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ARTICLE

Determination of Shelf Life Model of Pork Cutlet and Pork Lard during Accelerated Storage Conditions

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Abstract This study was carried out to establish shelf life for pork cutlet of ground meat and pork lard by using various quality indicators and to understand how quality changes in these products are accelerated by temperature. The samples were selected and purchased from markets in Korea, and the chosen quality indicators were total aerobic counts and coliform group in microbiological analyses, thiobarbituric acid reactive substances assay, volatile basic nitrogen, pH, acid value, and peroxide value in physical chemical analyses, and sensory evaluation. The pork cutlet samples were stored at −18℃, −6℃, and −1℃, whereas pork lard samples were stored at 10℃, 25℃, 35℃, and 45℃. These temperature conditions were set to real distribution conditions. The samples were then analyzed using various models including of reaction orders, arrhenius equation, and Q_{10} value. The quality limits for each sample were calculated, and shelf life was estimated. The results of this experiment highlighted the importance of temperature control during the distribution process of these products and revealed that temperature is a useful parameter for the establishment of a basic database for shelf life.

Keywords shelf life, pork cutlet, pork lard

Introduction

Recently, consumption and sale of meat products has constantly been increasing in Korea. In recent years, meat product sales increased by 56.7%, in 1990 as compared to 1980 (11.3 kg), by 62.4%, in 2000 as compared to 1990 (19.9 kg), by 82.2% in 2010 as compared to 2000 (31.9 kg), and by 90.9%, in 2015 (47.6 kg) (KMIA, 2015; Lee et al., 2013). Meat products are one of the most important nutrition sources and generates the unique compounds, flavor and texture during processing. But, meat is easy to microbial damage because of their high water content and the presence of important nutrients on the surface of the product. Therefore, it is important to manage shelf life of meat to eat safety food.

Society is becoming more complex, and consumers are seeking ease and convenience in their food purchases. Yet the level of information required to be provided for foods—taste, healthfulness, safety, and functionality—is also high. Customers are usually sensitive to quality changes in food related to their expiration. Food quality directly influences the degree of acceptability to consumers. Increased consumer perceptions about the role of food in maintaining and improving health are changing purchasing habits (Grunert, 2004; McCarthy et al., 2004; Rosa-Díaz, 2006). Consumers can judge the quality of the food based only on limited information. Shelf life is the most common information that consumers access. It is important to consumers for purchasing decisions, but shelf life labeling depends completely on the manufacturer of the product. A product should provide adequate levels of its characteristics at least as long as the stated shelf life, and the manufacturer should do the work necessary to determine the correct shelf life (García-García et al., 2008). However, small-scale manufacturers do not have properly equipped laboratory facilities and lack experienced laboratory personnel, knowledge, and skill. They tend to make shelf life labels with insufficient data or follow the labels on similar items made by other companies. The discrepancy between consumer quality perceptions and current shelf life labeling can cause distrust and confusion and makes consumer judgments about food safety difficult. In Korea, processed meat products need establishment of shelf life (MFDS, 2017); therefore, establishing a specialized and easily accessed shelf life laboratory manual is necessary for manufacturers of processed meat products. Above all, quality parameter criteria supported by experimental data and a resulting shelf life model are needed. Shelf life is established typically using an actual shelf life test, or an accelerated shelf life test according to storage period of the sample, also specifically whether the shelf life is more than 3 months. An accelerated shelf life test targets food that have long-term expiration dates. Extrapolation from exaggerated testing conditions to ambient conditions is performed usually based on established relationships between kinetic parameters and the storage environment (MFDS, 2017). Therefore, the aim of this study aims to serve a shelf life estimation using accelerated shelf life test on cutlet pork and pork lard.

Materials and Methods

Preparation of samples

One type of processed meat products was selected and purchased from market in Korea. Pork cutlet (M) manufactured by one companies was selected. The pork lard sample was obtained from one company (L). Each sample was transported to the laboratory at the temperature of distribution, and initial quality levels were analyzed immediately.

