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Effect of temperature fluctuation during frozen storage on beef quality

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Abstract

This study investigated the effects of fluctuating temperature on the quality of frozen beef, which were preserved under three different temperature fluctuation ranges (wide temperature fluctuation −18 ± 2°C, medium temperature fluctuation −18 ± 1°C, and small temperature fluctuation −18 ± 0.5°C). Results showed that, with an increase of in small temperature fluctuation, the rate of thaw loss significantly increased, total volatile basic nitrogen value increased. However, these temperature fluctuations did not influence the beef color, TBARS value, and muscle fiber diameter. This indicated that, under a certain level, smaller temperature fluctuation had better preservation on frozen beef.

Practical applications

This research provide a theoretical basis for reducing the effects of temperature fluctuation on the quality of frozen beef preserved in domestic freezers and small temperature fluctuation can be applied to the development of intelligent defrosts.

1 | INTRODUCTION

Temperature plays an essential role in the process of meat storage, while low temperatures can effectively control the growth of microorganisms and the effect of enzymes, thereby slowing down the rate of meat spoilage (Lambert et al., 1991). As a high-efficiency meat preservation method, frozen storage has been widely used (Kiani & Sun, 2011) since it has significant influence on maintaining meat quality and prolonging shelf life, especially when it comes to long-distance transportation of meat. Thus, frozen meat has become an essential form of international trade (Leygonie et al., 2012). Meanwhile, household frozen storage is also preferred by consumers for its convenience. From this perspective, frozen storage allows consumers to choose the consumption date during storage duration at their will without losing the sensory quality of meat (Muela et al., 2016).

However, during the freezing and thawing process of storage, the growth of ice crystals, weight loss, protein degradation, and the discoloration of fat and muscle would occur, which contribute to quality loss. The quality of frozen-stored meat is affected by a great number of factors, such as storage temperature, temperature fluctuation, way of packing, and environment humidity (Kong & Chen, 2018). Among these factors, temperature fluctuation may occur during various food storage duration, such as freeze-thaw cycles of the cold chain and the food storage in household freezers when door opening or defrosting happens. The exchange of air inside and outside the refrigerator and physical changes like defrosting result in frequent temperature fluctuation in domestic refrigerators. (Khan & Afroz, 2014a, 2014b). It was found that the numbers of door opening during three meals can add up to 40 to 50 times (Laguerre et al., 2002). Moreover, the temperature in the freezer could be raised during the defrosting process (Zhao et al., 2017), which create adverse effects on the meat stored in household freezers.

Previous studies have been carried out on how certain temperature fluctuation affects the quality of meat and poultry. Gormley et al. (2002) compared the effects of fluctuating regime involving three periods of −30 to −10°C to −30°C on consecutive weeks on frozen raw salmon, smoked mackerel, and stewed pork pieces, and concluded that temperature fluctuation cycles accelerated the development of rancidity of products. In the case of pork, Hansen et al. (2004) reported higher TBARS values in samples under fluctuating temperatures (−10 to −23°C and −23 to −40°C) than those stored at the corresponding constant temperatures (−10 and −23°C). In another case of beef, Wang et al. (2020) studied the effect of temperature fluctuations on the meat quality and muscle microstructure of frozen beef, which included storage at a constant −18 ± 0.1°C, and fluctuations between −18 and −17°C, −18 and −15°C, and −18 and −13°C.

In the studies above, simulations of temperature fluctuation during transportation and retail display have been studied, which have wider temperature fluctuation ranges. However, the impact of smaller temperature on frozen food storage in domestic refrigerators during defrosting cycles (Zhao et al., 2017), was barely covered before. Therefore, the objective of this study was to investigate the difference of three temperature fluctuation ranges (wide temperature fluctuation −18 ± 2°C, medium temperature fluctuation −18 ± 1°C, and small temperature fluctuation −18 ± 0.5°C) on beef preservation by analyzing changes in quality, spoilage, and tissue structures of samples.

