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Research Paper

Construction of shelf-life model for sealed package live scallop (*Argopecten irradias*) based on quality index

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ABSTRACT

The *Argopecten irradias* were treated by sealed package in the forms of vacuum, oxygen and air at 0, 5, 10 and 15°C, respectively. The results showed that the sealed packaging with oxygen was more conducive to maintaining the quality of live bivalve. The Sensory quality, survival rate and glycogen of live scallop deteriorated, and the total bacterial count increased over time, which caused the reaction rate of the total bacterial count and glycogen to be accelerated with the increase of storage temperature. The kinetics model based on Arrhenius equation could be applied to describe the shelf-life model of total bacterial count and glycogen with high accuracy for the sealed package live scallop (*Argopecten irradias*) with oxygen packaging and air packaging.

Key words: Live *Argopecten irradias*, packing condition, quality, shelf life, model.

INTRODUCTION

Marine bivalve is considered as delicate and healthy foodstuff in a number of dietary regimes (Anacleto et al., 2014). Marine bivalve is capable to survive for extended periods out of water and those intended for human consumption are traded as live animals. Though the increased production has improved the supply of this live product to the global market, the distribution and sale of live bivalve remain a complex issue (Barrento et al., 2013). The survival rate of bivalve without water tends to be affected by both intrinsic and extrinsic factors such as the physiological characteristics of bivalve, oxygen-free packaging, temperature and humidity, all of which are significant factors to consider for the storage and transport of live shellfish. At present, live scallop (*Argopecten irradias*) is usually packed by polyethylene box or string bag without water during transit for both the local market and abroad market within a short time period of 48 h. When transported and sold, live bivalve needs to be stored under suitable living conditions to extend its survival time. Across the supply chain, with no use of unitized seal-package, it is unavoidable for live scallop (*A. irradias*) to interact with the environment until delivery to the consumers. Hermetic packages with modified atmosphere provide an effective alternative to extending the survival time of these mollusks for sale (Pastoriza et al., 2004). The storage in hermetic packages ensures that live bivalve molluscs could preserve its freshness when delivered to the consumer. The storage in hermetic packages provides a particularly effective way to improve survival rate under favorable conditions. However, the survival rate and quality continue to decline over time, and typically, temperature and hermetic packages can affect quality and shelf life. The information on systematic modeling of the temperature dependence and validation under variable conditions relevant to the practical cold chain conditions would be significant to extending shelf life and improving cold chain management (Nielsen and Jorqensen, 2004; Tsironi et al., 2009). Shelf life is defined as the time during which a food item remains safe to consume, retains desired sensory, chemical, physical and microbiological characteristics and complies with any label declaration of nutritional data when stored under the recommended conditions (IFST, 1993). This detail also indicates whether the food remains of an acceptable quality to the consumer. Therefore, all the aforementioned parameters need to be taken into consideration when assessing the shelf life of a food item (Hough and Garitta, 2012). Therefore, this study was conducted to determine the functional relationship

Table 1: Standard score scale for sensory evaluation.

	1point	2 point	3 point	4 point	5 point
Colour and lustre	opaque and primrose yellow	Slightly opaque and to primrose yellow	Slightly opaque and to creamy white	Translucent and pale white	Translucent and creamy
Oder	Very unpleasant	Ammonia	Slightly to ammonia	Neutral	Characteristic sweet fresh
Flavor	Sickening	Sour	Slightly sour	Strong to mussel	Characteristic mild
Texture	Sort	Slightly soft	Slight firm	firm	Very firm

between the effects of temperature and quality change of live scallop (*Argopecten irradias*) at different package, which is beneficial to construct a shelf life model.

MATERIALS AND METHODS

Raw materials

Live scallops (*Argopecten irradias*) weighing 55.5±3.5 g and measuring 50±5 mm (length) from mussel farms in Changhai (Dalian, China) were collected in May 2019. They were immediately transported to the laboratory in a string bag without water. Then they were put into the depuration and temporary keeping at 7-15°C for 24 h after roughly selected, cleaned and sorted.

After this depuration and temporary keeping period, the batches including five live scallops (*Argopecten irradias*) were packed by high density polyethylene (HDPE, length: 32 cm, width: 25 cm) with three different atmospheres vacuum, air and 100% oxygen in temperature controlled cabinets set at 0, 5, 10 and 15°C.

The survival rate

The survival recognition was performed by observing the closing of shell valves while stimulating the soft tissue with a stick (Paukstis et al., 1997). If the shell valve of scallop had been closed in 30 s, the individual was deemed alive:

$$\text{The survival rate} = \frac{\text{The survival number}}{\text{sample number}}$$

Sensory analysis

Seven panels were trained to evaluate the sensory properties of fresh and cooked comprehensive impacts of the opened package. The fresh adductor mussels were assessed on texture, odor, flavor, and the outer mucus were assessed on the basis of color and luster. Then the cooked adductor muscles were assessed on flavor, odor with a scale from 1 to 5. Mussels were steam-cooked at 373 K for 4-6 min and they were cooled to approximately 308 K before serving the mussels on a half shell to trained panelist. Scoring was conducted as shown in Table 1 (Pastoriza et al., 2004; Marta and Pastoriza, 2011; Yi et al., 2013).