Conditions of storage

The cutlet meat was stored at −18℃, −6℃, and −1℃ (denoted M1-18, M1-6, and M1-1). Temperature conditions (−18℃) of cutlet meat was necessary to maintain the product qualities listed on the package based on legal standards (MFDS, 2017). The remaining temperature conditions (−6℃ and −1℃) reflected noncompliance with storage temperature conditions by either manufacturers or consumers. The prescribed storage condition of pork lard is usually room temperature, but pork lard is often stored outside of warehouses. Therefore, in this study, pork lard was stored at 10℃, 25℃, 35℃, and 45℃ (denoted L1-10, L1-25, L1-35, and L1-45), temperature conditions akin to real distribution conditions. The pork cutlet and pork lard samples were stored for 204 days, and experiments were performed once per week during that time. All analyses were performed in triplicate.

Selection of quality indicators

Quality indicators were selected according to the characteristics of each of the samples. Pork cutlet was analyzed using

microbiological analysis methods (total aerobic counts, TAC; coli form counts), physico-chemical methods (thiobarbituric acid reactive substances; thiobarbituric acid reactive substances (TBARS) assay, volatile basic nitrogen (VBN), and pH), and sensory evaluation. Pork lard was analyzed using physico-chemical methods (TBARS assay; acid value, AV; peroxide value, POV) and sensory evaluation. All analyses were carried out in triplicate for each formulation.

Analysis of microbiological growth

Each 10 g sample was diluted (1:10) in distilled water and homogenized using a stomacher (Stomacher® 400 Circulator, Seward, Ltd., UK) for 2 min at room temperature. Serial dilutions (1:10) from the homogenized microbial extracts (0.1 mL) were plated separately on each plate and spread thoroughly. TAC was determined using plate count agar (Difco, USA) incubated at 37±1℃ for 48 h. Coliform group counts were enumerated using deoxycholate lactose agar (Difco, USA) and were incubated at 37±1℃ for 24 h. All analyses were performed in triplicate, and results were expressed as logarithm colony-forming units per milliliter (Log CFU/mL).

Thiobarbituric acid reactive substances (TBARS) assay

TBARS assay was performed in triplicate using the modified method proposed by Witte et al. (1970) to assess lipid oxidation. On each sampling day, 10 g minced sample was homogenized with 25 mL 20% (w/v) aqueous trichloroacetic acid in 2 M phosphoric acid at room temperature. The homogenization was performed at 14,000×g for 1 min with a homogenizer (AM-7, Nihonseiki Kaisha Ltd., Tokyo, Japan). After homogenization and adjustment to 20 mL using distilled water, the supernatant was filtered through a Whatman paper (No. 1). After filtering, a 5 mL sample was reacted with 5 mL 2-TBA (0. 005 M in distilled water) in a test tube and stored for 15 h at room temperature in darkness. The TBA complex was measured at 530 nm using a spectrophotometer (Libra S22, Biochrom Ltd., Cambridge, UK). The results were calculated using the following equation and reported in milligrams malonaldehyde (MDA) per kilogram: all determinations were performed in triplicate.

$$\text{TBA (MDA mg/kg)} = \text{optical density value} \times 5.2$$

Volatile basic nitrogen (VBN)

VBN concentration is usually used to represent the level of corruption in meat. VBN was measured in the experimental sample in triplicate according to the Conway micropipette diffusion method (Pearson, 1976). Each 5 g sample was combined with 15 mL distilled water and homogenized with a homogenizer (AM-7, Nihonseiki Kaisha Ltd., Tokyo, Japan) at 10,000×g for 1 min. The supernatant was filtered using a Whatman paper (No. 1), and the filtrate was placed in a conical tube and adjusted to a final volume of 50 mL with distilled water. A 1 mL volume of filtered sample solution and 1 mL saturated potassium carbonate were placed in the outer section of a Conway micro diffusion cell (Sibata Ltd., Tokyo, Japan). Boric acid (0.01 N) was carefully transferred into the inner section, and the lid was immediately closed and the solution mixed carefully. The cell was incubated at 37℃ for 2 h, and then the solution in the inner section was titrated with 0.02 N sulfuric acid until the green solution turned pink. The concentration of VBN was calculated using the following equation: all determinations were performed in triplicate.

$$\text{VBN (mg \%)} = \frac{(b-a) \times f \times d \times 14.007 \times 0.02}{S} \times 100$$

where *a* is the titer for the blank (mL), *b* is the titer for sample (mL), *f* is the factor of 0.02 N sulfuric acid, *d* is the dilution rate, *S* is the weight of sample (g), and 14.007 is the molecular weight of nitrogen.

pH

Each 5 g sample was combined with 15 mL distilled water and then homogenized with a homogenizer (AM-7, Nihonseiki Kaisha Ltd., Tokyo, Japan) at 10,000×g for 1 min. The supernatant was filtered using a Whatman paper (No. 1), and then the filtrate was adjusted to a final volume of 50 mL with distilled water. Measurements were taken with a digital pH meter (AM-7, Nihonseiki Kaisha Ltd., Tokyo, Japan). All determinations were performed in triplicate.