2 | MATERIALS AND METHODS

2.1 | Sample preparation

A quantity of hind shanks of chilled fresh beef were purchased from a local market, and the postmortem time of these samples was 48 hr. Then they were transported to the laboratory using iceboxes within 2 hr. The samples were cut parallel to muscle fibers into equal portions of 250 g (approximately 0.13 m × 0.05 m × 0.05 m) in a clean bench (SW-CJ-2FD, AIRTECH, China) and packed in polyethylene fresh-keeping bags (medium size, BaoJie, China) without vacuum.

2.2 | Temperature fluctuation conditions

The samples were randomly assigned to be preserved in domestic freezers under one of the three different temperature fluctuation conditions, that is, (a) −18 ± 2°C, referred to wide temperature fluctuation; (b) −18 ± 1°C, referred to medium temperature fluctuation; (c) −18 ± 0.5°C, referred to small temperature fluctuation. The temperature was regulated in a certain fluctuation range by changing the setting of the thermostat on a domestic freezer. Temperature changes of the samples were monitored during freezing and frozen storage by inserting sensors into inside samples and observed using a connected data acquisition system (LXI, KEYSIGHT) linked to a personal computer. Before the study started, long-term temperature tests were carried out to ensure the fluctuation ranges were achieved by testing the sample temperature in different refrigerators at hourly intervals during test hours. During frozen storage, three thermocouples were used for the air temperature measurements within the cabinet of each freezer on a daily basis to confirm the normal operation of freezers. One was located in the top section, one in the middle section, and one at the bottom of the cabinet space. After 0, 7, 14, 30, 60, and 90 days of frozen storage, three samples per sampling point in each treatment group, and all samples were thawed and monitored with sensors until their core temperature had reached 0–4°C in a 25°C incubator. The thermocouple sensors were calibrated using the mixture of ice and water for 0°C before used.

2.3 | Thaw loss (%)

For quantitation of the thaw loss, the sample was removed from the wrapping, were weighed before and after thawing on an electronic scale. The thaw loss was calculated using the following equation: thaw loss (percent) = (weight before thawing − weight after thawing)/(weight before thawing) × 100. The mean values were calculated from three replicates.

2.4 | Color

The color of the samples was measured on Day 0 before the frozen storage began. During frozen storage at each sampling point, samples were thawed and the color of them was measured immediately using a colorimeter (CR-400, KONICA MINOLIA) equipped with an 8 mm (diameter) measuring. The settings for illuminant and the standard observer was D_{65}/2°, respectively. Five measurements of color values (CIE L^*, a^*, and b^*) were made on the surface of each sample. The colorimeter was calibrated with a white standard plate before measurements by placing the colorimeter vertical to the middle of the plate and running measuring process.

2.5 | Muscle fiber diameter

Samples were cut parallel to muscle fibers into blocks, then cut into sections perpendicular to the direction of the muscle fibers by a frozen meat slicer (CM 1900-1-1, Leica) before storage and after being withdrawn from the freezer at each sampling point. Sections were dyed (nontoxic environmentally friendly hematoxylin-eosin dye solution; Jiancheng Co., Ltd., Beijing, China), observed, and photographed (DP12, Olympus, Japan) with a phase contrast microscope (BX41, Olympus, Japan) at ×4 magnification. Image-Pro Plus software (5.1, Media Cybernetics Inc., USA) was used to measure fiber diameters. Measurements were made in triplicate.

2.6 | Total TVB-N value

According to GB/T 5009.44 Standard (GB/T, 2003), 10 g of meat samples was minced, extracted with 100 ml of water and filtered. Boric acid absorption solution (20 g/L, Sinopharm Chemical Reagent Co., Ltd.) and mixed indicator were added to the inner chamber of Conway's dish, while 1 ml of sample solution and 1 ml of saturated potassium carbonate solution (Sinopharm Chemical Reagent Co., Ltd.) were added to the outside of the dish. The dishes were sealed with water-soluble glue on the edge and placed in an incubator at 37°C for 2 hr, then opened and titrated with hydrochloric acid (0.001 mol/L, Sinopharm Chemical Reagent Co., Ltd.) until blue-violet color was observed. Control blank dishes were also made and evaluated in the same manner as were the samples.

