Regulation and optimization of water activity and quality of intermediate-moisture potato frozen cake

Yi Shi, Huan Yao, Danlu Yang, Jinhong Wu, Linnan Zhang, Shaoyun Wang and Zhengwu Wang

Department of Food Science and Engineering, School of Agriculture and Biology, Shanghai Jiao Tong University, Shanghai, China; Ningbo Feirun Marine Biotechnology CO., LTD, Zhejiang, China; College of Biological Science and Technology, Fuzhou University, Fuzhou, China

ABSTRACT
The deterioration of cakes during frozen storage is a notorious phenomenon. This study aimed to evaluate the effects of cryoprotectants (collagen peptide, sericin peptide, and curdlan) on the intermediate-moisture cake during frozen storage. The results showed that cryoprotectants had a positive impact on water state and properties of products. Compared with the control group, the intermediate-moisture cake with better water-holding capacity had better texture characteristics and flavor than the others had, including alleviating the decrement of hardness and chewiness and promoting the augment of sensory evaluation. This study provided more comprehensive theories for the effects of cryoprotectants on intermediate-moisture cake quality from the perspective of water state.

Regulación y optimización de la actividad del agua y la calidad del pastel de papa (patata) congelado de humedad intermedia

RESUMEN
El deterioro experimentado por los pasteles durante su almacenamiento congelado es notorio. Este estudio se propuso evaluar los efectos provocados por los crioprotectores (péptido de colágeno, péptido de sericina y curdlán) en el pastel de humedad intermedia durante el almacenamiento congelado. Los resultados dan cuenta de que los crioprotectores ejercieron un impacto positivo en el estado del agua y las propiedades de los productos. En comparación con el grupo de control, el pastel de humedad intermedia con mayor capacidad de retención de agua presenta mejores características de textura y sabor que los demás. Ello incluye la mitigación de la disminución de la dureza y la masticabilidad y el aumento de sus propiedades durante la evaluación sensorial. Este estudio aportó teorías más completas sobre los efectos de los crioprotectores en la calidad del pastel de humedad intermedia desde la perspectiva del estado del agua.

1. Introduction
Cakes are highly appreciated by consumers because of their good taste, beneficial nutritional profile and ready-to-eat convenience. However, the great majority of cakes circulating in the market are not ready-to-sell, led to the development of methods for the production and preservation of bakery products such as freezing technology. Although this technique enables businesses to reduce production cost and time due to its advantages on centralized manufacturing and distribution process (Selomulyo & Zhou, 2007), the deterioration during frozen storage is a notorious phenomenon. For example, the moisture migration and redistribution causing localized softening and drying, and the formation and growth of ice crystals causing structural distortion (Cauvain, 1998; He & Hoseney, 1990). Thus, the amount of unfrozen water in matrix is a major cause of product degradation during frozen storage. To improve the stability of frozen cakes, the control of water content and the addition of improvers might overcome these problems.

Intermediate moisture foods (IMFs) generally refer to a group of foods with 10%–50% (w/w) moisture content and the water activity between 0.65 and 0.9 (Prabhakar, 2014). In general, IMFs are considered as microbiologically stable at room temperature and can maintain certain initial characteristics of fresh food products (N. Y. N. Y. Lu et al., 2016). Soft cakes, such as Parfait, usually have a short shelf life at room temperature. When its water activity is controlled at 0.687–0.810, its shelf life at room temperature will be prolonged to 3 months. If stored under refrigeration, the shelf life will be even longer (Jelen, 2000).

Although IMFs have a longer shelf life during frozen storage, the growth and recrystallization of ice caused by the repeated fluctuation of temperature will lead to a destruction of the structure, thus hindering the development of such products. In the food industry, adding cryoprotectants is one of the most effective methods to alleviate the quality deterioration of foods during frozen storage. Traditional commercial cryoprotectant, such as polyphosphates, sugars, alcohols, and their compounds, are no longer conform with the current consumers’ pursuit of health.

