseer et al., 2021; Aleman et al., 2021). Indica rice flour without gluten protein is suitable for making gluten-free food products for celiac disease patients and is known to be mild, hypoallergenic and easily digestible (Majzoobi et al., 2016; Park et al., 2012; Wang et al., 2020). Indica rice has a high content of amylose (> 24%), a compact grain structure, a little starch gap, a slow water absorption, a poor viscosity and a high hardness, resulting in poor edibility after cooking. In China, indica rice is mainly used in the rice processing industry to make products such as rice noodles, noodle nests, rice cakes, etc. (Cheng et al., 2004). As we might expect, there would be plenty of broken-grain rice during the primary processing stage. According to statistics, 10-15% of broken-grain rice will be produced every year due to rough or deep processing of rice in China (Zhao et al., 2012), so the reuse of broken-grain rice is a critical problem in the food industry. Broken-grain rice can be used for making sponge cake by grinding it into rice flour, which is a good way for adding value to rice.

Extensive scientific studies have been published that the use of ingredients and techniques to develop different of gluten-free bakery products can get better sensory quality (Xu et al., 2020;

Gao et al., 2017). Aleman et al. (2021) developed a cupcake with 60% high protein brown rice flour, which gave a 100% desirability with an overall liking of 6.96. Wang et al. (2020) successfully made a no-wheat butter cake prepared from indica rice flour and developed an evaluation model based on the principal component analysis. The sponge cake made of 50% and 75% indica rice flour had an even pore size, a soft texture and a good elasticity.

The edibility of sponge cakes during storage can be affected by internal factors such as a microorganism, *A_w*, pH value, as well as external factors such as gas composition, relative humidity, temperature, light intensity, the packaging material and form (Smith et al., 2004). Sponge cakes with high moisture content and rich nutrients are prone to deteriorate through harmful microbial contamination, leading to a short shelf-life and causing enormous economic losses in the food industry. Sponge cakes are commonly preserved with acid chemical preservatives which are only suitable for products with low pH (pH <5.5) (Guynot et al., 2005). Consequently, a majority of manufacturers lengthen the cake's shelf-life by reducing the cake's pH and increasing the dosages and types of chemical preservatives during cake making. Those measures are low-cost and effective, but will affect the taste and harm consumers' health. Nowadays, more consumers will avoid foods with chemical preservatives and prefer natural, organic, and healthy foods. Natural food preservatives like nisin, flavonoids can be a response to current health concerns.

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However, they substantially increase the production cost in the food industry (Ng et al., 2019).

Due to the effect of restraining the growth of harmful microorganisms, modified atmosphere packaging (MAP) provides another useful method for extending shelf-life of cakes. This method refers to the packaging of a perishable product in an atmosphere that has been modified so that its composition is different from that of air (Khoshakhlagh et al., 2014; Rodriguez-Aguilera & Oliveira, 2009). The proportion of gas composition, including oxygen, carbon dioxide and nitrogen, significantly influences the food shelf-life (Guynot et al., 2005; Marín et al., 2002). Besides, the food appearance can remain intact under the MAP method if affected by external forces (Lee et al., 2011). Nitrogen, which is an inert gas, can inhibit the degradation of baked products by forming an anaerobic condition, and can also extend their shelf-life (Khoshakhlagh et al., 2014; Meng & Kim, 2019). In addition, the storage temperature is a vital factor influencing cake edibility and shelf-life, but also affecting the growth and reproduction of microbes as well as the starch staling rate (Meng & Kim, 2019). Baker & Rayas-Duarte (1998) reported that the starch staling rate has a negative temperature coefficient.

However, there are not enough researches on the effect of MAP and the storage temperature on the quality and microbial characteristics of IRSC. In addition, the development of sponge cakes prepared from indica rice flour has not only resulted in a larger variety of bakery products for celiac disease patients but also enhanced the economic value of indica rice. Consequently, the objectives of the present study are (1) to investigate the edibility and microbial characteristics of IRSC packaged under different gas effects at 25 °C and 37 °C during storage, and (2) to build quality prediction models using stepwise regression analysis for providing a theoretical basis of its industrial production on quality indicators of IRSC, including moisture content, Aw, pH, colony lump-sum, hardness, adhesiveness and resilience.

2 Materials and methods

2.1 Materials

The Y316 indica rice, which has 10.71% moisture content, 1.13% fat, 10.24% protein, 27.24% amylase and 0.48% ash (American Association of Cereal Chemists, 2000), is widely cultivated in China, and was purchased from Dongpo Cereals Co., Ltd. (Huanggang, Hubei, China) to be used in the present work. The rice was ground into powder using the 81M/AF-10 machine (Xihua Instrument Technology Co., Beijing, China) and sieved through a 100-mesh sieve to get particles of 150 µm-160 µm size before being used. Pastry quality improver (starch, sodium bicarbonate, xanthan gum, sucrose fatty acid enzyme) and cake emulsifying agent (glycerides mono, palm oil) were supplied by Meichen Group Co. (Guangzhou, Guangdong, China). Sorbitol liquid and compound preservatives (sodium dehydroacetate, sorbic acid) were purchased from Dongguan Guangyi Food Additive Industry Co. (Dongguan, Guangdong, China). Soybean oil was purchased from Fuming Trade Co. (Wuhan, Hubei, China). Whole eggs and powdered sugar were purchased from a local market in Wuhan, Hubei, China.