Total viable counts

Microbial analysis is adopted to detect viable natural microorganisms in scallop meat. The aerobic plate count (abbreviated as APC) was detected, followed by the description of Gram et al. (1987). Three groups of 4 g samples were continuously diluted with sterile 0.85% NaCl solution, and 1.0 ml of each dilution was plated into duplicate plates of appropriate agar. Plate count agar (Beijing Land Bridging Technology Co. Ltd. Beijing, China) was applied for counting aerobic plate count (APC) cells after incubation at 310 K for 48 h.

Glycogen level analysis

Glycogen levels were analyzed using a commercial glycogen analysis kit (Shanghai Zhen Biotechnplogy Co,Ltd, Shanghai, China). Briefly, the soft tissue was overall homogenized and placed in a boiling bath with 1 ml alkaline solution for 20 min. An additional boiling bath for 5 min was performed after the chromogenic reagent of kit was added. Glycogen concentration was calculated by the absorbance at 620 nm of samples abiding by an equivalent glucose standard.

Data collect and analysis

A total of 300 scallops were averagely stocked into 60 sealed packages of each group for diffident gas and temperature in order to avoid unpacked samples in survival time. Thus three repeated treatments of each trial

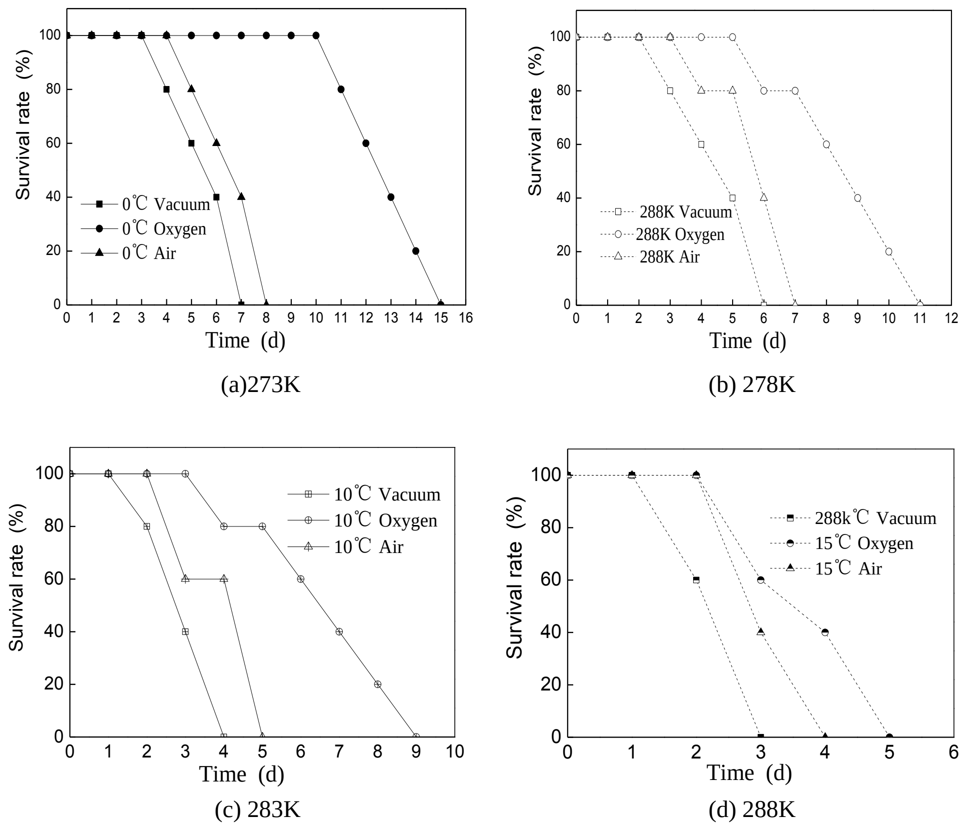

Figure 1: Survival rate of *Argopecten irradias* in different packaging at different temperature.

group were measured in every 24 h . The liner regressions and ANOVA of different temperature and time were performed using Orgin Pro 8.5.

The model of shelf -life

Generally, reaction rates for quality degradation (*N*) of sea food under isothermal conditions can be presented as shown in the following kinetic models (Van Boekel, 2008; Sofra et al., 2018). Quality data were analyzed using zero– and first–order kinetic model:

$$N = N_0 - k \cdot t \quad (1)$$

$$N = N_0 e^{k \cdot t} \quad (2)$$

where N_0 is the initial value of the quality at time zero, *N* is the value at time *t* and *k* is the rate constant. Arrhenius equation was applied to determine the degradation rate constant (*k*) on temperature which is described as follows:

$$k = k_0 \exp(-\frac{E_a}{RT}) \quad (3)$$

Where *k* is the rate of the change of the respective quality index at a reference temperature, k_0 is the frequency factor, *T* is the temperature in *K*, E_a is the activation energy of the studied action, that indicates the temperature dependence of the selected mode of degradation and *R* is the universal gas constant (8.314 J/mol/k). The activation energy (E_a) values were estimated from the slope of Arrhenius plots of ln (*k*) vs (*1/T*), by linear regression (Van Boekel, 2008; Sofra et al., 2018).