Antifreeze proteins (AFPs) are peptides and glycopeptides that can depress freezing point and modify the morphology of ice crystals (Xu et al., 2016). They also can inhibit the recrystallization of ice crystals by binding to the surface of ice crystals through an adsorption-inhibition mechanism (Clarke et al., 2002). Studies have shown that collagen...
peptide can be used as a cryoprotectant to improve bread quality and affect the moisture migration of dough during frozen storage (Xu et al., 2016). Sericin peptide has the function of antifreezing protection which can prevent cells and tissues from freezing denaturation (Tsujimoto et al., 2001). Adding a certain amount of sericin peptide into frozen food can not only improve the nutritional value of the product, but also improve the texture characteristics of the product (Gong et al., 2019).

Hydrocolloids can compete for water with polymers like protein and starch, thereby controlling the migration of water and improving the stability of products during frozen storage (Selomulyo & Zhou, 2007). Curdlan, a kind of polysaccharide produced by microorganism fermentation, can be used as stabilizer, thickener, or texturizer in food. It also can be used as cryoprotectant due to its strong hydrophilicity and freeze-thawed stability (Cong et al., 2007). Liang et al. (Liang et al., 2021) reported that curdlan could improve the quality and gluten network of frozen-cooked noodles by preventing ice crystals from growth and recrystallization.

Therefore, this study evaluate the effects of cryoprotectants (collagen peptide, sericin peptide, curdlan) on the quality of intermediate-moisture cake during frozen storage. The effects of cryoprotectants on the water content, water activity, water mobility, textural characteristics, and sensory quality of cakes before and after frozen storage were systematically investigated. The aim of this study is to offer some new scientific insight for quality improvement of intermediate-moisture frozen cake during frozen storage, and expand the application potential of collagen peptide, sericin peptide, and curdlan in food industry.

2. Materials and methods

2.1. Materials

Low-gluten flour (gluten≤9.5%) was purchased from Jiangsu Xinliang Flour Co., Ltd (Jiangsu, China). Sucrose was purchased from Guangzhou Fuzheng Food Co., Ltd (Guangzhou, China). Double-effect baking powder (Disodium dihydrogen pyrophosphate≤40%, Natrium Bicarbonate≥30%, corn starch, Calcium carbonate≥8%, calcium bis≤5%, Glyceryl Monostearate≤2%) was purchased from Angel Yeast Co., Ltd (Hubei, China). Eggs were purchased from Changshu Yongqing Agricultural Products Trading Co., Ltd (Changshu, China). Colza oil was purchased from Yihai Kerry Food Marketing Co., Ltd (Shanghai, China). Honey was purchased from Shanghai Guanshengyuan Bee Products Co., Ltd (Shanghai, China). Potato whole flour was purchased from Inner Mongolia Xisen Potato Whole Flour Co., Ltd (Inner Mongolia, China).

2.2. Preparation of intermediate-moisture potato frozen cake

The cake was prepared with 225 g wheat flour, 42 g potato flour, 140 g sucrose, 10 g baking powder, 240 g egg, 100 g oil, 140 g honey, 1.125 g whey powder, 1.125 g monoglyceride, and 1.125 g thickening agent. Cakes with collagen peptide, sericin peptide, and curdlan contained 0.225 g, 1.125 g, or 2.25 g collagen peptide, sericin peptide, and curdlan (0.1%, 0.5%, and 1.0% wheat flour basis). The addition of three different cryoprotectants was optimized by using a three-level and three-factor orthogonal experiment (Table 1). Cake with no cryoprotectant was used as control. Then, the cake paste was mixed in a vertical mixer. The cake paste was immediately divided into 100 g and transferred to a paper tray, then baked at 190°C/180°C for 28 minutes. Cooling the baked cake to room temperature and stored at −18°C for 0, and 4 weeks.

2.3. Determination of water activity and water content

The methods of testing the water activity and water content as described by Shima et al. (Mehrabi et al., 2017) were used with a brief modification. Equilibration at room temperature for 2 hours, the water activity of the core part in the cake piece was measured at room temperature using an H-BD5m water activity tester. The water content of the samples before and after freezing was determined by the weight discrepancy after drying at 105°C.

2.4. Water mobility determination

The water mobility of cake samples was determined using LF-NMR Analyzer (Niumag Corporation, Shanghai, China) according to the method described by Li et al. (Li et al., 2014) with some modification. Fragments of 10 mm × 10 mm × 10 mm were sealed in PET/PE bags. The spin-spin relaxation time (T2) of samples was performed by running Carr-Purcell-Meiboom-Gill (CPMG) sequences. The measurement parameters were the proton resonance frequency of 24.5 MHz, the test period TW was 1500 ms, the cumulative sampling number was 5000, and RGI was 20.0.