2.2 Preparation of IRSC

IRSC batter was made of 29.74% indica rice flour, 44.60% whole egg, 20.81% powdered sugar, 1.49% soybean oil, 1.78% cake emulsifying agent, 0.59% pastry quality improver, 0.89% sorbitol liquid and 0.09% compound preservatives. Egg white and egg yolk were mixed, heated to 40 ± 2 °C and put into a kitchen mixer (TB-7L, Cenyue Electric Appliance Co., Guangzhou, Guangdong, China). Powdered sugar was added and mixed with a whisk attachment until the mixture was foamy and formed stiff peaks. Indica rice flour, cake emulsifying agent, pastry quality improver and compound preservatives were added in small increments and gently folded into the whipped batter with a plastic kitchen spatula. Soybean oil and sorbitol liquid were added to the whipped batter and mixed well. For each sample, $40 \text{ g} \pm 2 \text{ g}$ of IRSC batter was poured into a cake mold (14 cm length $\times$ 8 cm width $\times$ 4 cm height) then baked at 210 °C (top) and 170 °C (bottom) for 15 min in a preheated oven (HL-2DW, Guangzhou Panyu Success Baking Equipment Manufacturing Co., Guangzhou, Guangdong, China).

2.3 Preservation methods

IRSC was allowed to cool at room temperature on a clean bench and immediately packed in polypropylene/Aluminium/Polyethylene (OPP/Alu/PE; Qingdao Chenkai Packing Co., Qingdao, Shandong, China) bags (30 $\times$ 25 cm and 110 µm thickness). The MAP used in this study was air packaging and nitrogen-filled packaging with OPP/Alu/PE using a vacuum & gas flushing machine (DZQ400-2D, Yute Packaging Machinery Manufacturing Co., Shanghai, China). The samples were divided into four groups and stored in low-temperature incubator (MJR-253, Sanyo co., Osaka, Japan) at 25 °C and 37 °C respectively. The measurement of IRSC quality indicators was performed once per week. The preservation tests and the analysis of quality indicators ended when mycelium appeared on the IRSC surface, when that surface soured or became sticky, indicating that the IRSC had rotted and deteriorated.

2.4 Evaluation of IRSC quality characteristics

The moisture content of IRSC was measured with the MA35 moisture analyzer (Sartorius Stedim Biotech GmbH, Germany). About 5.0 g of different samples were cut into small cubes and moved into a white plastic case for measuring the water Activity (Aw) using the water activity detector (Aw-center, Novasina, Switzerland) at 20 °C for 30 min. About 10.0 g of different samples were put into a 100mL beaker containing 90 mL of water and then was thoroughly mixed using the stomacher (SRS200, Xinle Electromechanical Technology Co., Shanghai, China). The pH value was measured with a pH meter (FE20, Mettler Toledo Instruments Co., Shanghai, China). In this study, the average results for three measurements are presented.

2.5 Texture profile analysis (TPA) evaluation

The texture analyzer can be used to objectively evaluate the edibility of cakes by measuring its physical indexes such as hardness, adhesiveness, resilience, springiness and chewiness. It can accurately indicate the relationship between the texture

and mechanical characteristics of the food (Szczesniak, 1963). Consequently, the food quality can be evaluated based on the curve of the recorded deformation. Numerous researches have reported the high correlations between sensory quality and texture data of a majority of foods such as rice cakes (Chuang & Yeh, 2006), muffins (Matos et al., 2014), and ordinary cakes (Feng et al., 2016). The freshness of cakes can be characterized through factors such as hardness, adhesiveness and springiness (Kumar et al., 2019; Pongsawatmanit, 2020).

During the experimental test, the texture was measured, 2h after baking, using the TA-XT2i texture analyzer (Stable Micro Systems, Surrey, UK) associated with the software “Texture Expert”. After cooling, IRSCs were kept at room temperature for 1 h and sliced ($3 \times 3 \times 3$ cm) from the middle. A cylindrical probe of 25 mm diameter in aluminum was used in the “Texture Profile Analysis” double compression test (TPA) to penetrate the IRSC at a depth of 50%, a speed of 5 mm/s, with a 2s delay between the first and the second compression. A triggering force of 5 g was applied and parameters obtained from the curves (Figure 1) included the hardness, the springiness, the cohesiveness and the resilience, which are defined in Table 1. Average results for three measurements were used for analysis (Gómez et al., 2007; Pio Ávila et al., 2019).

2.6 Microbiological analyses

The analysis procedures are shown in Figure 2.