2.7 | TBARS Values

Five grams of samples was homogenized with 20 ml of distilled water by meat grinder, and 25 ml of 200 g/L of trichloroacetic acid (TCA, Sinopharm Chemical Reagent Co., Ltd.) put in a dark room for 1 hr and then filtrated. Two milliliters of the collected supernatant was mixed with 0.02 mol/L of thiobarbituric acid (TBA) solution (2 ml) and incubated in boiling water for 20 min. After cooled with running water, the absorbance of each sample was measured by a UV spectrophotometer (Lambda 25, Perkin Elmer) at 532 nm. A mixture containing 2 ml of 0.02 mol/L of TBA solution and 2 ml of 100 g/L of trichloroacetic acid were as control blanks. TBARS were calculated using a standard curve of malondialdehyde.

2.8 | Statistical analysis

Determinations were performed on all three samples of every treatment group, and means and standard errors of each group were calculated. Data were statistically analyzed by the one-way ANOVA procedure of SPSS, version 17 (SPSS Inc., Chicago, IL). The difference of means among treatment groups was determined using Least Significant Difference Tests ($p < .05$).

3 | RESULTS AND DISCUSSION

3.1 | Thaw loss

Thaw loss level was higher in the wide fluctuation group and lower in the small fluctuation group than in the medium fluctuation group during most of the storage duration, as shown in Figure 1. The advantage of smaller temperature fluctuation in terms of maintaining the water holding capacity was observed at the beginning of this storage. Differences ($p < .05$) between small fluctuation group and the two other groups were observed on both Day 14 and 90. Combined with the following results of meat fiber diameters, it may

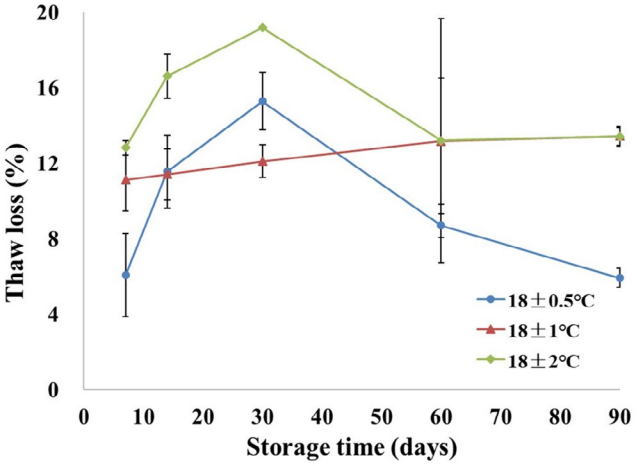

FIGURE 1 Change in thaw loss during storage at fluctuating temperatures. A lower thaw loss indicates a better water holding capacity of the sample ($n = 3$)

be inferred that most of ice crystal in three treatment groups may be formed in different positions, but the size of ice crystals may be not large enough to crush muscle fibers, which led to better retention of fluid in smaller temperature fluctuation group. Noticeable conclusions were obtained in previous studies by Gormley et al. (2002), which concluded that a smaller range of fluctuating temperature led to better retention of fluid in meat products, possibly due to wider temperature fluctuation accelerates the growth of ice crystals. Flores and Goff (1999) argued that temperature fluctuation induces recrystallization behavior. Moreover, the rate of crystals growth, as was proven by Huang et al. (2006), was positively correlated with the range of temperature fluctuation. Such growth destroys tissue structures of the sample and causes an increase in fluid loss.