2.5. Texture profile analysis (TPA)

Fragments of 40 × 20 × 20 mm were dissected from the center part of freeze-thawed cake. Texture parameters were measured using a texture analyzer equipped with a P36 probe (Stable Microsystems TA-XT2i, Scarsdale, NY, USA). The test parameters were set as follows: pre-test speed 2.0 mm/s, test speed 1.0 mm/s, post-test speed 4.0 mm/s, and compression degree at 20%. The measured parameters include hardness and chewiness (Karaoğlu et al., 2008).

2.6. Sensory evaluation

Six screened assessors rated the cake in terms of appearance, internal structure, hardness, viscosity, and flavor. The scoring criteria is shown in Table 2.

Table 1. Optimization of the formula for the addition of different cryoprotectants using an orthogonal experiment (L9 (3)3).

| Collagen peptide (%) | Sericin peptide (%) | Curdlan (%) |
|----------------------|---------------------|-------------|
| Control | 0 | 0 | 0 |
| 1 | 0.5 | 0.5 | 0.5 |
| 2 | 0.5 | 0.5 | 0.5 |
| 3 | 0.5 | 0.5 | 0.5 |
| 4 | 0.5 | 0.5 | 0.5 |
| 5 | 0.5 | 0.5 | 0.5 |
| 6 | 0.5 | 0.5 | 0.5 |
| 7 | 0.5 | 0.5 | 0.5 |
| 8 | 0.5 | 0.5 | 0.5 |
| 9 | 0.5 | 0.5 | 0.5 |
deviations, SDs) of three independent experiments. All statistical analyses were performed by using SPSS 19.0 for variance analysis and Minitab 17.0 for range analysis. The significance level of $P < .05$ was used.

3. Results and discussion

3.1. Regulating effect of cryoprotectants on the water activity and water content of potato frozen cake

As shown in Table 3, all the samples prepared based on the formula in Table 1 could meet the requirements of IMFs. The water activity of groups 1–9 was lower than those of the control group, while the water content was higher than those of the control group after 4 weeks frozen storage. The decrease of water activity and the increase of water content indicated that the water holding capacity of the cakes had been enhanced Kong et al. (Kong et al., 2016) reported that large ice crystals could cause physical damage to the food structure, which lead to the decrease of water holding capacity. They confirmed that AFPs could reduce the size of ice crystals and prevent the formation of large ice crystals, resulting a preservation of cellular structure. Wu et al. also reported that sercin peptides could interact with water molecules through hydrogen bonding, hydrophobic interactions, and non-bonding interactions, which could prevent water from forming ice (Wu et al., 2015). As reported by Nguyen et al., the structural match and hydrogen bond formation between ice surface and the collagen peptide could bind collagen peptide to ice, which could inhibit ice growth (Nguyen et al., 2018). Curdian could form helical structure by the bonding of hydrogen bonds with water molecules, and the structure will not change during freezing and thawing, thus

2.7. Statistical analysis

All experiments were run in triplicate unless specified and the experimental data was expressed as means (standard
curdlan could significantly improve the water-holding capacity of frozen products (Hatakeyama et al., 2016).

From the R value by the range analysis (Table 3), it could be seen that after 4 weeks frozen storage, curdlan had the greatest impact on water activity, followed by collagen peptide, and sericin peptide had the smallest effect. Collagen peptide had the greatest impact on water content, followed by sericin peptide, and curdlan had the smallest effect.

It had been widely reported that moisture had an important influence on the delicate taste and bulky appearance of cakes. Generally, cakes with low water content had poor taste and appearance. However, high water content would lead to high water activity of the products, which affect the safety of the products. Since all the tested samples were intermediate-moisture food with water activities lower than 0.9, the higher water content of frozen cakes the better quality of them. From Table 3, we found group 7 had the highest water content, and the adding amount for the cryoprotectants of it was 1% collagen peptide, 0.1% sericin peptide, and 1% curdlan, respectively. This result was almost agreed with the above referred result that the high content adding of collagen peptide and curdlan would help to increase the water content, leading to a better water holding capacity.