- a) A minced sample of 25 g was aseptically transferred into a sterile 500 mL flask, and mixed with 225 mL of

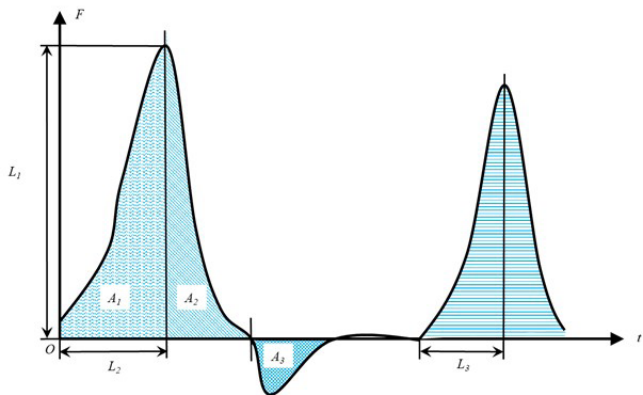


Figure 1. Schematic diagram of TPA curve.

- physiological saline (0.85% NaCl), resulting in a 10% dilution of the mixture. Using a stomacher (SRS200, Xinle Electromechanical Technology Co., Shanghai, China) for 2 min made the mixture completely uniform;
- b) The mixture, diluted at 10%, was collected via a sterile pipette and slowly injected along the inner surface into a test-tube. Another 9 ml of physiological saline was added to the sample and thoroughly mixed. In the end, two diluents of 1% and 0.1% concentration were made;
- c) Two diluent samples of 1ml each at 2~3 different dilution rates (10%, 1%, 0.1%) were extracted and placed in petri dishes containing 15-20 mL of liquid agar jelly cooled at 46 °C. Two tests using the same agar jelly and physiological saline were conducted for comparison;
- d) After the solidification of the agar jelly, all tested petri dishes were bred in an incubator under a temperature of 36 ± 1 °C for 48 ± 2 h;
- e) The number of the total colony unit (TCU) in the petri dish based on the plate count agar (PCA) method was determined (Lee et al., 2011). If the number went beyond the range of 30 to 300, the petri dish was considered invalid.

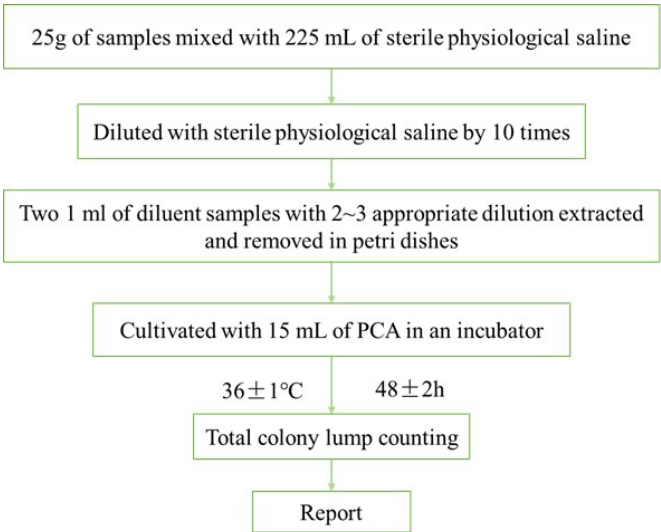


Figure 2. Procedures of microbial experiment.

Table 1. Characteristic parameters extracted from TPA curves.

parameter	Definition
hardness(g)	The maximum peak of the first compression curve (L_1 in Figure 1).
adhesiveness(g·sec)	The negative area of the curve between the end of the first compression and the beginning of the second compression (A_2 in Figure 1).
springiness	The ratio of samples height before and after deformation, namely, the ratio of the height during the second compression and that during the first compression L_3/L_2 (L_3 , L_2 in Figure 1).
resilience	The ability of the sample to return to its original shape after one compression, also known as, the area ratio of A_2/A_1 on the first compression curve (A_2 , A_1 in Figure 1).

2.7 Statistical analyses

All measurements were performed in three sets. Experimental data were statistically analyzed by using Microsoft EXCEL software (version 2007; Microsoft, Redmond, WA, USA) to determine significant differences. When ANOVA indicated high F values, multiple samples comparison were performed and Fisher's least significant difference (LSD) method was applied to discriminate among the means (Li et al., 2019). Pearson correlation and stepwise regression analyses were calculated using SPSS software (version 16.0; SPSS Inc, Chicago, IL, USA).

3 Results and discussion

3.1 Variations of moisture content and Aw of IRSCs during storage

Moisture content and Aw are basic physical properties of sponge cakes, closely related to food quality characteristics, such as hardness, elasticity, inside-mouth sensation, spoilage rate, etc. (Kim et al., 2012). Besides, their detection is conducive to predicting the edibility and shelf-life of foods. Figure 3 displays the variations of IRSCs moisture content and Aw under different temperatures and packaging methods during the storage period. Moisture content and Aw of IRSCs both decreased during the storage process. During the first three weeks of storage, the moisture content of IRSCs with air packaging decreased faster than that with nitrogen-filled packaging for the same storage temperature. However, compared to a higher storage temperature (37 °C), the moisture content decreased slower at a lower storage temperature (25 °C) from the third week to the sixth week. This reflects the fact that packaging methods have a major impact on the moisture content in the short-term (≤ 21 days) while the storage temperature plays an important role in the moisture content in the long-term. During the six weeks of preservation, the moisture content of IRSCs with nitrogen-filled packaging was higher than those using air packaging for the same preservation temperature.

