Study on freezing rates and energy consumption of freezing processes of the golden pomfret

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INTRODUCTION

Golden pomfret is very easy to decay after death due to its active and perishable nature. It is beneficial to find out an effective and low cost method to extend the shelf life of golden pomfret. Freezing can reduce microbial and enzymatic activities, oxidation and respiration, which is a common preservation method. High freezing rates produces fine and uniform extra- and intra-cellular ice crystals and causes little damage for fish. Quick freezing rate can be achieved by different velocity of cold medium at different freezing temperature: high velocity of cold medium at high freezing temperature or low velocity of cold medium at low freezing temperature. In general, cryogenic freezing leads to better freezing quality. But it is unknown how much operating costs will be increased with lower freezing temperature. In this paper, the experiment of golden pomfret frozen in different freezing conditions was conducted. Different freezing conditions was analyzed based on the freezing time and freezing rate. Finally, energy consumption and economic cost were studied to obtain the best freezing parameters. This study has guiding significance for golden pomfret freezing, based on quality maintenance and low operation cost.

MATERIAL AND METHODS

Samples (golden pomfret) were frozen in a cryogenic freezer. As shown in Figure 1, the freezing temperature was set as -40℃ and -80℃ by controlling the amount of LN_2 into the cryogenic freezer. 4 thermocouple thermometers were inserted into the thermal centre of the muscle of abdominal and back to record the temperature profile, respectively.

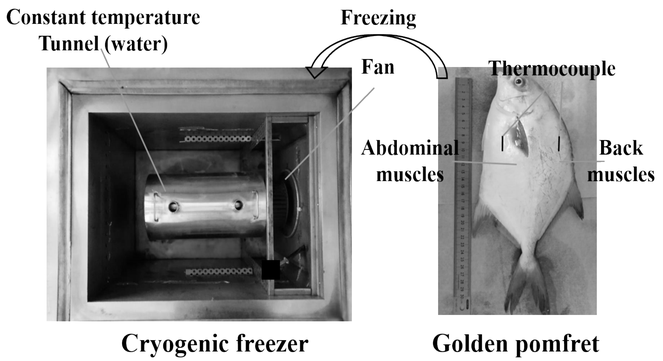

Figure 1 Experiment system (Left: the top view of cryogenic freezer with lid open; Right: golden pomfret)

t_{ch} is a characteristic time to pass through the largest ice crystal formation zone. Freezing time is determined by cooling time during which the center temperature drops from room temperature to -5℃ or -18℃. Freezing rate is the ratio between the minimum distance from the surface to the thermal center and the time elapsed for the surface reaching 0°C and the thermal center reaching -5°C (cm/h).

EXPERIMENTAL RESULTS

Experimental results show that it takes more freezing time for back muscle cooling than that of abdomen muscle. The back muscles are very thick and the meat content of back is very high. Therefore, it is difficult to cool down the back muscle, and this freezing process need in-depth study. The freezing curves of the back muscle is shown in Figure 2. (1) For the same freezing temperature, the higher the cold N_2 velocity flow, the shorter the cooling time is. (2) For the same cold N_2 velocity, the lower the freezing temperature is, the greater the freezing rate will be. Lowering the freezing temperature and increasing the cold N_2 flow velocity can increase the convective heat transfer coefficient to accelerate the freezing process.

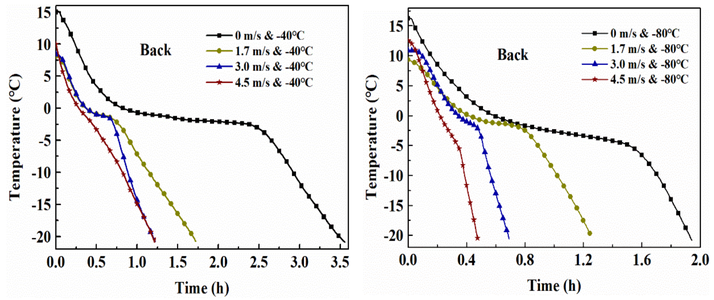

Figure 2. Temperature profile of back meat

Research of Bevilacqua (2010) showed that meat samples frozen with a characteristic freezing time (t_{ch}) less than 0.38 h will lead to the formation of intracellular ice crystals. The best freezing rates for meat frozen are more than 3.33 cm/h, which was proved by Grujic et al (1993). The following study focuses on the back muscles freezing (Table 1). The freezing rates are 3.67 cm/h, 4.18 cm/h and 6.35 cm/h for -40℃ at 4.5 m/s, -80℃ at 3.0 m/s and -80℃ at 4.5 m/s, respectively, which are more than 3.33cm/h. At the same time, their characteristic freezing time are 0.18 h, 0.06 h and 0.08 h, which are less than 0.38 h. The results show that the cold N_2 velocity should be more than 4.5 m/s when the freezing temperature is -40℃; while the cold N_2 velocity should be more than 3.0 m/s when the freezing temperature is -80℃. It can be seen that when the freezing of back muscles meet the requirements, the abdomen also achieve quick freezing for preservation. Therefore, this could get a better quality of frozen pomfret under freezing.