Acid value (AV)

AV measurements were performed in triplicate to assess lipid oxidation using a standard titration method according to the methods described in the *Food Code of Korea* (MFDS, 2015). Samples were melted at 60℃ before the experiments. Each 5 g sample was placed in an Erlenmeyer flask and mixed thoroughly with 100 mL neutralized ethanol-ether (1:2) mixture. The mixture was titrated with a solution of 0.05 M ethanolic potassium hydroxide as the standard reagent to phenolphthalein. AV was calculated using the following equation: all determinations were performed in triplicate.

$$\text{AV (mg KOH/g)} = \frac{5.611 \times a \times f}{S}$$

where *a* is the concentration of the ethanolic potassium hydroxide solution used (mL), *f* is the factor the ethanolic potassium hydroxide solution, and *S* is the weight of sample (g).

Peroxide value (POV)

Analyses of lipid oxidation were conducted by assessing following the official methods described in the *Food Code of Korea* (MFDS, 2015). Each 5 g sample was dissolved slightly by heating with 25 mL acetic acid-chloroform (3:2) mixture. This solution was homogenized slightly with 1 mL saturated potassium iodide solution and then placed in darkness for 10 min, after which it was homogenized thoroughly with 30 mL distilled water. The mixture was titrated with 0.01 N sodium thiosulfate using 1 mL starch solution as an indicator. Measurements were corrected with the blank test and carried out in at least triplicate.

$$\text{POV (meq/kg)} = \frac{(a-b) \times f}{S} \times 10$$

where *a* is the titer for 0.01 N sodium thiosulfate in the sample (mL), *b* is the titer for 0.01 N sodium thiosulfate in the blank (mL), *f* is the factor of 0.01 N sodium thiosulfate, and *S* is the weight of sample (g).

Sensory evaluation

Samples were prepared for sensory evaluation, which was carried out using 12 consumer-type panels on each day of sampling. Each panel independently evaluated the samples for appearance, flavor, and texture according to a hedonic rating method described (9=excellent, 5=acceptable, and 1=vile).

Data analysis via kinetics

The availability of so many processed products with long shelf lives adds difficulty to shelf-life estimations. Decreasing experimental costs and reducing the time spent, accelerated shelf life tests are often used to overcome this problem (Labuza and Schmidl, 1985; Nelson and Labuza, 1994). Accelerated shelf life tests using various kinetic models are useful for assessing the effects of temperature changes on product quality (Jedermann et al., 2009). Data obtained with accelerated shelf life tests was calculated through reaction order, Arrhenius equation, and Q_{10} value. These kinetic parameters have been described in previous studies (Kong et al., 2007; Wang et al., 2004).

Zero-order reaction

The data obtained from each experiment was adjusted according to the formula below. The zero-order reaction model, one of the best known models for establishing shelf life, was used to represent a linear evolution:

$$A_t = A_0 - kt$$

where A_0 is the initial quality value at time zero, A_t is the quality value at time t, t is the time of storage, and k is the reaction rate constant.

First-order reaction

The data obtained from each experiment was adjusted according to the formula below. The first-order reaction model, another well-known model for establishing shelf life, was used to represent an exponential evolution of the parameter:

$$\ln\frac{A_t}{A_0} = -kt$$

where A_0 is the initial quality value at time zero, A_t is the quality value at time t, t is the time of storage, and k is the reaction rate constant.

