



Microbial shelf-life estimation of frozen crispy chicken curry puff under accelerated storage conditions

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ABSTRACT

Aims: Shelf-life estimation, determination and validation of frozen food are essential in hazard analysis and critical control points (HACCP) and can be done by adopting an accelerated shelf-life (ASL) study to reduce the time and cost of a long-lasting experiment. This study aims to determine the microbial shelf-life of frozen crispy chicken curry puffs (FCCCP).

Methodology and results: An ASL study was performed at varying temperatures of -18 °C, -8 °C, 2 °C and 12 °C for 12 weeks. Samples were also maintained at -18 °C for 12 months for the shelf-life study. Along the studies, microbiological growth (total plate count, yeast and mould count, *Salmonella*), pH and moisture content were analysed periodically. Findings from the ASL study indicated that storage at 2 °C and 12 °C led to an increase in microbiological growth. Yeast and mold count (YMC) had the highest correlation and was used to estimate the shelf-life using the Arrhenius equation. The estimated shelf-life of FCCCP was 30.5 months at -18 °C, 6.86 months at -8 °C, 1.72 months at 2 °C and 0.47 months at 12 °C. The Q_{10} was 4.45, 3.99 and 3.62 at -18 °C to -8 °C, -8 °C to 2 °C and 2 °C to 12 °C, respectively. All samples were within the microbiological limit throughout the storage period in the actual shelf-life study. *Salmonella* was not detected in any of the studies.

Conclusion, significance and impact of study: These findings provide valuable data for frozen food small and medium enterprises (SMEs) to verify product shelf-life during HACCP application. It can serve as a reference in the shelf-life determination of frozen foods under inappropriate temperature conditions along the cold chain.

Keywords: Accelerated shelf-life, curry puff, frozen food, microbial growth, Q_{10}

INTRODUCTION

Curry puff (locally known as karipap) is a famous Southeast Asian snack commonly served as a breakfast and afternoon snack. Curry puff is a deep-fried pastry in a crescent shape stuffed with savoury fillings of spiced potatoes, onions and ground meats. It is believed that curry puff originated from the Malays with the influence of British Cornish pastry, Portuguese empanada and Indian samosa (Tan, 2011). Over the decades, lifestyle changes have led to preferences for convenience foods, including frozen pastries. The growing demand for convenience foods has boosted interest in the frozen food industry (Sen *et al.*, 2021). These foods offer minimal preparation to accommodate a busy lifestyle. However, improper temperature control during storage will deteriorate product quality and promote microbiological growth. Storage

temperature has been known as one of the most critical factors in shelf-life extension and has profoundly affected the quality of bakery products (Novotni *et al.*, 2017). The formation of ice crystals during the process can cause protein destruction and mechanical damage to food structure (George, 2000; Li *et al.*, 2020). Also, frozen bakery products are generally prone to the survival of fungal species and psychotropic microorganisms, resulting in slime or mold growth on surfaces, discolouration and off-odour and flavour (Kilcast and Subramaniam, 2000; Nychas and Panagou, 2011; Aneja *et al.*, 2014).

The accurate shelf-life of food products is essential to minimise food safety risks and maintain the highest product quality possible. Shelf-life estimation should be performed at a point of new product development. It is also necessary to estimate and validate the shelf-life