RESULTS AND DISCUSSION

Survival rate

The survival rate was in decline with the extension of storage time. As shown by statistical data (Figure 1), the percentage mortality varied from one batch to another when packaging was performed with different methods and at different temperatures. The live scallop stored in vacuum-package at 273, 278, 283 and 288 K, respectively firstly died on the 4d, 3d, 2d, 2d and completely died on 7d, 6d, 4d, 3d. The live scallop stored in oxygen-package at 273, 278, 283 and 288 K, respectively firstly died on 11d, 6d, 4d, 3d and completely died on the 15d, 11d, 9d, 5d. The live scallop stored in air package at 273, 278, 283, 288 K,

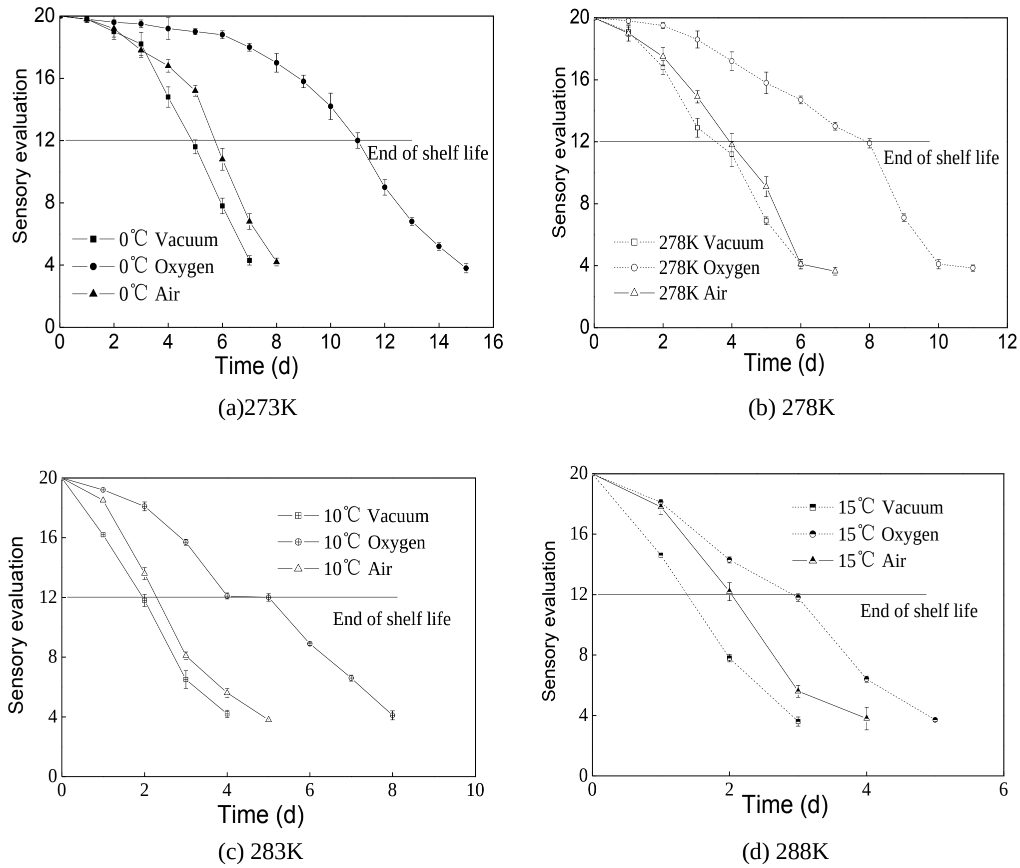

Figure 2: Sensory evaluation of *Argopecten irradiasin* different packaging at different temperature.

respectively firstly died on 5d, 4d, 3d, 3d and completely died on 8d, 7d, 5d, 4d. It was demonstrated that the low temperatures of 273 and 278 K were more conducive to the survival of scallop, as evidenced by the low and consistent mortality (Pastoriza et al., 2004; Marta et al., 2011; Ekanem and Achinewhu, 2006). Pastoriza et al. (2004) also demonstrated that a package filled with an O_2-rich atmosphere promoted the survival of mussels. It was indicated that the oxygen-package at 273 K was more favorable for the survival of calm, with zero mortality maintained for approximately 11 days.