Arrhenius equation

The Arrhenius equation is usually used to describe the temperature dependence of a reaction rate on isothermal conditions. The formula is as follows:

$$k = \mathrm{A}e^{-\frac{Ea}{RT}}$$

where k is the reaction rate constant, A is the constant, Ea is the activation energy (kcal/mol), R is the universal gas constant (R=1.987 cal · mol^{-1} · K^{-1}), and T is the absolute temperature (K). The above formula can be modified as follows:

$$\ln k = -\frac{Ea}{R}\times\frac{1}{T} + \ln A$$

Q_{10} value

Q_{10} value is a frequently used parameter to describe the temperature dependence of a reaction rate. It can be estimated via the quality changes at increases of 10℃. Q_{10} value is calculated as follows:

$$Q_{10} = \frac{\text{reaction rate at } (T + 10\ ℃)}{\text{reaction rate at } T\ ℃}$$

It can be transformed via the Arrhenius equation:

$$Q_{10} = e^{\frac{Ea}{R}\left[\frac{10}{T(T+10)}\right]}$$

where *Ea* is the activation energy (kcal/mol), *R* is the universal gas constant (*R*=1.987 cal/mol), and *T* is the absolute temperature (*K*).

Statistical analysis

All tests were conducted at least three times for each experimental condition, and mean values are reported. Analysis of variance was performed using SAS software (SAS ver. 9.3, SAS Institute Inc., Cary, NC, USA, 2010). Duncan's multiple range test ($p<0.05$) was used to determine the differences between the means.

Results and Discussion

Analysis of microbiological growth

Previously reported research has indicated that measures of microbial growth are the main components of estimations of shelf life for meat and processed meat products (Georgantelis et al., 2007; Heo et al., 2008; Roller et al., 2002; Zhao et al., 1994). Therefore, two microbiological experiments were carried out in this study, including total aerobic bacteria (TAC) in the ground meat kind of pork cutlet. The initial TAC value of pork cutlet (M) was 2.87±0.03 Log CFU/mL. Samples were stored at each experimental temperature over 204 days, and experiments were carried out on each weekly sampling day. The TAC value of pork cutlet −18℃ (M1-18) was 7.75±0.05 Log CFU/mL at day 204 that of pork cutlet −6℃ (M1-6) was 8.09±0.05 Log CFU/mL at day 204, and that of pork cutlet −1℃ (M1-1) was 6.31±0.03 Log CFU/mL at day 78. These values in ground meat samples differed significantly during the storage period according to temperature conditions ($p<0.05$), a result consistent with those of a study by Kim et al. (2008), who reported that TAC values of ground meat patties increase significantly during storage periods. This tendency that increase of TAC value during storage periods is consistent with that reported by a previous study (Heo et al., 2008). The TAC values of the ground meat samples are shown in Table 1 and 2. In case of coliform group, all sample were not detected.

Thiobarbituric acid reactive substances (TBARS) assay

TBARS assay is a widely using method for measuring contents of MDA generated from hydroperoxides. Previous studies have reported that MDA content is closely related both to the amount of lipids present during storage period and off flavor