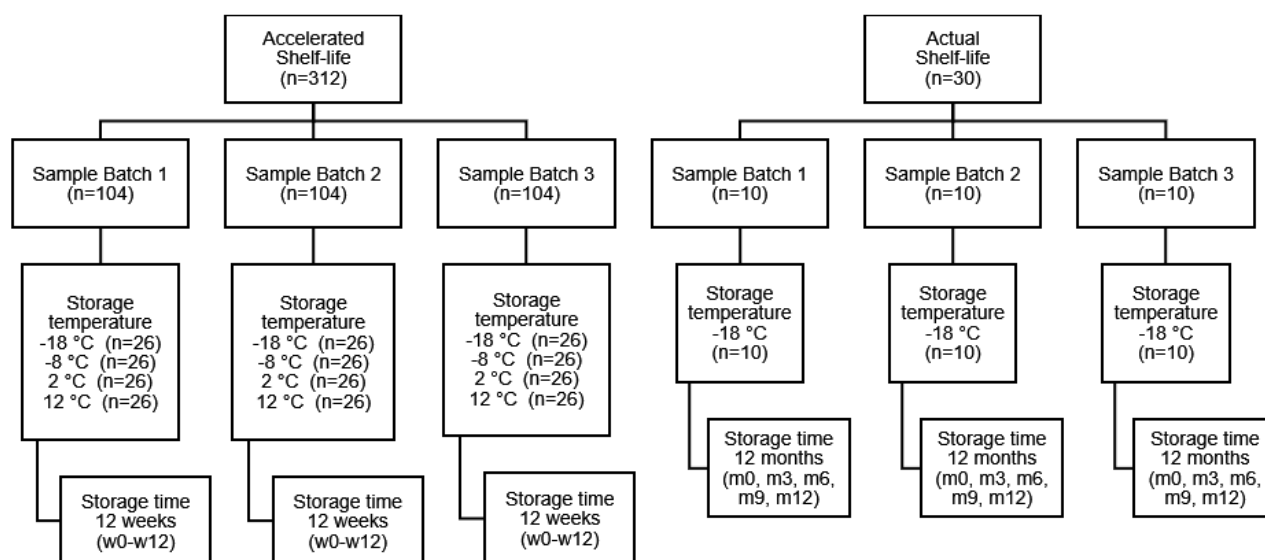


Figure 1: Schematic figure of the experimental design.

under other circumstances: absence of supporting evidence for current product shelf-life, modification or reformulation of products and production process, or legal requirements (FSAI, 2019). Prolonged degradation rates distinguish the deterioration of frozen foods and involve a very long study over a minimum period of 6-12 months. Accelerated shelf-life (ASL) is a methodology developed under accelerated testing conditions to evaluate the effects of formulations and processing parameters on product stability related to safety and quality. ASL allows time reduction in estimating product shelf-life for relatively long shelf-life products such as frozen foods (Fu and Labuza, 1997). Study within the temperature fluctuation range that may occur in frozen foods distribution is necessary to predict product shelf-life. Accelerated shelf-life studies using Arrhenius and Q_{10} approach on frozen food have been conducted extensively for decades (Childers and Kayfus, 1982; Martin *et al.*, 2005; Park *et al.*, 2018; Syahrul *et al.*, 2020). However, no studies have comprehensively explored the accelerated storage temperatures on the microbial shelf-life of frozen curry puffs.

This study used FCCCP samples produced by one of the frozen food SMEs in Selangor, Malaysia. The food SME was in the process of implementing HACCP for accreditation and shelf-life has been one of the fundamental parts of HACCP procedures. All the frozen products were stored at -18 °C per guidelines from The Codex Code of Practice for the Processing and Handling of Quick Frozen Foods (CAC, 1994). Under the frozen storage temperature, the desired shelf-life is targeted to be 12 months (Alsailawi *et al.*, 2020). Thus, the shelf-life determination of frozen food is time-consuming and costly. Besides, scarce literature on local snacks and frozen curry puffs is available. Therefore, this study focuses on ASL testing to determine whether it can be applied successfully for the frozen product having a

longer expected shelf-life. In addition, the findings would support the financial, technical, and knowledge resources of the small and medium-sized food industry during HACCP implementation. The purpose of this study is to determine the microbial shelf-life of FCCCP using the ASL testing approach under storage temperatures of -18 °C, -8 °C, 2 °C and 12 °C.

MATERIALS AND METHODS

Samples and experimental design

A total of 342 samples (finished products) were purchased from the local frozen food SME in Gombak, Selangor, Malaysia (Figure 1). Three batches were obtained (114 samples per batch) during each production day. Before analysis, the samples were transferred from the production plant to the laboratory in their original packaging with ice packs in a cold storage box (0-4 °C). Two samples were used to determine each batch's initial pH, moisture content and microbiological load (week 0) before being stored at selected storage temperatures for further accelerated and actual shelf-life studies.

Microbiological analysis

A whole FCCCP (30 g) was grounded using mortar and pestle to ensure homogeneity of the sample. A 25 g of the sample and 225 mL of 1% of bacteriological peptone water (Oxoid Ltd; Hampshire; UK) were aseptically homogenised using a stomacher (Bagmixer 400-P, Interscience, France) for 60 sec. The suspension was serially diluted and plated for microbial enumeration. Total plate count (TPC) was identified using Plate Count Agar (PCA; Oxoid Ltd; Hampshire; UK) and incubated at 35-37 °C for 48 h. Yeast and mold count (YMC) used potato dextrose agar (PDA; Oxoid Ltd; Hampshire; UK) and

incubated at 25-30 °C for 3-5 days. *Salmonella* growth was assessed using xylose lysine deoxycholate agar (XLD; Oxoid Ltd; Hampshire; UK) and incubated at 35-37 °C for 24 h. Visible colonies were counted using a colony counter (Galaxy230 Colony Counter; Rocker Scientific Co. Ltd.; Taiwan). All analyses were performed in triplicate, and results were reported as log₁₀ CFU/g (colony-forming units) for all samples.

pH and moisture content analysis

Samples were finely ground using a mortar and pestle before diluting with 1:1 ratios of distilled water. The pH of samples was then analysed using a digital pH meter (3505; Jenway; ST15 OSA, UK). Approximately 3 g of each ground sample was measured by a moisture analyser (XM-50; Precisa Instruments Ltd.; Switzerland) for moisture content analysis.