Sensory analysis

As shown in Figure 2, the sensory quality deteriorated significantly as the storage time was extended. The sensory quality of oxygen-package scored close to 20 points before 5 d at 273 K, despite a decline to 12 points after 11 d. At 278 K, however, oxygen-package failed to score 20 points after 4 d. The sensory quality of vacuum-package at 273 K was reduced noticeably after 3 d. The sensory quality of air and vacuum-package rendered the meatinedible after 4 d at 278 K. The slight odor of vacuum-package was found after 1d and the meat was rendered inedible in 2d, which bears similarity to the air-package in 3d, except that the color was deeper than vacuum-package. The peculiar smell of air and vacuum packaging at 288 K was discovered after 1 day. With a sensory evaluation conducted by the training team, a better understanding could be obtained regarding the effects of vacuum, air and oxygen on the quality of live shellfish under different temperature conditions. The sensory quality at 283 and 288 K was in decline at a faster pace and the time during which the meat remained edible (shelf life) was shorter than at 273 and 278 K. The sensory evaluation showed the direct consumption situation of live shell, which can be taken as the significant criteria of shelf life for various food items, such as iced and fresh frozen fish (Özyurt et al., 2014; Wu et al., 2016), mussel (Xing et al.2013; Lilongfei et al., 2014) and so on (Zhu et al., 2018; Zhou et al., 2017). The sensory evaluation was also conducted on ultimate quality throughout the shelflife (Ding et al., 2015; Grete et al., 2016). The shelf life of scallop in sealed packaging was determined with 12 points in sensory evaluation as the end-of-shelf index. According to the above evaluation method, the shelf life for oxygen package was 10d, 7d, 5d and 2d, respectively at 273, 278, 283 and 288 K. The shelf life for vacuum package was 4 d, 3d, 1d and 1d, respectively at 273, 278, 283 and 288 K. The shelf life for air package was 5d, 4d, 2d and 2d, respectively

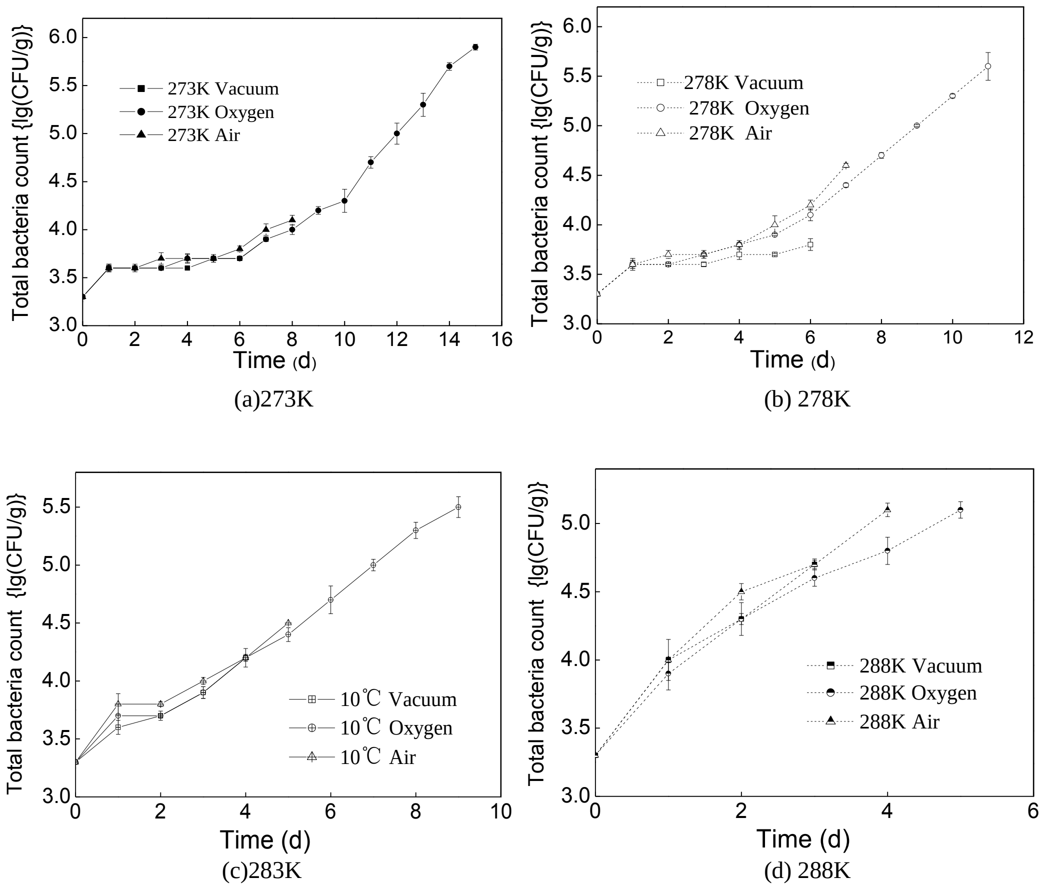

Figure 3: Total bacterial count of *Ruditapes philippinarum* in different packaging at different temperature.

at 273, 278, 283 and 288 K.