During IRSCs preservation, the internal water molecules migrate to the adjacent hydroxyl group of polysaccharide molecules via the water molecule bridge formed among them. The removable water molecules continuously spread to the adjacent positions, and at the same time, moisture was gradually lost, leading to the spatial rearrangement and recrystallization of starch molecules (Ji et al., 2007; Park et al., 2012). The water molecules migration or redistribution results in starch aging, also known as cake aging (Baik & Chinachoti, 2000; Piazza & Masi, 1995). The Aw of IRSCs decreased faster at 37 °C than at 25 °C because high temperature accelerated the migration and loss of water molecules. The moisture content and Aw of IRSCs with nitrogen-filled packaging showed the smallest reduction at a temperature of 25 °C, suggesting that the water loss rate is related to the packaging method, the temperature and the barrier performance (Sang et al., 2015). A poorer barrier performance and a higher temperature result in more water loss. As an inert gas, nitrogen might have the effect of restraining water migration and loss, thus inhibiting IRSC aging and preventing it from becoming dry and hard. In consequence, nitrogen-filled packaging and low storage temperature (25 °C) have a synergistic effect which can significantly restrain the reduction of moisture content and Aw in IRSCs, and therefore maintain the edibility of IRSCs for a long period.

3.2 Variations of hardness and adhesiveness of IRSC during storage

Hardness can be used to describe the force exerted by the mouth on the cake when shewing it, which represents the peak pressure on the sample when it is first deformed. The softer the texture, the smaller the hardness. The starch aging could have a great influence on the cake's hardness (Osella et al., 2005). Starch aging usually has two stages: short-term and long-term. In the short-term stage of aging, amylose molecules mainly form double helix structures through the effect of hydrogen bonds. With the double helix formation, amylose molecules will pile

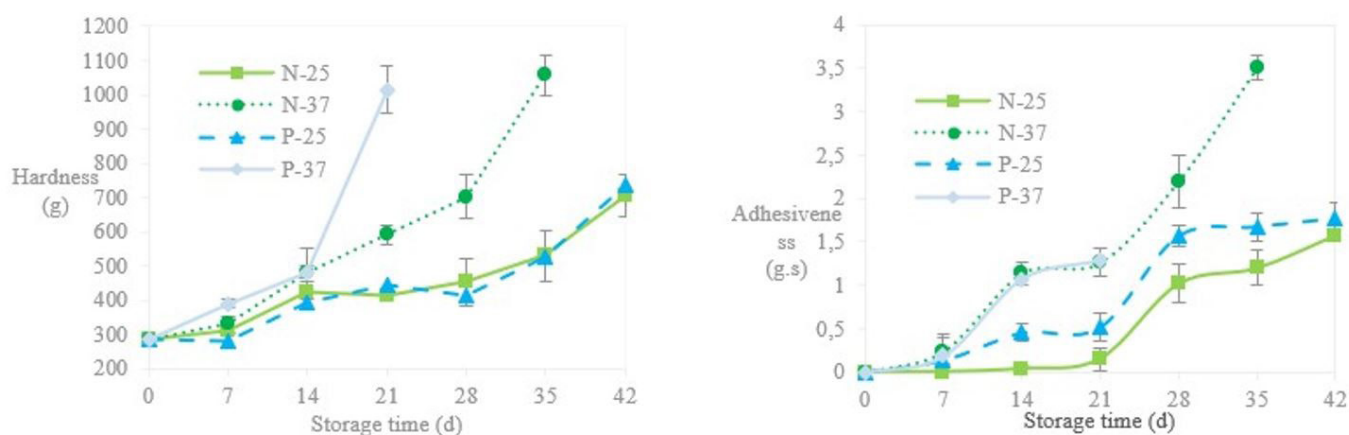


Figure 3. Changes of moisture content and Aw of IRSC during storage. N-25: IRSCs were stored in nitrogen-filled packaging at 25 °C; N-37: IRSCs were stored in nitrogen-filled packaging at 37 °C; P-25: IRSCs were stored in air packaging at 25 °C; P-37: IRSCs were stored in air packaging at 37 °C.

up and crystallize again under hydrogen bonds; this would take hours or days to complete. Long-term aging is mainly caused by the piling-up and recrystallization of the short lateral chain of amylopectin through the effect of hydrogen bonds with the double helix structure as the matrix. Compared to amylopectin, amylose is more prone to aging because the helical spatial structure of amylose occupies a small space and is easy to merge and crystallize under the effect of intermolecular hydrogen bonding (Thanathornvarakul et al., 2016). Due to the high amylose content (27.24%), the indica rice flour will age faster, which results in the hardening of IRSC (Purhagen et al., 2012).