Estimation of shelf-life by accelerated shelf-life study

FCCCP samples were stored in original FFF packaging at storage temperatures of -18 °C, -8 °C, 2 °C and 12 °C for 12 weeks. Microbiological, pH and moisture analyses were performed weekly to evaluate sample deterioration during the study. The temperature scheme was designed based on Q₁₀ principles of 10 degrees apart, the company's current storage temperature of -18 °C and temperature fluctuation or inappropriate conditions that may occur along the cold chain. Storage temperatures were controlled by a temperature controller (ITC-308; Inkbird; Itech Europe Limited; London; England).

The temperature was used as an accelerating factor to speed up the deterioration reactions of FCCCP in this study. The reaction order of microbiological growth as a function of storage time was determined by linear regression analysis. The determination coefficient (R²) value was used to define the best model for the Arrhenius relationship model. A higher value of R² allowed fewer estimation errors among all order reactions (Pulungan *et al.*, 2018; Calligaris *et al.*, 2019). The rate constant (*k*) represented the value of the linear equation slope. The Arrhenius equation simulated temperature dependence on microbial growth. Arrhenius described temperature dependency of the rate of food quality loss where logarithmic values of reaction (ln *k*, measured in week⁻¹) were plotted against the reciprocal value of the absolute temperature (1/*T*, measured in °K). The rate constant and temperature relationship were visually observed as a straight line. The value of *k* at each temperature and the activation energy, *E_a*, was derived from the Arrhenius equation; Equation 1:

$$\ln k = \ln A - (E_a/RT) \quad (\text{Equation 1})$$

where *k* is the rate constant, *A* is the pre-exponential factor, *E_a* is activation energy (kJ/mol), *R* is the universal gas constant (8.31 kJ/mol) and *T* is an absolute temperature (in Kelvin, °K). The *k* value, the slope, is used in the shelf-life equation (Equation 2) based on zero

degree of order reaction to estimate the shelf-life of FCCCP at different temperatures (Calligaris *et al.*, 2019).

$$SL = (A - A_0)/k \quad (\text{Equation 2})$$

where *A₀* is the indicator value after food production (initial microbial count), and *A* is the indicator value corresponding to the microbiological limit referred to by the Food and Drug Administration (FDA, 2013). These data were further applied in the Q₁₀ calculation and shelf-life model to describe the shelf-life of FCCCP as a function of storage temperature. A linear equation on temperature dependency of shelf-life (Equation 3) is derived from the shelf-life plot as Arrhenius was fulfilled.

$$\ln SL = -bT + c \quad (\text{Equation 3})$$

where SL is shelf-life, *T* is the temperature (measured in °C and *b* and *c* are experimental parameters that correlate with the slope and intercept of the regression line. Q₁₀ is a measure of temperature sensitivity of reaction rate as the increase of 10 °C, expressed by equation (Equation 4) as follows (Labuza and Schmidl, 1985):

$$Q_{10} = \text{Shelf-life at temperature } T \text{ (°C)} / \text{Shelf-life at } [T \text{ (°C)} + 10 \text{ °C}] \quad (\text{Equation 4})$$

Actual shelf-life study using real data storage

FCCCP samples were stored at a recommended temperature of -18 °C and analysed (microbiological, pH and moisture analyses) at three-month intervals until they reached a commercial target shelf-life of 12 months. Findings from this study will be used to compare the estimated shelf-life.

Statistical analysis

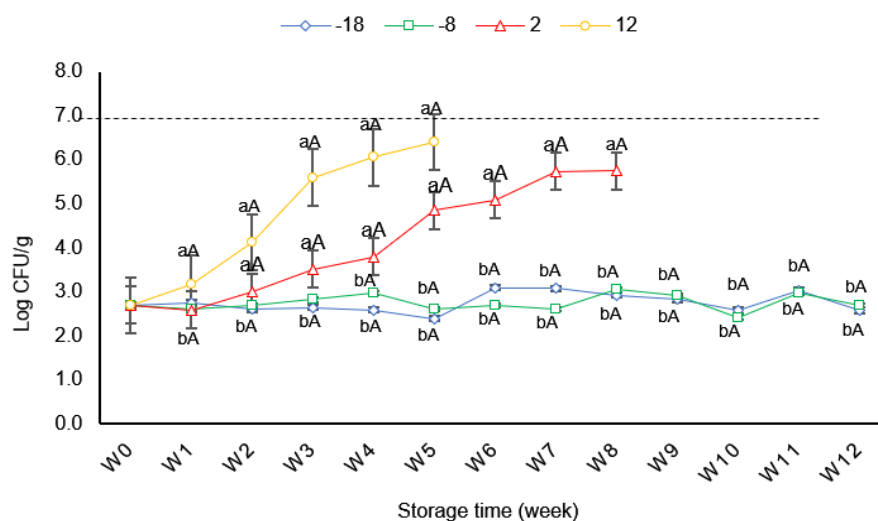
The data were analysed using the General Linear Model (GLM) procedure in Minitab 19 software. Tukey's multiple comparison test was performed to compare statistically significant differences in treatment means. Statistical significance was defined at a *p* ≤ 0.05. Linear regression analysis was performed using Microsoft Excel 2016 (Microsoft Corp., Redmond, WA, USA). The data were reported as the mean of three batches of samples: mean ± standard deviation (SD).