The total viable count

The total viable count of all groups exhibited an increasing trend with the extension of storage time as shown in Figure 3. Besides, the total number showed a significant variation with the temperature and the gas in packaging. The total number of colonies at low temperatures (273 and 278 K) was considerably higher than at high temperatures (283 and 288 K), suggesting that bacterial colony is favored by higher temperatures and the decomposition products of dead mussels in each package (Marta and Pastoriza, 2011). Meanwhile, the viable count of air package was measured to be higher than the vacuum and oxygen package of the stored scallop. The approach to packaging had impact on the total number of colonies as well, as the total number of colonies in the air packaging was shown to increase at a faster pace when compared with the other two groups at the identical temperature. The cause of such a phenomenon is that, in case of air package, both anaerobic and aerobic colonies were grown simultaneously, thus leading to a faster-paced rise in the numbers of colonies. The growth rate of colony in vacuum packaging was observed to be slightly slower than in oxygen-filled packaging, which is attributed to the majority of colonies being aerobic colonies under oxygen condition (Ruiz and Moral, 2004; Hélène et al., 2012; Turan et al., 2013).

Glycogen

The content of glycogen decreased with different temperatures in three types of package, as shown in Figure 4. The pace of decline in glycogen was found to be slower in the vacuum than in air and oxygen package. Meanwhile, the glycogen of clam in vacuum groups at the time of death reached 6.41 mg/g (day 7), 6.67 mg/g (day 6), 6.94 mg/g (day 4) and 6.06 mg/g (day 3) respectively for 273, 278, 283 and 288 K. Glycogen plays a relatively significant role in energy storage (Du and Mai, 2004), and the level of glycogen decreased due to stressors throughout the longest starvation (Riley, 1976), as a result of which glycogen is the only source of energy for live scallop to sustain life activities at the time of starvation. The lowest level of glycogen consumption in the vacuum packaging

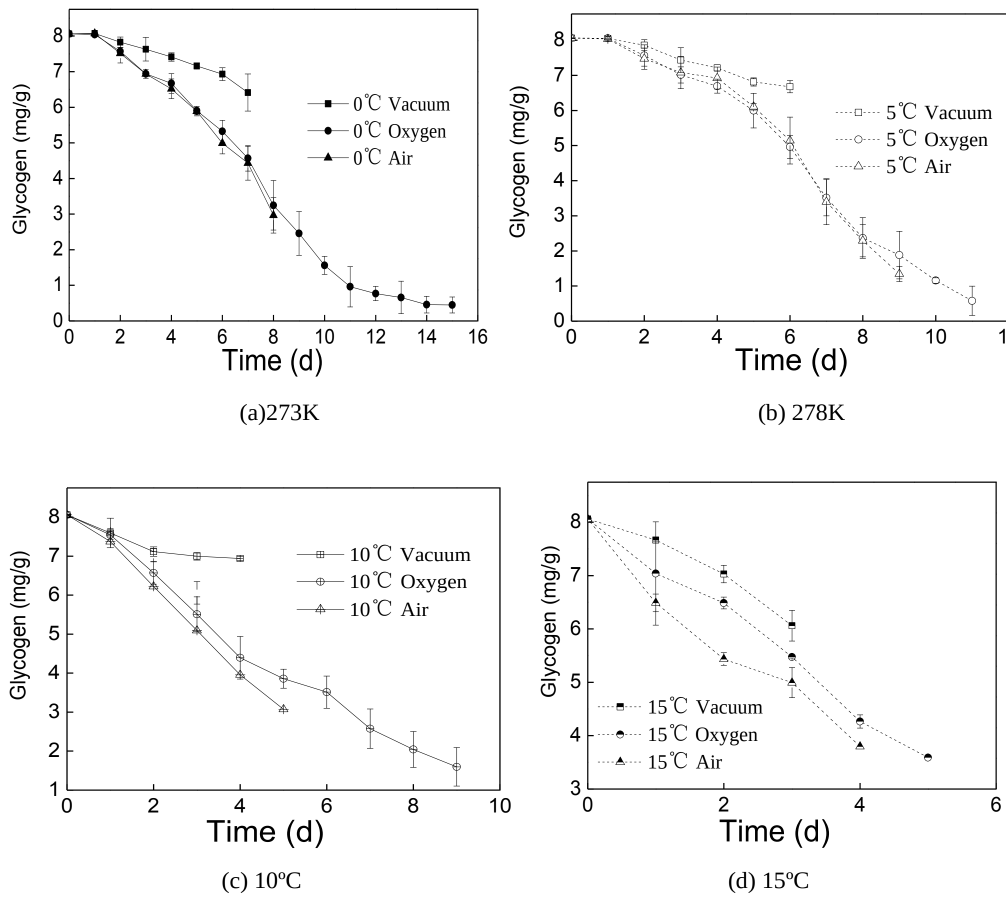

Figure 4: The changes of glycogen content of *Argopecten irradias* in different packaging at different temperature.

Table 2: Regression equation, activation energy (E_a) and prefactor (k_0) of quality index.