3.2. Effect of cryoprotectants on the water mobility of potato frozen cake

The formation and recrystallization of ice crystals during frozen storage will destroy the network structure of cakes and cause the migration of water in them, which will reduce their water holding capacity (Matuda et al., 2008). Therefore, it is necessary to investigate the water mobility in frozen cakes for further understanding the effect of cryoprotectants on decreasing the quality deterioration of frozen cakes during frozen storage.

Figure 1 was the T2 relaxation time distribution curve of a sample. The curve showed two peaks: T21 (1 ~ 10 ms), T22 (10 ~ 100 ms), which represented deep bound water and semi-bond water, respectively (Doona & Baik, 2007). The

**Figure 1.** Nuclear magnetic resonance T2 spectroscopy.
**Figura 1.** Espectroscopia de resonancia magnética nuclear T2.

**Figure 2.** Proportion of deep bound water in cakes frozen at 4 (dark grey) weeks.
**Figura 2.** Proporción de agua ligada en profundidad en los pasteles congelados a las cuatro semanas (gris oscuro).
Table 4. Regulating effect of hardness and chewiness of potato frozen cake by the adding of different cryoprotectant.

| Collagen peptide | Sericin peptide | Curdulan (%) | Hardness /g | Chewiness /g |
|------------------|----------------|--------------|-------------|--------------|
|                  |                |              | 0 week      | 4 week       | 0 week       | 4 week       |
| Control          | 0              | 0            | 756.988±138.32abc | 1897.463±232.66abc | 548.933±92.31abc | 1160.875±124.42abc |
| 1                | 0.1            | 0.1          | 888.150±70.36abc | 1934.938±365.66abc | 594.543±45.00abc | 1160.875±124.42abc |
| 2                | 0.1            | 0.5          | 839.433±102.65ab | 1923.695±90.77abc | 554.970±62.82abc | 1189.375±161.73abc |
| 3                | 0.1            | 1            | 594.598±96.20c  | 1828.76±236.73abc | 430.095±69.66abc | 993.683±48.50abc |
| 4                | 0.5            | 0.1          | 585.853±112.43c | 1715.088±196.69bc | 397.595±77.41abc | 967.945±144.81bc |
| 5                | 0.5            | 0.1          | 624.578±38.92c | 2091.080±385.93abc | 420.470±33.33abc | 960.120±92.96abc |
| 6                | 0.5            | 1            | 523.393±47.29c | 1796.280±213.73abc | 353.730±30.07abc | 1235.755±267.91abc |
| 7                | 1              | 0.1          | 861.918±21.78c | 1857.490±378.54abc | 551.303±20.06abc | 989.468±160.03abc |
| 8                | 1              | 0.5          | 637.065±107.13bc | 1638.890±186.96c | 425.068±72.79abc | 870.088±198.29c |
| 9                | 1              | 1            | 861.918±92.36c | 2191.010±82.05c  | 550.775±57.08abc | 859.963±117.57c  |

Different superscripts within the same column indicate significant difference according to the Fisher PLSD test at the 0.05 confidence level. 

Rj value refers to the range value.

Los distintos superEindices dentro de la misma columna indican diferencias significativas según la prueba PLSD de Fisher a un nivel de confianza de 0.05.

Tij se refiere al valor medio del índice de evaluación para cada nivel de un factor.

El valor Rj se refiere al valor del rango.

Table 5. Sensory evaluation score.

| Collagen peptide | Sericin peptide | Curdulan (%) | 0 week | 4 week | 0 week | 4 week |
|------------------|----------------|--------------|--------|--------|--------|--------|
| Control          | 0              | 0            | 65.4±7.22* | 65.4±7.22* | 65.4±7.22* | 65.4±7.22* |
| 1                | 0.1            | 0.1          | 62.8±4.66* | 64.4±5.90* | 62.8±4.66* | 64.4±5.90* |
| 2                | 0.1            | 0.5          | 64.4±5.90* | 64.4±5.90* | 64.4±5.90* | 64.4±5.90* |
| 3                | 0.1            | 1            | 62.8±3.19* | 62.8±3.19* | 62.8±3.19* | 62.8±3.19* |
| 4                | 0.5            | 0.1          | 63.2±5.45* | 63.2±5.45* | 63.2±5.45* | 63.2±5.45* |
| 5                | 0.5            | 0.5          | 60.4±5.94* | 60.4±5.94* | 60.4±5.94* | 60.4±5.94* |
| 6                | 0.5            | 1            | 61.4±6.62* | 61.4±6.62* | 61.4±6.62* | 61.4±6.62* |
| 7                | 1              | 0.1          | 63.4±6.58* | 63.4±6.58* | 63.4±6.58* | 63.4±6.58* |
| 8                | 1              | 0.5          | 65.0±5.79* | 65.0±5.79* | 65.0±5.79* | 65.0±5.79* |
| 9                | 1              | 1            | 63.2±5.76* | 63.2±5.76* | 63.2±5.76* | 63.2±5.76* |