RESULTS AND DISCUSSION

Microbiological quality during storage

Three microbiological analyses were used in evaluating FCCCP samples: TPC, YMC and *Salmonella* count. *Salmonella* sp. is a microbiological concern mainly associated with poultry-based food products, causing severe foodborne illness (Mead *et al.*, 2010; Roccato *et al.*, 2015; Shafini *et al.*, 2017). Microbiological results during 12 weeks of storage, expressed as log₁₀ (CFU/g), are presented in Figure 2. TPC and YMC of samples at

(a)



(b)

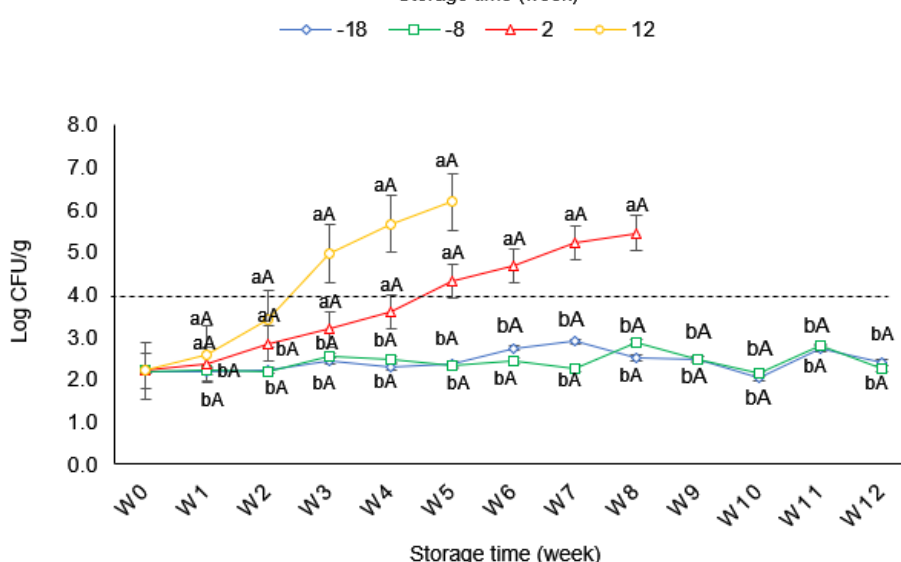


Figure 2: Microbiological growth of (a) total plate count and (b) yeast mould count during storage at -18 °C, -8 °C, 2 °C and 12 °C. Different superscript letters indicate a significant difference at $p \leq 0.05$. Data are means of three replicate samples and error bars indicate $\pm$ SD.

freezing temperatures of -18 °C and -8 °C showed stable and minimal microbial growth for 12 weeks. TPC at all storage temperatures was safe and within the microbiological limit of 10^7 (FSANZ, 2018) (Figure 2a). The initial TPC of the FCCCP sample was 2.70 ± 0.36 CFU/g. After 12 weeks, the count was 2.58 ± 0.64 log CFU/g and 2.70 ± 0.22 log CFU/g at -18 °C and -8 °C. Samples showed no significant change in TPC and physical evaluation during the 12-week storage period. A similar result was demonstrated by Rosli *et al.* (2019) in ready-to-bake frozen paratha samples, where a non-significant change of TPC was found throughout 15 weeks of frozen storage at -18 °C. This is also in line with a previous study by Yadav *et al.* (2009) on frozen chapatti samples during a 6-month storage period.