3.2 | Color

Decreases in meat color (CIE L^*, a^*, and b^*) occurred with fluctuation in all treatment groups (shown in Figure 2). The lightness (L^*) of small fluctuation group decreased steadier than those in other groups, while the lightness of medium fluctuation group decreased at the fastest rate and remained the lowest one for up to 60 days. The recovery of lightness agreed with those of Holman et al. (2017), which indicated that the reflection of meat increased with free water released due to muscle protein denaturation during thawing (Farouk & Wieliczko, 2003; Holman et al., 2017). Although no differences were found among all groups ($p > .05$), the redness of the small fluctuation group remained relatively stable from Day 14 to 60 when compared to medium and wide fluctuation groups. It is possible to say that wider temperature fluctuation results in more considerable alterations in meat color, which could be a result of its negative impact on myoglobin denaturation during frozen storage duration (Alonso et al., 2016). This can be supported by Gormley et al. (2002) who reported that the fluctuating regime caused bigger changes in the color of salmon samples than those stored under constant

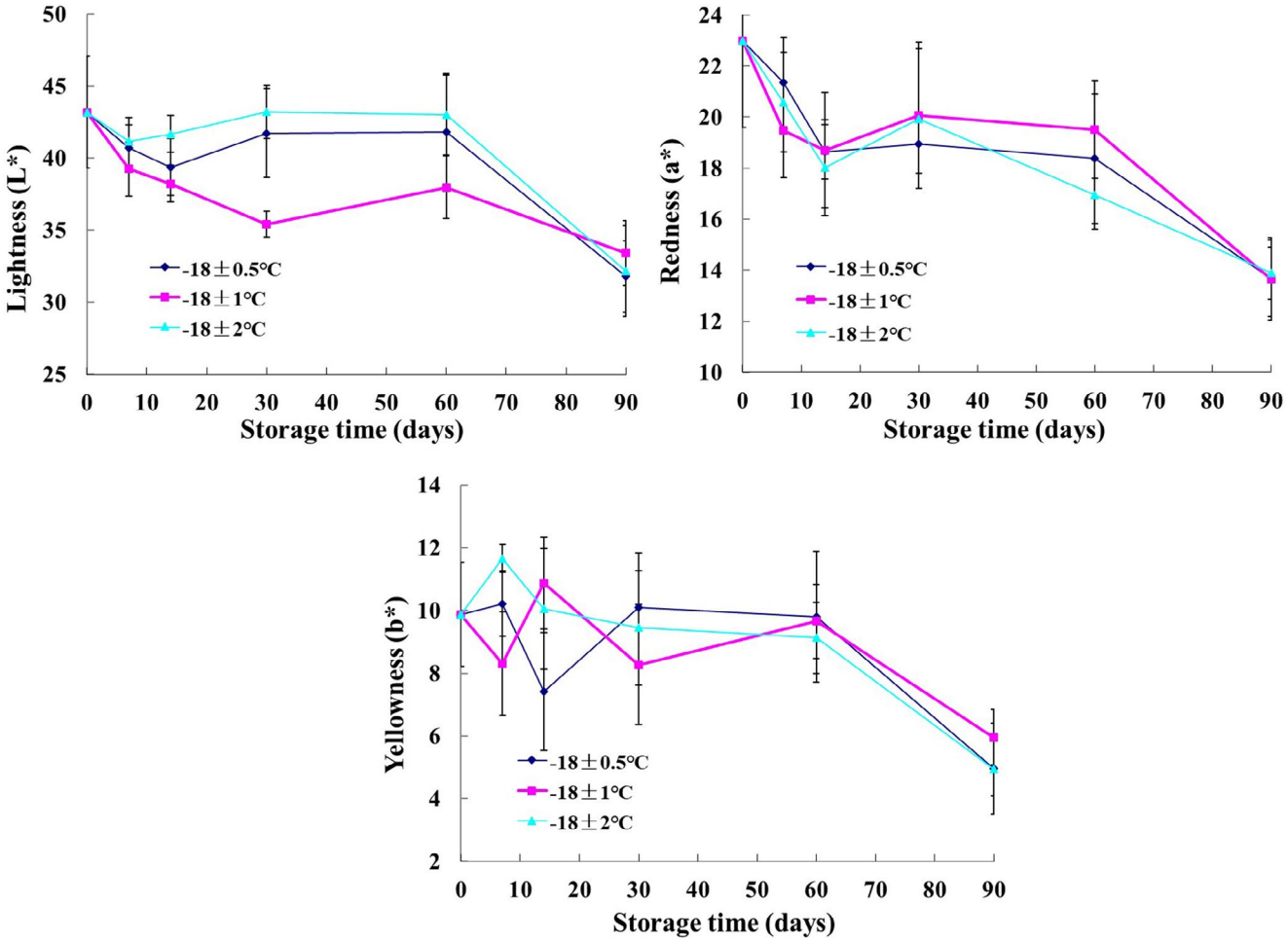

FIGURE 2 Change in meat color coordinates (CIE L^*, a^*, b^*) during storage at fluctuating temperatures. A smaller change of the L^*, a^*, b^* value or a smoother curve indicates a brighter color of the sample ($n = 3$)

temperatures. Moreover, Tang et al. (2014) confirmed that frequent temperature fluctuation accelerated the discoloration of tuna samples during freeze-thaw cycles of the cold chain. Opposite to the present study, Huang et al. (2006) found no significant correlation between fluctuating temperature and discoloration of frozen meat samples stored for 21 days, however, treatment group with