Different superscripts within the same column indicate significant difference according to the Fisher PLSD test at the 0.05 confidence level. 

Rj value refers to the range value.

Los distintos superEindices dentro de la misma columna indican una diferencia significativa según la prueba PLSD de Fisher a un nivel de confianza de 0.05.

Tij se refiere al valor medio del índice de evaluación para cada nivel de un factor.

El valor Rj se refiere al valor del rango.

### 3.3. Effect of cryoprotectants on the texture characteristics of potato frozen cake

Results of TPA test for all potato frozen cakes were illustrated in Table 4. In this study, the hardness and chewiness of cake were used to evaluate the quality of potato frozen cakes.
Hardness is an important index for evaluating cake quality, which is closely associated with human perception of freshness. Chewiness refers to the time required to chew the cake to the suitable for swallowing (T. M. T. M. Lu et al., 2010). Therefore, high values of chewiness are related with dense, which is not desirable in cakes. As shown in Table 4, the hardness and chewiness of cakes gradually increased with frozen storage time. The increase in the hardness and chewiness as a consequence of frozen storage indicates the destruction of gluten network by ice crystals during the freezing process (Yadav et al., 2009).

The hardness and chewiness of groups 3, 4, 5, 6, and 8 were significantly (P < .05) lower than those of the control group before freezing. After four weeks frozen storage, the hardness and chewiness of groups 3, 4, 6, 7, and 8 were lower than those of the control group. The improvement was similar to the phenomenon of water migration, which further proved that there was a certain correlation between water migration and product quality during frozen storage. Lahtinen et al. (Lahtinen et al., 1998) reported that water content is the most important factor affecting the softness of cakes. Mehmet et al. (Karaoglu et al., 2008) also reported a significant negative correlation between water content of cakes and cake firmness. Thus, the improvement of water holding capacity of cakes might be helpful to reduce its hardness and chewiness, and delay its quality deterioration during frozen storage.

Meanwhile, from the R value by the range analysis (Table 4), it could be seen that before freezing, collagen peptide had the largest impact on the hardness and chewiness of the cakes. After 4 weeks frozen storage, collagen peptide had the greatest impact on the chewiness. Thus, among the three cryoprotectants, collagen peptide had the greatest influence on the hardness and chewiness before and after frozen storage. This result was similar to the results of water activity and water content. High content of collagen peptides could improve the texture of cakes, which might be due to the inhibition of ice crystals (Nguyen et al., 2018). In addition, collagen peptides could also modify ice crystals to make them smaller and more evenly distributed, thus making the texture of cake delicate and soft (Ling et al., 2018).

3.4. Sensory evaluation of cake

According to the sensory evaluation scores in Table 5, after 4 weeks frozen storage, groups 7 and 8 had similar sensory evaluation scores with the control group. Meanwhile, as the R value shown in Table 6, it could be seen that after 4 weeks frozen storage, collagen peptide had the greatest impact on the sensory evaluation, followed by curdlan, and sercin peptide had the smallest effect. This result almost agreed with the above result that the high content addition of collagen peptide could help to increase the quality of cakes. Therefore, we could realize that the intermediate moisture cake with better water holding capacity would have better sensory quality after freezing.

4. Conclusion

This study investigated the effects of cryoprotectants in frozen intermediate moisture cake. Collagen peptide, sercin peptide and curdlan were added in frozen intermediate moisture cakes to weaken the quality deterioration of cakes during frozen storage. The underlying mechanism of cryoprotectants on quality regulation and optimization during frozen storage was elucidated from water state and properties. In addition, the texture and sensory properties were also explored to analyze the quality of frozen cakes. The results showed that the improvement of water holding capacity improved the quality of intermediate-moisture cakes during frozen storage, including alleviating the decrement of hardness and chewiness and promoting the augment of sensory evaluation. The results provided a theoretical basis and technical reference for revealing the effects of cryoprotectants on water mobility, texture and flavor of intermediate-moisture cake during frozen storage, and expand the application potential of collagen peptide, sercin peptide and curdlan in food industry.