Quality Index	Package	Regression	R^2	k_0	E_a
Total number of colonies	Oxygen	y=-4109.9x +11.715	0.973	1.22×10^5	34171.35
	Air	y=-8824x+29.753	0.977	8.35×10^{12}	73366.27
Glycogen	Oxygen	y=-1811.1x+6.4299	0.933	6.20×10^2	15058.21
	vacuum	y=-5463.5x+18.43	0.901	1.01×10^8	45425.724
	air	y=-2734.3x+9.631	0.931	1.52×10^4	22734.064

can be attributed to the inability of scallop to breathe as normal as a result of the lack of oxygen in the vacuum package, which is a leading cause of glycogen consumption (Liu et al., 2017).

Establishment of shelf-life prediction model for live scallop

According to Equations 1 and 2, the reaction rate constant *k* was obtained, the logarithm fits the corresponding *1/T* linearly, the obtained *Ea* and k_0 are shown in Table 2.

Combining the Zero-order and First-order kinetic model with the Arrhenius equation (Equation 3), the storage time assessment model with the variables of temperature *T* and quality factor should be obtained, as shown in Equations 4 and 5.

Zero-order shelf-life model:

$$SL_0 = \frac{|N - N_0|}{k_o \times \exp\left(-\frac{Ea}{T \times R}\right)} \qquad (4)$$

Table 3: Kinetics equations and shelf life prediction models of live scallop (*Argopecten irradias*).

Quality Index	Package method		
	Oxygen	Vacuum	Air
Total number of colonies	$SL_{12}=\dfrac{\lvert InN-InN_0\rvert}{1.22\times10^5\times exp\left(-\dfrac{34171.35}{T\times R}\right)}$	/	$SL_{32}=\dfrac{\lvert N-N_0\rvert}{8.35\times10^{12}\times exp\left(-\dfrac{73366.27}{T\times R}\right)}$
Glycogen	$SL_{13}=\dfrac{\lvert N-N_0\rvert}{620.12\times exp\left(-\dfrac{15058.21}{T\times R}\right)}$	$SL_{23}=\dfrac{\lvert N-N_0\rvert}{1.01\times10^8\times exp\left(-\dfrac{45425.724}{T\times R}\right)}$	$SL_{33}=\dfrac{\lvert InN-InN_0\rvert}{1.52\times10^4\times exp\left(-\dfrac{22734.064}{T\times R}\right)}$

Table 4: Endpoint value of quality indexes for shelf-life of quality index.

Quality index	Oxygen	Vacuum	Air
Total number of colonies	4.50	/	3.70
Glycogen	1.26, 3.51, 3.86, 5.47	7.53	6.90

Table 5: Predicted and measured shelf-lives of live scallop (*Argopecten irradias*).

Package	Quality Index	Temperature/K	Shelf life measured value /d	Shelf life prediction value/d	Relative error%
Oxygen	Total viable coun	273	10	8.75	12.51
		278	7	6.67	4.67
		283	5	5.14	2.79
	Glycogen	273	10	10.82	8.25
		278	7	6.42	8.26
		283	5	5.29	5.84
Air	Total viable coun	273	5	5.52	10.38
		278	4	3.20	19.88
		283	2	1.90	5.14
	Glycogen	273	5	5.67	13.39
		278	4	3.96	1.11

First- order shelf-life mode:

$$SL_1=\frac{\lvert\ln N-\ln N_0\rvert}{k_o\times\exp\left(-\dfrac{Ea}{T\times R}\right)} \quad (5)$$

The shelf life was primarily affected by factors such as storage temperature, initial freshness quality value and terminal freshness quality value under the circumstance of different packing methods. Based on the prediction model of shelf life, the storage time under a specific storage temperature can be obtained, that is, shelf life. In addition, according to the storage temperature, initial freshness quality value and storage time, the freshness quality index under certain storage temperature and time can be obtained as well. Substituting the resulting k_0 and *Ea* into the formula (4) and (5), a shelf life prediction model is constructed, as shown in Table 3. Based on sensory evaluation, 12 points was identified as the minimum value of acceptable quality, which could determine the shelf life. Based on sensory evaluation, the total numbers of colonies were correlatively analyzed. The value of different temperatures in the same package was approximate at the end of shelf life, for which the average of the total number of colonies in the same package can be applied to determine the end quality index value of shelf life. The content of glycogen in the oxygen package at varying temperatures was distinctive due to the difference in survival time. Besides, a linear relationship was discovered with the temperature change, and the linear equation was obtained as follows: *y=1.2988(T-273) +0.279* (R^2 = 0.94，*T*: 273 K～278K). Meanwhile, the linear equation was substituted into formula 4 or 5 to serve as the dynamic end point shelf life predicted by the glycogen characteristic index (Xie et al., 2013). Table 4 shows the shelf-life end values of the quality indexes of live products such as scallop in different packages.

The shelf life calculated by applying the equations (shown in Table 5) was compared with that of sensory evaluation with an error of less than 20%, which evidenced the effectiveness of the predicted shelf-life model. The total number of bacteria, pH and glycogen can be applied to the prediction made of shelf life for oxygen and vacuum package. However, only the total number of bacteria and glycogen can be applied to the prediction of shelf life for air packaging. The prediction model of shelf life is shown in Table 5.