more frequent fluctuation showed higher lightness value. This could be due to the impact of long-term frozen storage on sample color, as Kim et al. (2016) argued earlier that color degradation of beef muscles might be more affected by temperature fluctuation after 21 days of display.

3.3 | Muscle fiber diameters

The photos of the frozen beef slices during frozen storage, as shown in Figure 3, showed obvious decreases in all groups, while no differences were observed ($p > .05$) among them. By analyzing the data obtained from these photos (Figure 4), it can be noticed that muscle fiber diameters showed downward trends as storage duration prolonged. However, higher values of muscle fiber diameter were observed in the small temperature fluctuation group between Day 14 and 90. Improvements in medium and wide fluctuation group appeared to be rather similar, while the wide fluctuation group maintained the lowest value before Day 60. Tang et al. (2014) argued that temperature fluctuation could result in the expand of voids between muscle fibers. These voids could be filled with larger ice crystals in samples stored under fluctuating temperatures than those stored under constant temperatures (Flores & Goff, 1999), as the main reason for the decrease in muscle fiber diameter during frozen storage is the extrusion of muscle fibers caused by recrystallization. The results of the present study showed a possible effect of small temperature fluctuation on decelerating the decrease of diameters of muscle fibers during frozen storage. As a result, a better texture of frozen beef can be maintained with smaller temperature fluctuation.

3.4 | TVB-N values

During the storage duration, overall increasing trends were observed for all three groups (Figure 5), among which the smallest increase of total volatile basic nitrogen (TVB-N) was in the small fluctuation