Figure 2b showed that the YMC of samples stored at -18 °C and -8 °C were within the microbiological limit of 10^4 during the 12-week storage period (FDA, 2013). The YMC at week 0; 2.20 ± 0.35 CFU/g was slightly increased to 2.41 ± 0.56 log CFU/g and 2.26 ± 0.24 log CFU/g at -18 °C and -8 °C by the end of the storage time. However, none of these differences was statistically significant. In this study, -8 °C can be considered a safe storage temperature for FCCCP since the microbiological growth (TPC and YMC) was minimal and did not differ significantly from the recommended storage temperature of -18 °C throughout the weeks. This is also comparable to those reported by Martin *et al.* (2021) and Park *et al.* (2018), which used higher storage temperatures than -8 °C. Martin *et al.* (2021) found no mold growth on pearl

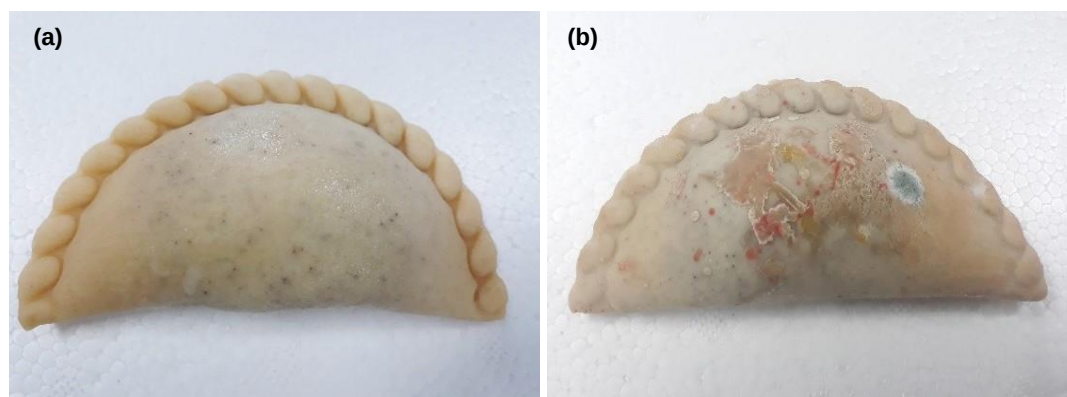


Figure 3: Evaluation of sample appearance. (a) Black spots start to appear on the sample stored at 12 °C at week 1; (b) Mould growth on the skin of the sample stored at 12 °C at week 4.

millet sourdough bread samples when stored at -5 °C for 14 days. Park *et al.* (2018) also showed an acceptable TPC on ice cream samples stored at -6 °C during the accelerated shelf-life study.

A similar increasing pattern of microbial growth (TPC and YMC) at storage temperatures of 2 °C and 12 °C can be observed throughout this study. TPC of samples stored at 2 °C and 12 °C were increased from 2.70 ± 0.36 CFU/g to 5.76 ± 0.28 CFU/g at week 8 (2 °C) and 6.41 ± 0.37 CFU/g at week 5 (12 °C), respectively (Figure 2a). YMC results also revealed fungi growth from 2.20 ± 0.35 CFU/g to 5.44 ± 0.13 CFU/g at week 8 (2 °C) and 6.17 ± 0.36 CFU/g at week 5 (12 °C), respectively (Figure 2b). Samples at elevated temperatures exceeded the acceptable YMC limit starting from week 5 (5.44 ± 0.13 CFU/g) and week 3 (6.17 ± 0.36 CFU/g). Taken together, FCCCP samples stored at the higher temperatures of 2 °C and 12 °C indicated a rapid rate of aerobic bacteria and yeast and mold growths. Following these findings, Galarz *et al.* (2016) highlighted that microbial growth accelerates concurrently with a reduced shelf-life as the storage temperature increases while predicting microbial growth on food samples. Lainez *et al.* (2008) also pointed out a similar finding where refrigerated storage temperatures of 7 °C could not prevent mold growth on part-baked bread samples throughout 28 days.

Figure 3 shows the example of mold growth on sample skin stored at 12 °C. Visible black spots appeared on sample skin at 2 °C and 12 °C as early as week 1, even with low YMC. The presence of an unpleasant odour, however, was detected late in week 3 (12 °C) and week 6 (2 °C). In this study, microbial metabolites such as acids and alcohol are probably responsible for the unpleasant odour in the bakery samples (Khoshakhlagh *et al.*, 2014). As for the early presence of black spots on the sample skin, this might be due to an oxidation reaction that can continue at refrigerated temperature. Oxidation reaction will cause bran particles naturally present in flour, one of the FCCCP ingredients for curry puff skin, to become dark brown or black spots (Cauvin, 2001). Similarly, Hussain *et al.* (2018) found that curry puff samples (control) exposed to temperature fluctuation

during storage formed black spots on the surface of the skin after four weeks. However, Sultana *et al.* (2014) found that black spots detected on chapatti samples stored at a refrigerated temperature of 6 °C on day 30 were associated with a low water activity of samples that led to fungal growth. In this study, samples stored at 2 °C and 12 °C were excluded from further analysis from week 6 and week 9, respectively, due to physical evaluation and high microbiological results from the previous week. *Salmonella* sp. was not detected in all samples stored at -18 °C, -8 °C, 2 °C and 12 °C.

pH value and moisture content during storage

Significance differences in pH value between storage temperatures of -18 °C, -8 °C and 12 °C were presented in Figure 4. The pH values at -18 °C and -8 °C exhibited a stable pattern due to minimal reaction rate and microbial growth during frozen storage. However, a different pattern was observed at 2 °C and 12 °C, where pH declined over the weeks associated with the increased microbial load on FCCCP samples, especially yeast and mold. Fungal metabolism causes changes in food composition that are strongly related to high water activity and slightly acidic pH due to the secretion of natural organic acids (Vylkova, 2017).