Figure 4 shows the changes in the hardness and adhesiveness relatively to the preservation time for different temperatures and packaging methods. The IRSCs became gradually hard during the whole process of preservation. The hardening rate of IRSCs stored at 37 °C was notably faster than those stored at 25 °C. This is due to the fact that the rapid migration and loss of water at high temperatures promote the crystallization of starch, which accelerates staling and increases the hardness of IRSCs. The differences in hardness changes of IRSCs resulting from different packaging methods were negligible at a storage temperature of 25 °C, while the packaging method had a significant influence on the hardness at a higher storage temperature (37 °C) (Gélinas et al., 1999). This suggests that the packaging method plays a considerable role in IRSCs aging at a high temperature.

For all cases, IRSCs adhesiveness increased significantly during the storage period. At a storage temperature of 37 °C, the adhesiveness variation of IRSCs in nitrogen-filled packaging almost followed the same trend as that in air packaging. However, at a lower storage temperature (25 °C), the adhesiveness of IRSCs with air packaging increased faster than those with nitrogen-filled packaging. With the same packaging method, a higher preservation temperature (37 °C) led to a larger increase rate of adhesiveness. The adhesiveness change is mainly caused by the contamination from fungi like *Aspergillus flavus*, *Penicillium citrinum*, *Penicillium paxilli* and *Aspergillus niger*, (Smith et al., 2004) and bacteria like salmonella and bacillus subtilis (Morassi et al., 2018). Those fungi and bacteria can utilize

nutrients including starch and protein of IRSC to grow and produce metabolites like mucus, which might be the key factor for the adhesiveness increase. It can be concluded that 37 °C is the optimum temperature for the growth and propagation of fungi and bacteria, while nitrogen can effectively isolate oxygen and inhibit its growth and propagation.

3.3 Variations of springiness and resilience of IRSC during storage

The springiness corresponds to the ratio of the sample height before and after deformation, while resilience reflects the ability of the sample to return to its original shape after being compressed by an external force. The excellent springiness and resilience of IRSC contribute to keeping the appearance intact and preventing damage from external force; they are also used to evaluate the inside-mouth sensation. In other words, IRSCs having the appropriate springiness and resilience are easy to chew and swallow.

Figure 5 shows the variation of springiness and resilience during preservation. It can be seen that both the springiness and resilience of IRSCs decreased rapidly in the first two weeks, along the same path to reach values of 0.80 and 0.18, respectively on the 14th day. As a result, the packaging method and storage temperature had little influence on the springiness and resilience of IRSCs in the initial 14 days. From the third to the sixth week, the springiness and resilience of IRSCs stored at 25 °C were obviously larger than those stored at 37 °C. The springiness of IRSCs with a nitrogen-filled packaging and stored at 37 °C had the fastest decline during the storage process, with a minimum value of 0.63 in the fifth week. From the fourth to the sixth week, IRSCs with a nitrogen-filled packaging and stored at 25 °C had a comparatively slow rate of decrease in springiness and resilience. It can be summarized that the migration and loss of water were restrained, while the aging rate of IRSCs was confined effectively at the lower temperature. IRSCs that were preserved for a long time (≥ 14 days) at a lower temperature can maintain a relatively good springiness and resilience. In addition, nitrogen-filled

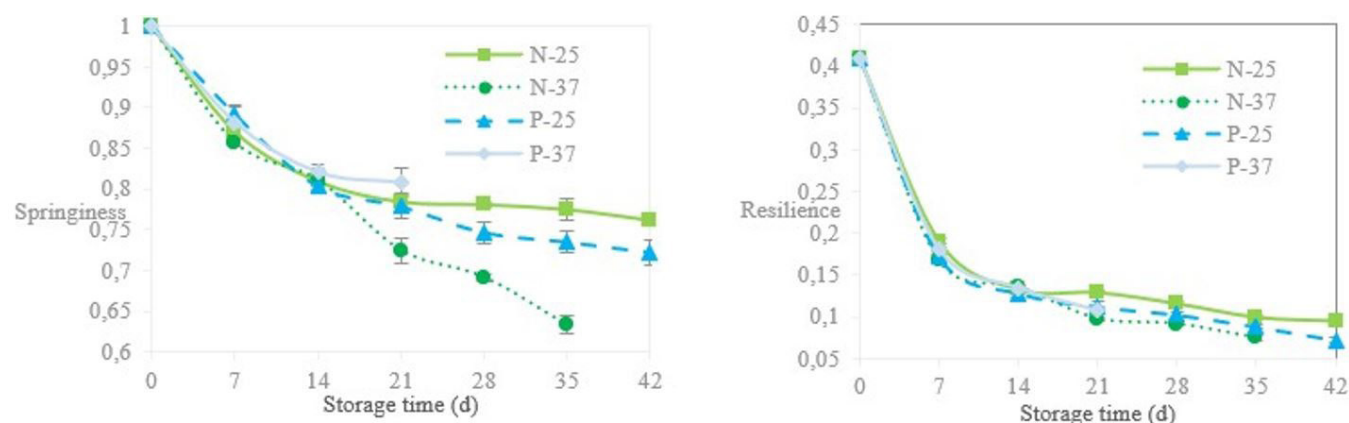


Figure 4. Changes of hardness and adhesiveness of IRSC during storage. N-25: IRSCs were stored in nitrogen-filled packaging at 25 °C; N-37: IRSCs were stored in nitrogen-filled packaging at 37 °C; P-25: IRSCs were stored in air packaging at 25 °C; P-37: IRSCs were stored in air packaging at 37 °C.