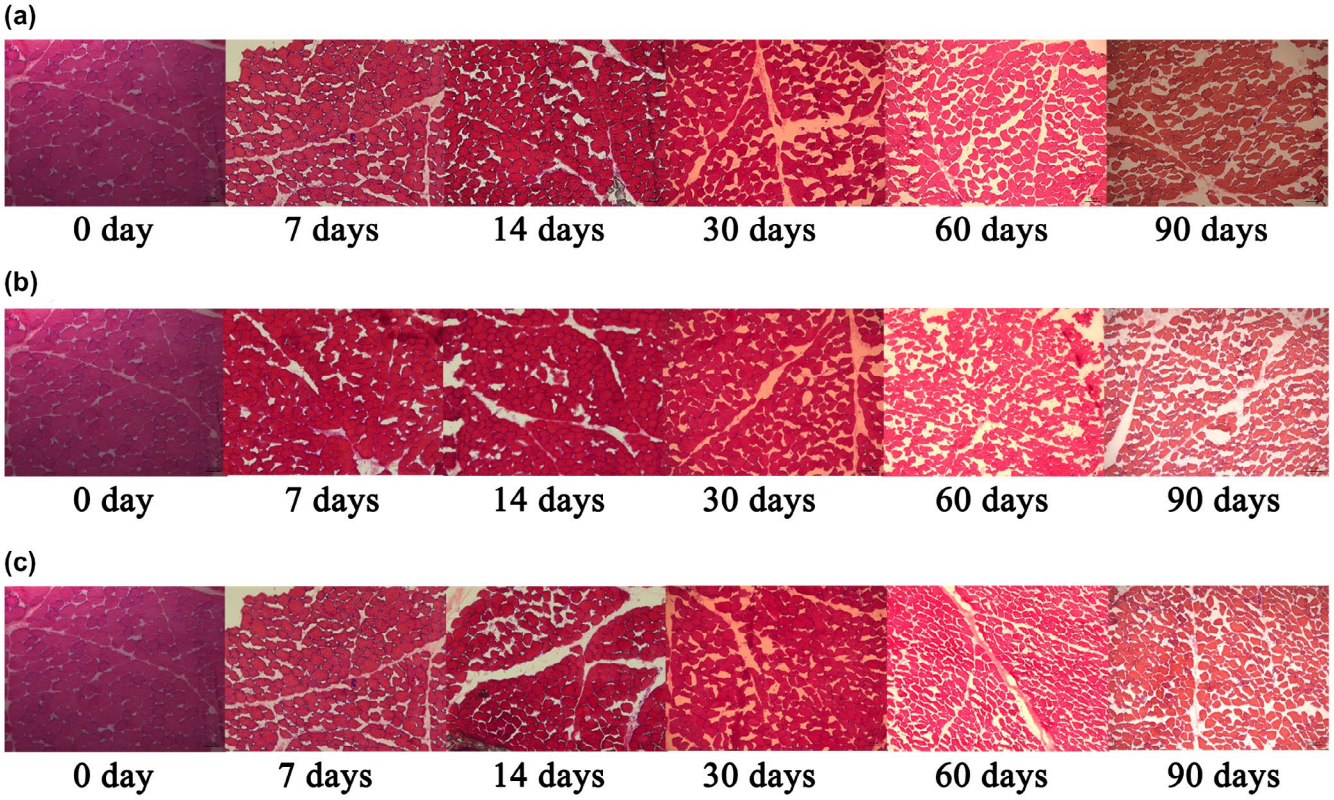

FIGURE 3 Photos of changes in the tissue structure of the packaged samples during the 90-day storage period. (a) Small range fluctuation (−18 ± 0.5°C). (b) Medium range fluctuation (−18 ± 1°C). (c) Wide range fluctuation (−18 ± 2°C) (n = 3)

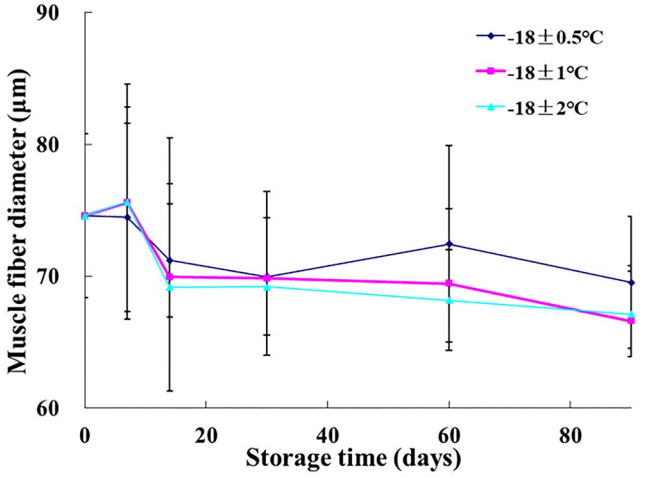

FIGURE 4 Change in muscle fiber diameter during storage at fluctuating temperatures. A smaller change in muscle fiber diameter indicates better maintenance of the taste of the sample (n = 3)