Acknowledgments

This work was funded by the Natural Science Foundation of China (Grant No. 31972017) and the National Key R&D Program of China (Grant No: 2016YFD0400206).

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Natural Science Foundation of China (31972017); Research Startup Fund of Yibin University (2013QD04); National Key R&D Program of China (2016YFD0400206).

ORCID

Yi Shi https://orcid.org/0000-0003-3975-7775

References

Cauvain, S. P. (1998). Improving the control of staling in frozen bakery products. Trends in Food Science & Technology, 9(2), 56–61. 10.1016/S0924-2244(98)00003-X
Clarke, C. J., Buckley, S. L., & Lindner, N. (2002). Ice Structuring Proteins - A New Name for Antifreeze Proteins. Cryoletters, 23 (2), 89–92. <Go to ISI>://WOS:000175681500003.
Cong, F. S., Zhang, H. B., & Zhang, W. J. (2004). The properties of curdlan and its applications in food and pharmaceutical fields. Food Science, 25(11), 432–435. 10.1016/j.jcs.2003.08.015
Doona, C. J., & Baik, M-Y. (2007). Molecular mobility in model dough systems studied by time-domain nuclear magnetic resonance spectroscopy. Journal of Cereal Science, 45(3), 257–262. 10.1016/j.jcs.2006.07.015
Gong, S., Yang, D., Wu, Q., Wang, S., & Wu, J. (2019). Evaluation of the antifreeze effects and its related mechanism of sercin peptides on the frozen dough of steamed potato bread. Journal of Food Processing and Preservation, 43(1), e14053. https://doi.org/10.1111/jfpp.14053
Hatakeyama, T., Iijima, M., & Hatakeyama, H. (2016). Role of bound water on structural change of water insoluble polysaccharides. Food Hydrocolloids, 53(FEB.), 62–68. https://doi.org/10.1016/j.foodhyd.2014.12.033
He, H., & Hoseney, R. C. (1990). Changes in bread firmness and moisture during long-term storage. Cereal Chemistry, 67(6), 603–605. https://doi.org/10.1002/aoc.990040605
Jelen, P. (2000). Foods, 2. Food Technology. Wiley-VCH Verlag GmbH & Co. KGaA.
Karaoglu, M. M., Kotancilar, H. G., & Gercelkasan, K. E. (2008). The Effect of Par-baking and Frozen Storage Time on the Quality of Cup Cake.
Lu, Ling, Lahtinen, Porcine Oxidation Science, 34–43.

Karaoglu, M. K., Kotancilar, H. G., & Gergekasan, K. E. (2008). The effect of par-baking and frozen storage time on the quality of cup cake. International Journal of Food Science & Technology, 3(10), 1778–1785. doi:10.1111/j.1365-2621.2007.01698.x

Kong, C. H. Z., Hamid, N., Liu, T. T., & Sarojini, V. (2016). Effect of Antifreeze Peptide Pretreatment on Ice Crystal Size, Drip Loss, Texture, and Volatile Compounds of Frozen Carrots. Journal of Agricultural and Food Chemistry, 64(21), 4327–4335. https://doi.org/10.1021/acs.jafc.6b00046

Lahtinen, S., Levola, M., Jouppila, K., & Salovaara, H. (1998). Factors affecting cake firmness and cake moisture content as evaluated by response surface methodology. Cereal Chemistry, 75(4), 547–550. doi:10.1093/oxfordjournals.jbchem.a002946

Li, Y., Li, X., Wang, J. Z., Zhang, C. H., & Xie, X. L. (2014). Effects of Oxidation on Water Distribution and Physicochemical Properties of Porcine Myofibrillar Protein Gel. Food Biophysics, 9(2), 169–178. doi:10.1007/s11483-013-9329-9

Liang, Y., Qu, Z. T., Liu, M., Zhu, M. F., Zhang, X., Wang, L., Jia, F., Zhan, X. B., & Wang, J. S. 2021. Further interpretation of the strengthening effect of curdlan on frozen cooked noodles quality during frozen storage: Studies on water state and properties. Food Chemistry, 346(2), 128908. <Go to ISI>://WOS:000614807500015. doi:10.1016/j.foodchem.2020.128908.