Moisture content plays a vital role in influencing the stability and quality of food products. In this study, the moisture content of FCCCP samples was 40-50 %, which is considered higher. The intrinsic composition of bakery products with a water content of around 40% and water activity within 0.94-0.97 is susceptible to fungal growth (Legan, 1993; Alpers *et al.*, 2021).

Based on Figure 4, the moisture content of FCCCP samples at all storage temperatures did not change significantly during the storage time. The moisture content at freezing temperatures of -18 °C and -8 °C was $47.00 \pm 0.82\%$ at the beginning; slightly fluctuated and decreased to $43.80 \pm 1.24\%$ and $40.56 \pm 1.19\%$ at -18 °C and -8 °C at week 12. Ridzal *et al.* (2020) highlighted that longer frozen storage time was found to reduce the moisture content of curry puff samples due to water removal during

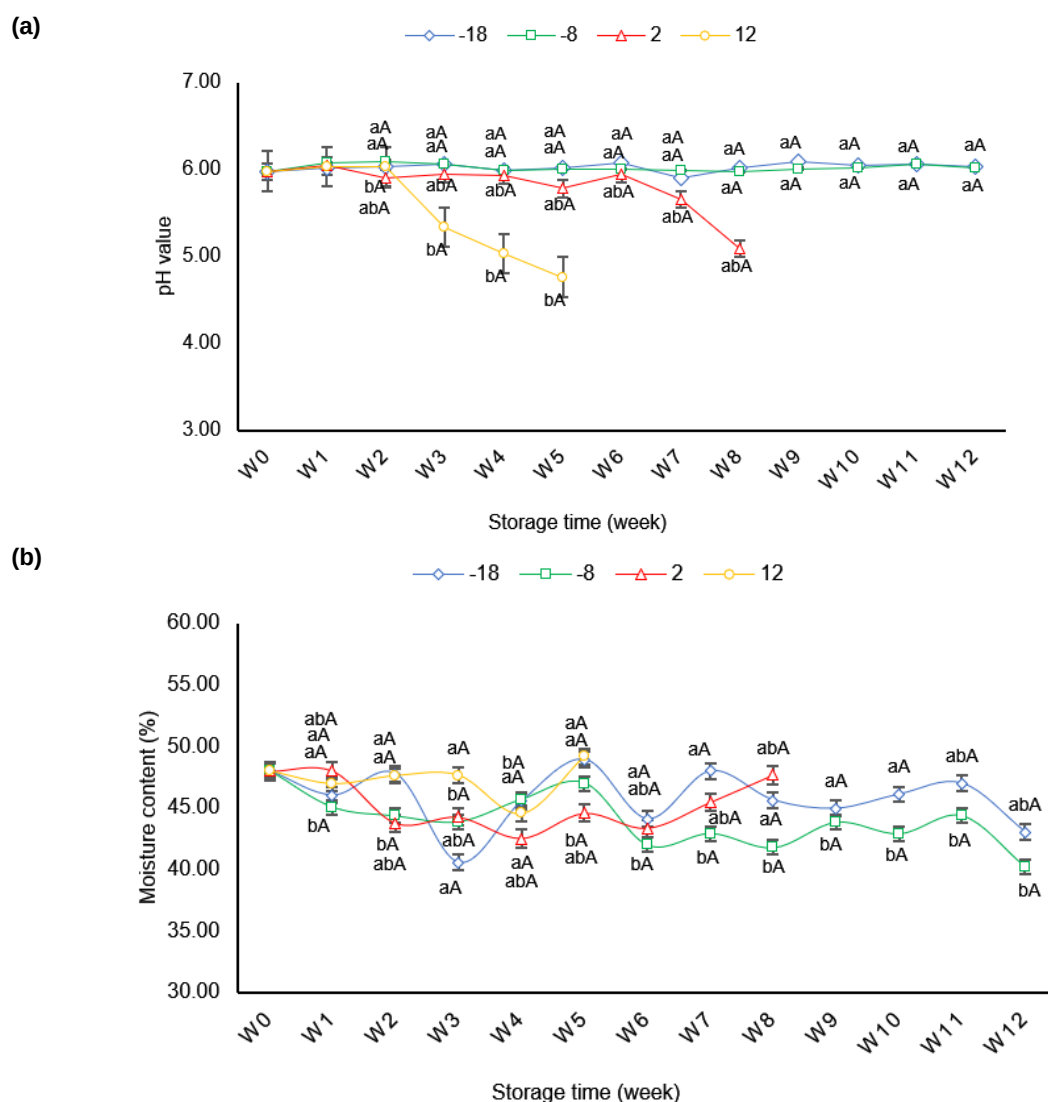


Figure 4: Change of (a) pH and (b) moisture content during storage at -18 °C, -8 °C, 2 °C and 12 °C. Different superscript letters indicate a significant difference at $p \leq 0.05$. Data are means of three replicate samples and error bars indicate $\pm$ SD.