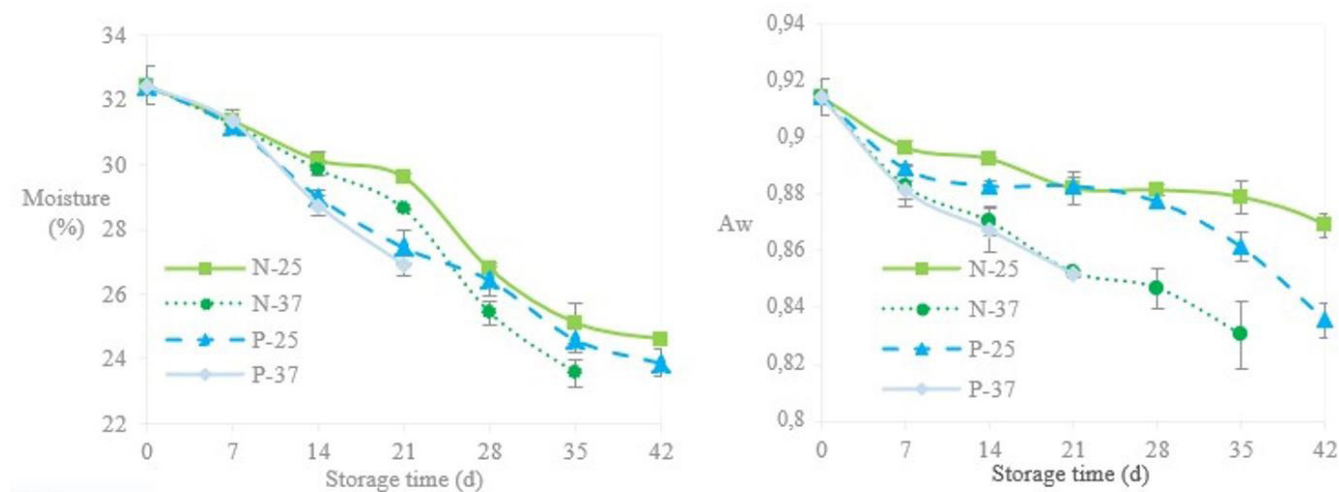


Figure 5. Changes of springiness and resilience of IRSC during storage. N-25: IRSCs were stored in nitrogen-filled packaging at 25 °C; N-37: IRSCs were stored in nitrogen-filled packaging at 37 °C; P-25: IRSCs were stored in air packaging at 25 °C; P-37: IRSCs were stored in air packaging at 37 °C.

packaging would slow the reduction in the springiness and resilience of IRSCs.

3.4 Variations of pH and TCU of IRSC during storage

During the period of preservation, IRSCs can easily deteriorate under the effect of light, O₂, pH, microbes and other factors. As for IRSCs of high Aw (> 0.85), the microbes contamination would dominate the process of IRSCs degradation (Ji et al., 2007). The TCU obtained from experiments can reflect the shelf-life of IRSCs. The Ministry of Health of the People's Republic of China (MHPRC) guidelines specify that a number of total colony lump of 1.5×10^3 CFU/g of food is the allowable limit for pastry (GB 7099-2003 Hygienic standard for pastry and bread). All kinds of microorganisms have an appropriate pH range. The pH value has an important role in the growth of microorganisms and food deterioration. The majority of bacteria need an optimum pH of about 7.0 to grow and multiply, while fungi need a wider range of pH values.

The changes of TCU according to different temperatures and packaging methods can be seen in Table 2. Compared to the IRSCs stored at 25 °C, the TCU was higher for those stored at 37 °C with the same packaging method. Nitrogen-filled packaging produced a smaller number of total colony lump than air packaging when stored at the same temperature. At 37 °C, which is the optimal temperature for microbial reproduction, it was observed that air packaging provided sufficient oxygen for bacteria to grow and reproduce while nitrogen packaging inhibited the growth and reproduction of aerobic bacteria. At a storage temperature of 25 °C, the pH value of IRSCs increased slightly, whereas it experienced a little drop when the IRSCs were stored at 37 °C. The pH value changed around 7.0 within a minor range, which indicates that bacteria and fungi both polluted the IRSCs. Different temperatures would promote the growth and reproduction of different types of microbes

Table 2. Changes of pH and TCU of IRSC during storage.