Ling, L. S., Chen, X., & Wang, S. (2018). Quality Protection and Action Mechanism of Antifreeze Peptide on Frozen Potato Dough Subjected to Freeze-Thaw Cycles. Food Science, 39(10), 7–13 1002-6630(2018) 39:10<7:DRXKXK=2>TX2-G

Lu, N. Y., Zhang, L., Zhang, X., Li, J., Labuza, T. P., & Zhou, P. (2016). Molecular migration in high-protein intermediate-moisture foods during the early stage of storage: Variations between dairy and soy proteins and effects on texture. Food Research International, 82(April), 34–43. https://doi.org/10.1016/j.foodres.2016.01.026

Lu, T. M., Lee, C. C., Mau, J. L., & Lin, S. D. (2010). Quality and antioxidiant property of green tea sponge cake. Food Chemistry, 119(3), 1090–1095. https://doi.org/10.1016/j.foodchem.2009.08.015

Matuda, T. G., Chevallier, S., Filho, P. D. A. P. A., LeBail, A., & Tadini, C. (2008). Impact of Guar and Xanthan Gums on Proofing and Calorimetric Parameters of Frozen Bread Dough. Journal of Cereal Science. 48(3), 741–746. https://doi.org/10.1016/j.jcs.2008.04.006

Mehrab, S., Koushki, M., & Azizi, M. H. (2017). Effect of Grape Syrup as a Replacement for Sugar on the Chemical and Sensory Properties of Sponge Cake. Current Research in Nutrition and Food Science, 5(2), 126–136. https://doi.org/10.12944/Cmntfg.5.2.09

Nguyen, C. T., Yuan, M., Yu, J. S., Ye, T., Cao, H., & Xu, F. (2018). Isolation of ice structuring collagen peptide by ice affinity adsorption, its ice-binding mechanism and breadmaking performance in frozen dough. Journal of Food Biochemistry, 42(3), e12506. https://doi.org/10.1111/jfbc.12506

Prabhakar, K. (2014). Intermediate Moisture Foods. Encyclopedia of Food Microbiology. 372–376. https://doi.org/10.1016/b978-0-12-384730-0.00103-7

Tsujimoto, K., Takagi, H., Takahashi, M., Yamada, H., & Nakamori, S. (2001). Cryoprotective Effect of the Serine-Rich Repetitive Sequence in Silk Protein Sericin. Journal of Biochemistry, 129(6), 979–986. https://doi.org/10.1093/oxfordjournals.jbchem.a002946

Williams, P. D., Oztop, M. H., McCarthy, M. J., McCarthy, K. L., & Lo, Y. M. (2011). Characterization of Water Distribution in Xanthan-Curdlan Hydrogel Complex Using Magnetic Resonance Imaging, Nuclear Magnetic Resonance Relaxometry, Rheology, and Scanning Electron Microscopy. Journal of Food Science, 76 (6), E472–E478. https://doi.org/10.1111/j.1750-3841.2011.02227.x

Wu, J. H., Rong, Y. Z., Wang, Z. W., Zhou, Y. F., Wang, S. Y., & Zhao, B. (2015). Isolation and characterisation of sericin antifreeze peptides and molecular dynamics modelling of their ice-binding interaction. Food Chemistry, 174(May), 621–629. https://doi.org/10.1016/j.foodchem.2014.11.100

Xu, C., Wu, J. H., Ling, L., & Wang, S. Y. (2016). The cryoprotective effects of antifreeze peptides from pigskin collagen on texture properties and water mobility of frozen dough subjected to freeze–thaw cycles. European Food Research & Technology, 243(7), 1–8. https://doi.org/10.1007/s00217-016-2830-x

Yadav, D. N., Patki, P. E., Sharma, G. K., & Bawa, A. S. (2009). Role of ingredients and processing variables on the quality retention in frozen bread doughs: A review. Journal of Food Science and Technology-Mysore, 46 (1), 12–20. <Go to ISI>://WOS:000262555400002. https://doi.org/10.1111/j.1750-3841.2008.01020.x