Table 1. The changes of pork cutlet during storage at −18℃ and −6℃

Day/ −18℃	TAC	Mal	VBN	pH	Sensory	Day/ −6℃	TAC	Mal	VBN	pH	Sensory
0	2.87±0.03^{z}	0.88±0.00^{s}	8.68±0.02^{q}	6.45±0.04^{a}	9.00±0.00^{a}	0	2.87±0.03^{no}	0.88±0.00^{x}	8.68±0.02^{u}	6.45±0.04^{ab}	9.00±0.00^{a}
1	2.90±0.11^{z}	0.90±0.00^{s}	9.24±0.03^{p}	6.45±0.00^{a}	9.00±0.00^{a}	1	2.81±0.13^{o}	1.03±0.05^{w}	9.24±0.04^{t}	6.58±0.12^{a}	9.00±0.00^{a}
8	2.85±0.04^{z}	0.91±0.00^{s}	9.24±0.01^{p}	6.44±0.16^{a}	9.00±0.00^{a}	8	3.00±0.05^{no}	1.11±0.05^{v}	9.24±0.03^{t}	6.46±0.00^{ab}	9.00±0.00^{a}
15	2.60±0.06^{z}	1.09±0.00^{r}	10.37±0.01^{no}	6.44±0.04^{ab}	9.00±0.00^{a}	15	3.15±0.07^{n}	1.18±0.06^{v}	9.80±0.01^{s}	6.47±0.16^{ab}	8.75±0.25^{a}
22	3.37±0.04^{y}	0.95±0.05^{s}	10.09±0.36^{o}	6.42±0.02^{ab}	9.00±0.00^{a}	22	3.51±0.05^{m}	1.36±0.00^{u}	10.09±0.38^{s}	6.43±0.00^{ab}	8.75±0.75^{a}
29	3.62±0.14^{x}	1.36±0.05^{q}	10.37±0.58^{no}	6.42±0.24^{abc}	8.75±0.25^{ab}	29	3.72±0.12^{m}	1.44±0.02^{tu}	10.09±0.41^{s}	6.37±0.00^{ab}	8.25±0.25^{a}
36	3.74±0.03^{w}	1.51±0.05^{p}	10.37±0.14^{no}	6.38±0.11^{abc}	8.75±0.25^{ab}	36	4.17±0.07^{l}	1.42±0.00^{tu}	10.93±0.27^{r}	6.32±0.00^{b}	7.75±0.33^{a}
43	4.23±0.03^{v}	1.52±0.00^{p}	10.93±0.14^{lm}	6.37±0.00^{abcd}	8.83±0.17^{a}	43	4.89±0.01^{k}	1.48±0.06^{t}	10.93±0.19^{r}	6.30±0.02^{b}	7.50±0.25^{a}
50	4.23±0.06^{v}	1.51±0.05^{p}	10.65±0.14^{mn}	6.36±0.01^{abcde}	8.83±0.17^{a}	50	4.89±0.03^{k}	1.62±0.00^{s}	11.21±0.30^{qr}	6.34±0.00^{b}	7.75±0.33^{b}
57	4.47±0.01^{u}	1.62±0.00^{no}	10.93±0.58^{lm}	6.33±0.00^{abcde}	9.00±0.00^{a}	57	5.13±0.02^{k}	1.77±0.00^{r}	11.21±0.37^{qr}	6.30±0.10^{b}	7.00±0.58^{c}
64	4.72±0.06^{t}	1.54±0.05^{op}	10.93±0.06^{lm}	6.33±0.00^{abcde}	8.33±0.67^{abc}	64	5.61±0.05^{j}	1.94±0.04^{q}	11.49±0.09^{pq}	6.08±0.00^{c}	6.75±0.42^{c}
71	4.84±0.06^{s}	1.66±0.00^{n}	11.21±0.03^{l}	6.33±0.00^{abcde}	8.50±0.05^{abc}	71	5.86±0.62^{ij}	3.75±0.00^{m}	11.77±0.12^{pq}	6.01±0.23^{cd}	6.75±0.67^{c}
78	5.09±0.03^{r}	2.62±0.06^{i}	11.21±0.03^{l}	6.32±0.00^{abcdef}	8.25±0.75^{abcd}	78	6.10±0.07^{i}	3.80±0.00^{m}	11.77±0.25^{pq}	5.92±0.08^{cdef}	6.67±0.58^{c}
85	5.42±0.02^{q}	2.08±0.06^{m}	11.68±0.01^{k}	6.30±0.04^{abcdefg}	8.33±0.67^{abc}	85	6.65±0.02^{hi}	3.13±0.06^{p}	12.33±0.02^{o}	5.98±0.24^{cde}	5.42±0.08^{d}
92	5.65±0.02^{p}	2.19±0.06^{l}	10.93±0.03^{lm}	6.28±0.02^{bcdefg}	8.33±0.67^{abc}	92	6.90±0.07^{h}	3.33±0.11^{o}	10.93±0.06^{r}	5.93±0.00^{cdef}	4.75±0.65^{d}