Conclusion

This research is aimed at figuring out the effects of varying temperatures and gas conditions on the quality of sealed package live scallop (*A. irradias*) and constructing the reaction kinetics model of total bacterial count and glycogen.

The *A. irradias* were subjected to treatment by sealed package in the forms of vacuum, oxygen and air at 273, 278, 283 and 288 K, respectively. The results showed that sealed packaging with oxygen was more conducive to maintaining the quality of live scallop. The sensory quality, survival rate and glycogen of live scallop decreased, while the total bacterial count was on the increase in store and transportation, as a result of which the reaction rate of the total bacterial count and glycogen were improved with the increase of storage temperature.

The kinetics model could be applied to describe the total bacterial count and glycogen with a high accuracy of the sealed package live scallop (*A. irradias*) with oxygen packaging and air packaging. Meanwhile, the relative error between the forecast values and measure values was less than 20%. The dynamic models established in this study were validated as effective in making prediction of the shelf life of live bivalve.

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REFERENCES

Anacleto P, Maulvault AL, Bandarra NM, Repolho T, Nunes ML (2014). Effect of warming on protein, glycogen and fatty acid content of native and invasive clams. Food Research International. 64(64): 439–445.https://doi.org/10.1016/j.foodres.2014.07.023

Barrento S, Lupatsch I, Keay A (2013). Metabolic rate of blue mussels (Mytilus edulis) under varying post-harvest holding conditions. Aquatic Living Resour. 26: 241–247. https://doi.org/10.1051/alr/2013050

Cyprian O, Lauzon HL, J´ohannsson R (2013). Shelf life of air and modified atmosphere-packaged fresh tilapia (Oreochromis niloticus) fillets stored under chilled and superchilled conditions. Food Sciences& Nutrition. 1(2): 130–40. https://doi.org/10.1002/fsn3.18

Ding T, Li Tingting, Li Jianrong, et al (2015). Applicability Analysis of Microbial Growth Dynamics Models and Establishment of Shelf-life Model for Salmon Slices duing the Cold Storage[J]. J. Chinese Institute of Food Sci. Tech. 15(5): 63-73. https://doi.org/10.16429/j.1009-7848.2015.05.009

Du SB, Mai KS (2004). Effects of starvation on energy reserves in young juveniles of abalone Haliotis discus hannai Ino. J. Shellfish Res. 23: 1037–1039. https://www.highbeam.com/doc/1G1-132270256.html

Ekanem EO, Achinewhu SC (2006). Mortality and quality indices of live West African hard-shell clams (Galatea paradoxa Born) during wet and dry postharvest storage. J. Food Proc. Preserv. 30(3): 247-257. https://doi.org/10.1111/j.1745-4549.2006.00052.x

Gram L, Trolle G, Huss HH (1987). Detection of specific spoilage bacteria from fish stored at low (0 °C) and high (20 °C) temperatures. Int. J. Food Microb. 4(1): 65–72. https://doi.org/10.1016/0168-1605(87)90060-2

Grete L, Bjorn TR, Stein HO, et al (2016). Shelf life of snow crab clusters (Chionoecetes opilio) stored at 0 ºC and 4 ºC [J]. Food Control. 59: 454-460. https://doi.org/10.1016/j.foodcont.2015.06.019

Hough G, Garitta, L (2012). Methodology for sensory shelf-life estimation: A review. J. Sensory Stud. 27(3): 137-147. https://doi.org/10.1111/j.1745-459x.2012.00383.x

http://bhl-china.org/bhldatas/pdfs/p/proceedingsofnat65nati.pdf

IFST (1993). Shelf life of foods-guidelines for its determination and prediction. London, U.K: Institute of Food Science & Technology.

L.Lauzon H，Margeirsson Bj rn，Arason S，et al (2012). Conservation of fresh golden redfish (Sebastes marinus) fillets:influence of bleeding，modified atmosphere packaging usingdifferent gas mixtures and superchilling on quality deterioration[J]. 26(2): 185-191. http://www.unuftp.is/static/fellows/document/alisa12prf.pdf

Lilongfei, Qinxiaoming, Zhoucuiping, et al (2014). Analysis of quality changes and shelf-life of low temperature distribution oyster meat[J]. fishery modernization, 41(5): 39-43. https://doi.org/10.3969/j.issn.1007-9580.2014.05.009

Liu H, Liu J, Tian Y et al. (2017). Comparison of Manila Clam Ruditapes philippinarum between Air Exposured Storage and Wet Storage[J]. fisheries science. 36(3): 267-273. https://doi.org/10.16378/j.cnki.1003-1111.2017.03.003

Marta B, Pastoriza L (2011). Quality of live packaged mussels during storage as a function of size and oxygen concentration[J]. Food Control. 22(2): 256-265. https://doi.org/10.1016/j.foodcont.2010.07.007