the frozen stage, causing condensation and ice crystallisation to appear on packaging material. Likewise, ice crystallisation was found on the sample surface and inner surface of sample packaging in this study during storage time. This relationship was also consistent with prior studies by Hussain *et al.* (2018) and Pan *et al.* (2020). The moisture content at elevated temperatures was slightly higher towards the end of the storage. The sample's moisture content increased from $47.00 \pm 0.82\%$ to $48.65 \pm 0.09\%$ at week 8 (2 °C) and $49.48 \pm 2.24\%$ at week 5 (12 °C), respectively. This may associate with deterioration changes of pastry products during storage, such as softening, moisture uptake and mold growth (Cauvain and Young, 2010). At elevated temperatures, moisture migrates from filling to pastry, thus contributing

to moisture content and promoting fungal growth on the pastry skin (Cauvain, 2016).

Estimation of shelf-life

An accelerated shelf-life study was developed for longer shelf-life products. Regression analyses were performed at all storage temperatures to determine the order reaction to be used in the Arrhenius model. Regression equations and value of the determination coefficient, R^2 , for samples at -18 °C, -8 °C, 2 °C and 12 °C were illustrated in Table 1. YMC have a better fit towards the zero-order linear regression equation than TPC, indicating a potential marker for this ASL study. From the results, YMC also reached its maximum microbiological limit of

Table 1: Evaluation of the linear regression equation for the estimated shelf-life of frozen crispy chicken curry puff.

	Temp (°C)	Zero-order		First-order		Second-order	
		Linear equation	R ²	Linear equation	R ²	Linear equation	R ²
TPC	-18	y = 0.0133x + 2.6649	0.0551	y = 0.0046x + 0.979	0.0517	y = -0.0016x + 0.3761	0.0482
	-8	y = 0.0064x + 2.7108	0.0187	y = 0.002x + 0.9972	0.0146	y = -0.0006x + 0.3689	0.0108
	2	y = 0.4533x + 1.8484	0.9585	y = 0.1133x + 0.8042	0.9598	y = -0.0296x + 0.4134	0.944
	12	y = 0.8177x + 1.8191	0.9607	y = 0.1872x + 0.837	0.9471	y = -0.0452x + 0.3957	0.9192
YMC	-18	y = 0.0238x + 2.2535	0.1397	y = 0.0096x + 0.8117	0.1374	y = -0.0039x + 0.4444	0.1331
	-8	y = 0.0188x + 2.269	0.1007	y = 0.0074x + 0.8197	0.0964	y = -0.0029x + 0.4405	0.0918
	2	y = 0.4382x + 1.5651	0.9881	y = 0.1215x + 0.6676	0.9866	y = -0.0355x + 0.4715	0.9588
	12	y = 0.875x + 1.1049	0.9707	y = 0.2251x + 0.5664	0.9636	y = -0.0623x + 0.4971	0.9367

10⁴ faster than TPC, which makes it suitable to be applied for shelf-life estimation (Figure 2). Bakery products are prone to have YMC as the cause of spoilage during storage (Smith *et al.*, 2004; Cauvain, 2016). Fungi can grow to spoilage levels on unbaked dough for bread and pastries and even in fruit and cream filling of pastry products during refrigerated storage (Fleet, 2011).

Regression results in Table 1 displayed the reliability of correlation rates as the rate constant, *k* (slope), increased with the rising of storage temperature: 0.0238, 0.0188, 0.4382 and 0.8750 at 18 °C, -8 °C, 2 °C and 12 °C respectively. Temperature dependence of *k* value throughout 12 weeks of storage was described in the Arrhenius model. Logarithmic of the rate constant, *k* (derived from Table 1), was plotted against 1/absolute temperature (Arrhenius plot). The equation was $y = -10085x + 35.25$ with a coefficient of R², 0.8257 and activation energy, *E_a* of 83.8507 kJ/mol. In this study, activation energy, *E_a*, represented the minimum energy required to trigger yeast and mold growth at storage temperatures. Higher *E_a* displays a slower rate of reaction, thus expected to maintain the original quality of the sample for a more extended storage period (Jafari *et al.*, 2017). Higher R² values showed the reliability of the equation in estimating the shelf-life of FCCCCP samples. The *k* value (slope of Arrhenius equation) and cut-off limit of log 4 CFU/mL by FDA standard (FDA, 2013) were applied in the shelf-life equation (Equation 2).