Storage method	Storage time	pH	TCU (CFU/g)
N-25	0	6.70 ± 0.01 ^c	0
	7	6.85 ± 0.05 ^{ab}	0
	14	6.87 ± 0.00 ^{ab}	10
	21	6.93 ± 0.06 ^{ab}	10
	28	6.94 ± 0.15 ^{ab}	0
	35	6.96 ± 0.01 ^a	10
	42	6.97 ± 0.01 ^a	170
N-37	49	6.98 ± 0.04 ^a	>1500
	0	6.87 ± 0.00 ^a	0
	7	6.82 ± 0.03 ^{ab}	10
	14	6.82 ± 0.06 ^{ab}	30
	21	6.82 ± 0.01 ^{ab}	80
	28	6.81 ± 0.04 ^{ab}	590
	35	6.80 ± 0.04 ^{ab}	>1500
P-25	0	6.80 ± 0.00 ^c	0
	7	6.87 ± 0.00 ^b	0
	14	6.95 ± 0.01 ^b	10
	21	6.94 ± 0.01 ^b	0
	28	6.95 ± 0.08 ^b	0
	35	7.03 ± 0.04 ^a	80
	42	7.09 ± 0.01 ^a	>1500
P-37	0	6.87 ± 0.00 ^a	0
	7	6.73 ± 0.08 ^{ab}	>1500

N-25: IRSCs were stored in nitrogen-filled packaging at 25 °C; N-37: IRSCs were stored in nitrogen-filled packaging at 37 °C; P-25: IRSCs were stored in air packaging at 25 °C; P-37: IRSCs were stored in air packaging at 37 °C. Values are the average of triplicates ± standard deviation. Different letters in each column represent statistical difference ($P < 0.05$).

in various ways and those microbes feed on nutriment in IRSCs such as starch, protein, fat, etc., to generate metabolites of different pH values. It was suggested that high temperature (37 °C) might lead to the production of acid components while a

low temperature (25°C) would contribute to alkaline ingredients formation. IRSCs had the longest shelf life (42 days) when they were stored at 25°C with nitrogen-filled packaging. When air packaging was used and the preservation temperature was set at 37 °C, IRSCs deteriorated within 7 days. It can therefore be said that nitrogen-filled packaging and low temperature have a positive impact on preventing pollution from microbes, as well as they also have the synergistic effect of prolonging the shelf life of IRSCs.

3.5 The establishment of predicted models of IRSC quality

Correlation analysis of storage methods and IRSC quality indicators

Table 3 lists the results of the Pearson correlation analysis on 12 variables, including air packaging, nitrogen-filled packaging, storage temperature (25 °C and 37 °C), storage time, moisture content, Aw, pH, TCU, hardness, adhesiveness, resilience. The results showed that the storage temperature was positively correlated to TCU and hardness (0.365*, 0.307*), but negatively correlated to the pH (-0.534**). That is, the higher the storage temperature, the bigger the total number of colonies and the greater the hardness. In the calculation process, the packaging methods were assigned a number namely 1 and 2 for air packaging and nitrogen-filled packaging respectively. There was a remarkable positive correlation between packaging methods and moisture content (0.353**), while it existed an apparent negative correlation between packaging methods and TCU (-0.245*). Simply put,

IRSCs packaged with nitrogen had a higher moisture content and a smaller TCU. The storage time was positively correlated to TCU and hardness, but negatively correlated to the moisture content, Aw, adhesiveness and resilience. It was observed that the edibility of IRSCs gradually deteriorated as the storage time increased. There was a significant positive correlation between the moisture content and the resilience (0.538**), while a high negative correlation was noted between the moisture content and hardness (-0.497**). Consequently, IRSCs with smaller moisture would have a bad resilience and a significant hardness.

From Table 3, it can be observed that the above-mentioned 12 variables have different degrees of inter-correlations which could confirm the fact that there was an information overlap for analyzing IRSCs quality. This provided a base for further analyses (Terpinc et al., 2012).

Stepwise regression analysis of storage methods and IRSC quality indicators

Table 4 shows the results of the stepwise regression analysis with independent variables including the packaging method (X_p), the storage temperature (X_t), the storage time (X_i), and dependent variables such as the moisture content (Y_M), Aw (Y_{Aw}), pH (Y_{pH}), TCU (Y_T), hardness (Y_H), adhesiveness (Y_A) and resilience (Y_R).

Based on data in Table 4, the F value of each regression equation had a significant level, indicating that the regression analysis results were reliable. During the preservation process,

Table 3. Correlation analysis of storage methods and IRSC quality indicators

	Packaging method	Storage temperature	Storage time	Moisture content	Aw	pH	TCU	Hardness	Adhesiveness
Packaging method	1								
Storage temperature	0.055	1							
Storage time	0.207	-0.268	1						
Moisture content	0.353**	-0.028	-0.580**	1					
Aw	-0.074	-0.233	-0.526**	0.694**	1				
pH	-0.072	-0.534**	0.081	0.077	-0.025	1			
TCU	-0.245*	0.365*	0.391**	-0.244	-0.357*	-0.483**	1		
Hardness	0.219	0.307*	0.626**	-0.497**	-0.681**	-0.105	0.498**	1	
Adhesiveness	0.192	-0.121	-0.608**	0.251	0.256	0.179	-0.341*	-0.520**	1
Resilience	-0.108	-0.051	-0.444**	0.538**	0.627**	-0.304	-0.172	-0.635**	0.280

**The correlation is significant at the 0.01 level (2-tailed); *The correlation is significant at the 0.05 level (2-tailed).