Table 1. Freezing time and freezing rate of the back muscle

Temperature (℃)	Velocity of cold N_2 (m/s)	Freezing time (h)			Freezing rate (cm/h)
		center to -5℃	center to -18℃	-1.71℃ ~ -5℃	
-40	0	2.65	3.36	1.10	0.81
-40	1.7	0.90	1.58	0.19	2.38
-40	3	0.77	1.12	0.10	2.78
-40	4.5	0.59	1.12	0.18	3.67
-80	0	1.51	1.88	0.71	1.42
-80	1.7	0.89	1.21	0.16	2.42
-80	3	0.52	0.66	0.06	4.18
-80	4.5	0.34	0.45	0.08	6.35

ENERGY AND COST ANALYSIS

The heat absorption required for golden pomfret freezing can be obtained by integrating the apparent specific heat with the coordinate axis (Figure 3). The heat absorption of pomfret is 241.77 kJ/kg for cooling from 30℃ to -18°C. LN_2 will release all latent heat and partial sensible heat after entering the cryogenic freezer (Table 2). The energy loss of the freezer is 13.34% with freezing temperature and exhaust gas temperature of -40℃. The energy loss of the freezer is 23.69% with freezing temperature and exhaust gas temperature of -80℃. The lower the freezing temperature is, the lower the exhaust gas temperature of the freezer will be, leading to a greater consumption of liquid nitrogen.

Table 2. Comparison of LN_2 consumption (0.6 kg golden pomfret)

Freezing temperature (℃)	-40	-80
LN_2 consumption (kg)	0.3992	0.4551
Cold energy consumption (kJ)	174.19	198.58
Exhaust gas temperature (℃)	-40	-80
Energy loss (%)	13.34	23.69

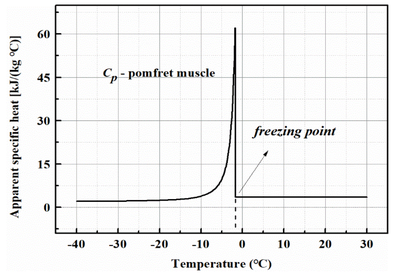

Figure 3. Apparent specific heat of back muscle of golden pomfret (fitted by empirical formulas)

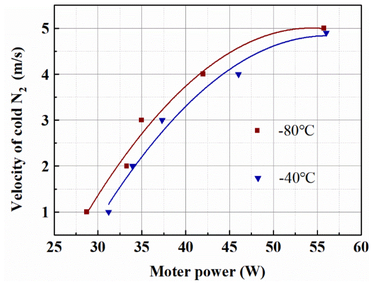

Figure 4. Cold N_2 velocity varies with motor power under different low temperature

Different fan motor powers result in different cold N_2 velocity. Cold N_2 velocity increases with the increase of the motor power of the fan (Figure 4). For the same motor power, there will be a higher cold N_2 velocity with -80℃ freezing than that of -40℃ freezing. Combined the moter power (Figure 4) with freezing time (Table 1), the electric consumption of different freezing conditions was obtained (Figure 5). There is a smallest freezing time for freezing to -18℃ with -80℃ at 4.5 m/s. Therefore, it takes the lowest electric energy with -80℃ at 4.5 m/s among the feasible freezing conditions, while the highest electric energy was -40℃ at 4.5 m/s. The operating cost of the freezer mainly includes consumption of LN_2 and electric energy. 10 million golden pomfret were assumed to be frozen per year in China. It can be seen that there is the lower operation cost for -40℃ at 4.5 m/s (Figure 6). However, the operation cost of -80℃ at 4.5 m/s is only 1.045 times that of -40℃ at 4.5 m/s. Above all, there is no obvious difference among -40℃ at 4.5 m/s, -80℃ at 3.0 m/s and -80℃ at 4.5 m/s.

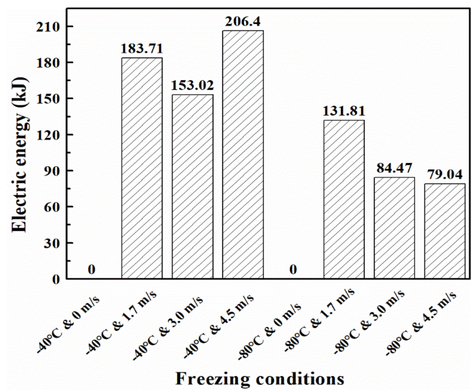

Figure 5. Electric energy consumption by the fan under different freezing conditons

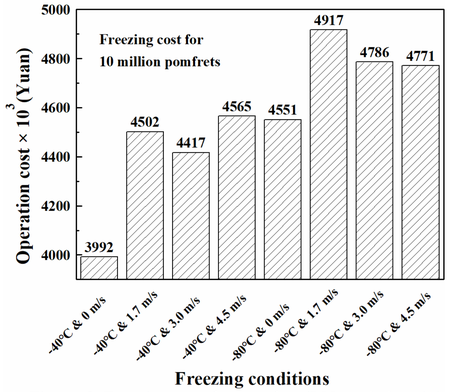

Figure 6. Freezing cost for pomfret (LN_2 and electricity consumption) under different freezing conditons (Yuan, RMB)

CONCLUSION

Lower temperature freezing can improve the quality of frozen golden pomfret. Based on experiment, the freezing time and freezing rate show the better freezing parameters are -40℃ at 4.5 m/s, -80℃ at 3.0 m/s and -80℃ at 4.5 m/s. The energy and economy analysis show that there is no obvious difference among the3 freezing conditons. Therefore, the best freezing condition for golden pomfret with low cryogenic temperature was -80℃ at 4.5 m/s, which contribute to the best frozen quality and a lower operation cost.