The estimated shelf-life of FCCCCP samples at -18 °C, -8 °C, 2 °C and 12 °C were presented in Table 2. A storage temperature of -18 °C was expected to preserve the sample microbiologically safe at the most extended shelf-life among other samples by 30.5 months, followed by storage temperatures of -8 °C, 2 °C and 12 °C, which by 6.86 months, 1.72 months and 0.47 months. This was in line with Park *et al.* (2018) where the predicted shelf-life of ice cream sample using the total aerobic count parameter was found to be 27.98 months at -18 °C, 5.09 months at -6 °C, 2.62 months at -1 °C and 1.38 months at 4 °C. Study by Bosmans *et al.* (2014) also showed that sub-zero storage temperature significantly prolongs microbial shelf-life and retard the staling of bakery products. The findings of FCCCCP estimated shelf-life at 12 °C was up to only 0.47 months (2.04 weeks), similar to the YMC in this study. The deterioration of the sample at 12 °C was captured in this study, where the sample was within the microbiological limit until week 2. Higher

Table 2: Estimated shelf-life of ice cream at -18 °C, -8 °C, 2 °C and 12 °C.

Temp (°C)	Estimated shelf-life (month)	Q ₁₀
-18	30.5	4.45
-8	6.86	3.99
2	1.72	3.62
12	0.47	

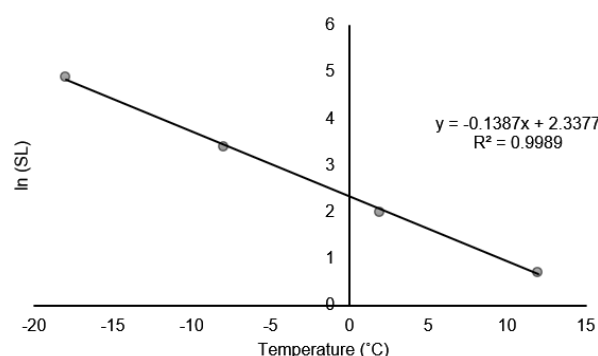


Figure 5: Shelf-life plots of FCCCCP using YMC as a shelf-life indicator.

storage temperatures favour microbial spoilage and reduce the shelf-life of frozen foods. Findings of shelf-life estimation were summarised in Figure 5, the shelf-life plot. Q₁₀ of the FCCCCP sample was 4.45, 3.99 and 3.62 at -18 °C to -8 °C, -8 °C to 2 °C and 2 °C to 12 °C, respectively. The Q₁₀ of 4.45 indicated that the rate of YMC growth increases 4 times as the temperature increases by 10 °C. The increase of Q₁₀ corresponded to temperature dependency as higher consistency changes in the sample can be observed when 10 °C of the storage temperature was raised. Q₁₀ values from 2 to 20 were usually found in the literature related to frozen food samples (Fu and Labuza, 1997).

Actual shelf-life

This study's samples were within the microbiological limit after a 12-month storage period. TPC and YMC of the sample were slightly decreased from 2.70 ± 0.36 log CFU/g to 2.51 ± 0.45 log CFU/g and 2.20 ± 0.35 CFU/g to 1.77 ± 0.76 CFU/g along with the storage. This was

probably due to the death of microbial cells exposed to long-frozen storage. Microorganisms may express no detrimental effects, be killed and undergo sub-lethal or metabolic injury when subjected to environmental stress such as freezing (Vasafi *et al.*, 2019). According to these findings, the FCCCP sample could be safe for more than 12 months as the predicted ASL since the microbial growth was insignificant and declined from the initial count. The pH value for the sample was maintained at around 5.98 ± 0.10 and the moisture content decreased throughout this study from $47.00 \pm 0.82\%$ to $40.17 \pm 0.73\%$, which could result from moisture migration and ice sublimation during the prolonged storage period. *Salmonella* sp. was not detected in any sample. Samples also showed no significant change in terms of physical appearance.

CONCLUSION

Overall, the ASL model developed in this study could be considered a good model and able to estimate the microbial shelf-life of FCCCP with the determination of a coefficient (R^2) of 0.8257. An increase in storage temperature from $-18\text{ }^{\circ}\text{C}$ to $12\text{ }^{\circ}\text{C}$ reduced the estimated shelf-life from 30.5 to 0.47 months. These findings can serve as a valid measure of product shelf-life under inappropriate temperature conditions and as references for further shelf-life studies related to frozen convenience foods.

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