Table 4. Regression equations of storage methods and quality indicators of IRSC.

Quality indicators	Regression equation	F value	R ²
Moisture content	$Y_M=31.955-0.137X_t+0.011X_p$	21.846**	0.337
Aw	$Y_{Aw}=0.946-0.001X_t-0.001X_i$	15.728**	0.428
pH	$Y_{pH}=7.173-0.013X_t$	16.763**	0.285
TCU	$Y_T=-3232.317+45.310X_t+98.181X_i$	13.450**	0.390
Hardness	$Y_H=-265.273+11.375X_t+16.387X_i$	34.938**	0.642
Adhesiveness	$Y_A=0.399-0.05X_t+0.59X_p-0.048X_i$	17.723**	0.550
Resilience	$Y_R=0.206+0.010X_p-0.002X_i$	76.259**	0.197

**The correlation is significant at the 0.01 level (2-tailed).

the storage temperature played a decisive role in IRSCs quality indicators such as Aw, pH, TCU, hardness, adhesiveness and it was even the unique influencing factor of the pH. The packaging method had a little impact on the moisture and resilience of IRSCs. Consequently, the storage temperature has a more significant impact on the staling rate of IRSCs than the packaging method (Sang et al., 2015). With the storage temperature and packaging method known, the IRSCs quality characteristics can be accurately predicted for a specific time by calculating the regression models presented in Table 4.

4 Discussion

There is a growing demand for gluten-free products, which creates chance in the search for products by celiac consumers and makes profits in the Grain& Oil food Manufacturer. Although gluten-free flour generally results in low volume and poor texture for cakes compared with wheat flour, different types of bakery products free of gluten will have a quite good technological and sensory quality by evaluating formulation optimization. The quality of gluten-free cake is influenced by many factors, such as milling method of grain, type and composition of flour, flour particle size, processing techniques and parameters, and other constituents and additives in cake batter (e.g., fiber, gum, emulsifier). Qualities of gluten-free cakes can be improved by adding functional ingredients such as gums, proteins, and emulsifiers, which will be the focus of process optimization and quality improvement of gluten-free cake in food industry.

The storage and preservation of cakes is a complex problem in the food industry, involving numerous factors including the moisture content, Aw, pH, preservatives, harmful microbes, redox-reaction, permeability characteristics of the packaging material, temperature, humidity, pressure, and gas composition around the cake, etc. Nowadays, various physical preservation technologies can help overcome the limitations of chemical preservatives to extend the shelf-life of cakes. Those technologies include the modified packaging atmosphere, the microwave pulse technology, and the utilization of deoxidizer and low permeability packaging materials etc. However, there are only few researches on the effects of the above-mentioned technologies on the edibility and shelf-life of cakes. The possibility of having those technologies progressively replacing chemical preservatives is of great significance to the food industry development. In order to obtain a satisfactory shelf-life for products using compounded physical preservation techniques, further experimental researches should be carried out on the subject.

5 Conclusion

This work investigated the influence of packaging methods and storage temperatures on the characteristics of IRSCs quality including moisture, Aw, hardness, adhesiveness, springiness, resilience, pH and TCU.

The results showed that the packaging method had a major impact on IRSCs moisture content in the short-term (≤ 21 days) while the storage temperature plays a vital role in the long-term. During the six weeks of preservation, the moisture content of IRSCs with nitrogen-filled packaging was higher than that of

those using air packaging and the IRSCs Aw decreased faster at a high temperature. The hardening rate of IRSCs stored at 37 °C was notably faster than those stored at 25 °C, and it was found that the packaging method could exert a significant influence on the hardness at the higher temperature (37 °C). A higher preservation temperature (37 °C) led to a larger increase rate of adhesiveness. The adhesiveness of IRSCs with air packaging increased faster than that of those with nitrogen-filled packaging at 25 °C. IRSCs that were preserved for a long time (≥ 14 days) at a lower temperature could maintain a good springiness and resilience. In addition, it was noted that nitrogen-filled packaging also had a certain influence in constraining the rapid decline of springiness and resilience of IRSCs. Compared with the IRSCs stored at 25 °C, their TCU was higher than that of those stored at 37 °C. IRSCs with nitrogen-filled packaging had a smaller TCU than those with air packaging when stored at the same temperature.

To sum up, the storage temperature had a more significant influence than the packaging method on the characteristics of IRSCs quality. Nitrogen-filled packaging and low temperature had a synergizing effect of extending the shelf-life of IRSCs for nearly 10 days. Quality prediction models combining packaging methods, storage temperatures and quality indicators of IRSCs could accurately evaluate the characteristics of IRSCs quality and its shelf-life under different storage time and methods.

Conflict of interest

No conflict of interest exists in this manuscript.

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