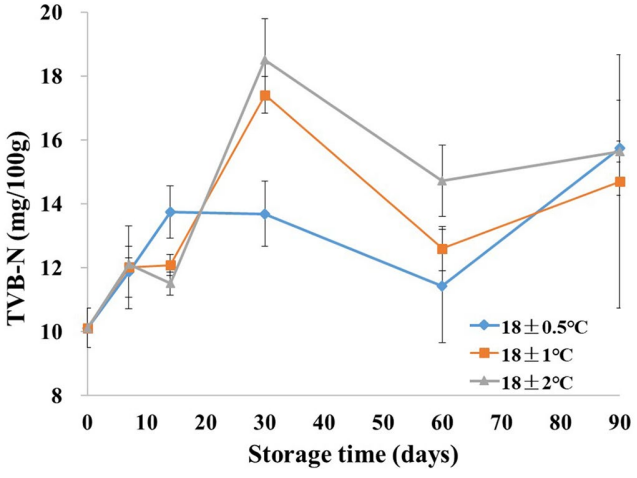

FIGURE 5 Change in the TVB-N values during storage at fluctuating temperatures (n = 3)

group. No differences ($p > .05$) were found among three treatment groups during the first 10 days, which were in accordance with the report of Zhang et al. (2012). From Day 30 to 60, the small fluctuation group showed lower values than groups with wider fluctuations ($p < .05$). Results of the present study are in consistent with the report of Huang et al. (2006) on frozen storage pork. Although there would be no bacterial growth during frozen storage at −18°C, the TVB-N, a general index to evaluate food spoilage, may increase for other factors, which led to the difference of three treatment groups. Olafsdottir et al. (2006) observed that temperature abuse made a difference between cod samples from the same batch by resulting in more rapid production of TVB-N. Literature also found that the TVB-N value of air-packaged broiler meat preserved under certain temperature fluctuation higher than those preserved under constant temperature (Zhang et al., 2012).

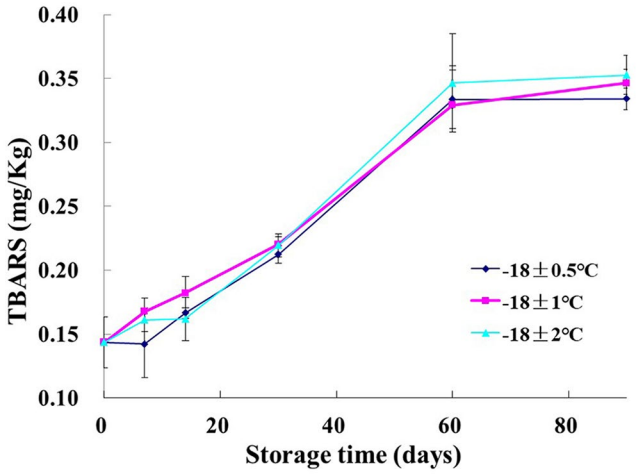

FIGURE 6 Change in the TBARS values during storage at fluctuating temperatures ($n = 3$)

3.5 | TBARS values

Continuous increases in TBARS values were observed during the storage period, while no differences ($p > .05$) emerged among groups (Figure 6). These results coincided with those obtained by Huang et al. (2006) in the study of frozen pork preserved under different ranges of temperature fluctuations. The small fluctuation group, however, maintained an extremely small degree of lipid oxidation up to 7 days. This could be explained by the partial isolation of the oxygen of the packed samples. As reported by Pettersen et al. (2004), excluding oxygen from packaged turkey samples prevents muscle lipids from the oxidative degradation during frozen storage. Another possible reason is that small temperature fluctuation could reduce lipid oxidation. A sharp increase of the lipid oxidation degree was recorded between Day 7 and 14 of storage in the small fluctuation group. This may be due to the fact that the fresh-keeping bag gradually failed to protect the samples after Day 7 and samples eventually became fully exposed to oxygen. The highest TBARS values among three treatment groups were found in the wide fluctuation group after Day 30.

4 | CONCLUSION

Overall, our data demonstrated that small temperature fluctuation had the best performances on color and thaw loss of frozen beef, and showed a relatively slower formation of TVB-N than other treatment groups. These findings suggest that smaller temperature fluctuation helps maintain beef quality during frozen storage. Therefore, this result could provide a theoretical basis to develop intelligent thermostat technology for frozen meat storage.

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CONFLICT OF INTEREST

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

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