Nielsen MK, Jorqensen BM (2004). Quantitative relationship between trimethylamineoxide aldolase activity and formaldehyde accumulation in white muscle from gadiform fish during frozen storage. J. Agric. Food Chem. 52(12): 3814–3822. https://doi.org/10.1021/jf035169l

Özyurt G, Kuley E, Özkütük S, Özogul F Özyurt, Gülsün, Kuley E , Özkütük, Serhat, et al (2014). Sensory, microbiological and chemical assessment of the freshness of red mullet (Mullus barbatus) and goldband goatfish (Upeneus moluccensis) during storage in ice[J]. Food Chemistry. 114(4): 505-10. https://doi.org/10.1016/j.foodchem.2008.09.078

Pastoriza L, Bernárdez M, Sampedro G, Cabo ML, Herrera JJR (2004). Elevated concentrations of oxygen on the stability of live mussel stored refrigerated. European Food Research and Technology. 218: 415-419.https://doi.org/10.1007/s00217-004-0873-x

Paukstis GL, Janzen FJ, Tucker JK (1997). Comparative survivorship of sympatric native North American Gastropods (Anguispira, Mesodon, Physella, Pleurocera) and an introduced bivalve (Dreissena) exposed to freezing temperatures. Veliger. 40(1): 67–70. https://lib.dr.iastate.edu/zool_pubs/7

Riley RT (1976). Changes in the total protein, lipid, carbohydrate, and extracellular body fluid free amino acids of the Pacific oyster Crassostrea gigas, during starvation. Proceedings of the National Shellfish Association. 65: 84–90.

Ruiz C，Moral A (2004). Free amino acids in muscle of Norway lobster(Nepropsnovergicus) in Controlled and modified atmosphereduring chilled storage [J]. Food Chemistry. 86 (1): 85—91.

https://doi.org/10.1016/j.foodchem.2003.08.019
Shamshad SI, Kher UN, Riaz M, Zuberi R, Qadri RB (1990). Shelf life of shrimp (Penaeus merguiensis) stored at different temperatures [J]. Food Science. 55: 1201-1205. https://doi.org/10.1111/j.1365-2621.1990.tb03898.x
Sofra C, Tsironi T, Taoukis PS (2018). Modeling the effect of pre-treatment with nisin enriched osmotic solution on the shelf life of chilled vacuum packed tuna. J. Food Eng. 216: 125–131.https://doi.org/10.1016/j.jfoodeng.2017.08.014
Tsironi T, Dermesonlouoglou E, Giannakourou M , et al (2009). Shelf life modelling of frozen shrimp at variable temperature conditions[J]. LWT - Food Science and Technology. 42(2): 664-671. https://doi.org/10.1016/j.lwt.2008.07.010
Turan H，Kocatepe D (2013). Different MAP conditions to improvethe shelf life of sea bass[J]. Food Science and Biotechnology. 27 (2): 195-200. https://doi.org/10.1007/s10068-013-0255-x
Van Boekel MA (2008). Kinetic modeling of food quality: A critical review. Comprehensive Reviews in Food Science and Food Safety. 7(1), 144–158. https://doi.org/10.1111/j.1541-4337.2007.00036.x
Wu X, Xie J, Wang X (2016). Establishment and Evaluation of the Shelf-life Prediction Model for Small Yellow Croaker under Different Store Temperatures [J]. Packing Engineering. 30(19): 84-90.https://doi.org/10.19554/j.cnki.1001-3563.2016.19.017
Xie J, Zhang L, Su H, et al (2013). Quality kinetic model and shelf life prediction of green vegetable (Brassica rapa var. chinensis) [J]. Transactions of the Chinese Society of Agricultural Engineering. 29(15): 271-278. https://doi.org/10.3969/j.issn.1002-6819.2013.15.033
Xing S, Zhang X, Ma C, et al. (2013). Microbial Growth Kinetics Model of Tilapia under Variable Temperatures[J]. 44(7): 194-198.https://doi.org/10.6041/j.issn.1000-1298.2013.07.034
Yi J, Xu Q, Hu X, Dong P, Liao X, Zhang Y (2013). Shucking of bay scallop (argopecten irradians) using high hydrostatic pressure and its effect on microbiological and physical quality of adductor muscle. Innovative Food Science & Emerging Technologies. 18(2): 57-64. https://doi.org/10.1016/j.ifset.2013.02.010
Zhou G, Cui Y, Yang W, et al (2017). Impact of Controlled Freezing-point Storage on the Portunustrituberculatus Quality and Model Construction of Its Shelf-life [J]. J. Nuclear Agric. Sci. 31(4):719-727. https://doi.org/10.11869/j.issn.100-8551.2017.04.0719
Zhu Y, Ji H, Liu S, et al (2018). Selection for Packing Condition andPrediction for Shelf Life of Vacuum Fried Crispy Shrimps[J]. J. Guangdong Ocean Univ. 38(4): 35-42.https://doi.org/10.3969/j.issn.1673-9159.2018.04.005