99	6.08±0.05^{n}	2.29±0.05^{k}	12.07±0.21^{j}	6.23±0.24^{bcdefg}	8.25±0.75^{abcd}	99	7.11±0.09^{gh}	3.53±0.06^{n}	12.86±0.03^{n}	5.89±0.00^{cdefg}	4.92±0.00^{d}
106	5.87±0.12^{o}	2.40±0.06^{j}	12.26±0.35^{ij}	6.27±0.04^{abcdefg}	8.25±0.75^{abcd}	106	7.45±0.11^{ef}	3.74±0.00^{m}	13.13±0.02^{mn}	6.01±0.00^{cd}	3.50±0.25^{e}
113	6.27±0.03^{m}	2.29±0.06^{k}	12.05±0.13^{j}	6.26±0.08^{abcdefg}	8.25±0.75^{abcd}	113	7.29±0.09^{fg}	3.94±0.06^{l}	13.39±0.19^{lm}	5.70±0.05^{fghijk}	3.33±0.67^{e}
120	6.45±0.02^{l}	2.40±0.06^{j}	12.46±0.12^{i}	6.24±0.13^{bcdefg}	8.50±0.50^{abc}	120	7.57±0.07^{ef}	3.53±0.06^{n}	13.55±0.14^{kl}	5.75±0.16^{efghi}	3.33±0.67^{e}
127	6.62±0.01^{k}	2.61±0.06^{i}	12.85±0.01^{h}	6.22±0.23^{bcdefg}	8.00±0.00^{bcde}	127	7.68±0.05^{cde}	4.14±0.11^{k}	13.81±0.14^{jk}	5.84±0.04^{defgh}	3.42±0.48^{e}
134	6.78±0.01^{j}	2.82±0.05^{h}	12.31±0.01^{ij}	6.20±0.06^{cdefg}	8.00±0.00^{bcde}	134	7.77±0.12^{bcde}	4.55±0.06^{j}	14.07±0.58^{ij}	5.79±0.02^{defghi}	3.42±0.48^{e}
141	6.92±0.00^{i}	2.92±0.06^{g}	13.24±0.13^{g}	6.14±0.02^{efg}	7.50±0.50^{defg}	141	7.68±0.11^{cde}	4.75±0.00^{i}	14.59±0.06^{gh}	5.71±0.24^{fghijk}	3.25±0.25^{e}
148	7.17±0.10^{g}	3.03±0.03^{f}	13.44±0.01^{fg}	6.19±0.08^{cdehg}	7.00±0.00^{fg}	148	7.84±0.04^{abcd}	4.95±0.05^{h}	14.33±0.28^{hi}	5.67±0.00^{ghijklm}	2.88±0.33^{ef}
155	7.28±0.02^{fg}	3.13±0.01^{e}	13.63±0.07^{ef}	6.18±0.13^{cdefg}	7.75±0.25^{cdef}	155	7.90±0.02^{abc}	5.16±0.05^{g}	14.85±0.45^{fg}	5.63±0.04^{hijklmn}	2.88±0.33^{ef}
162	7.05±0.01^{h}	3.24±0.06^{d}	13.83±0.14^{de}	6.16±0.05^{defg}	7.00±0.00^{fg}	162	7.94±0.06^{abc}	4.75±0.01^{i}	15.10±0.03^{ef}	5.67±0.00^{ghijklm}	2.42±0.76^{fg}
169	7.38±0.02^{ef}	4.18±0.17^{b}	14.02±0.27^{cd}	6.11±0.00^{fg}	7.25±0.75^{efg}	169	8.04±0.05^{ab}	5.56±0.05^{e}	15.36±0.02^{de}	5.58±0.16^{ijklmn}	2.08±0.67^{gh}
176	7.47±0.01^{de}	3.24±0.01^{d}	14.22±0.19^{c}	6.15±0.19^{efg}	6.75±0.25^{g}	176	7.98±0.05^{abc}	7.39±0.06^{a}	15.62±0.19^{cd}	5.54±0.00^{jklmn}	1.50±0.00^{hi}
183	7.62±0.06^{bc}	4.60±0.05^{a}	15.00±0.01^{a}	6.12±0.08^{fg}	7.25±0.75^{efg}	183	8.02±0.04^{ab}	5.56±0.07^{f}	15.88±0.30^{bc}	5.42±0.14^{mn}	1.00±0.00^{i}
190	7.55±0.02^{cd}	3.87±0.06^{c}	14.61±0.03^{b}	6.10±0.05^{fg}	7.50±0.50^{defg}	190	8.06±0.08^{ab}	6.58±0.01^{d}	16.14±0.12^{bc}	5.50±0.05^{klmn}	1.00±0.00^{i}
197	7.69±0.02^{ab}	4.08±0.06^{b}	15.19±0.01^{a}	6.08±0.22^{g}	7.50±0.50^{defg}	197	8.11±0.13^{a}	6.98±0.00^{c}	15.88±0.03^{bc}	5.46±0.24^{lmn}	1.00±0.00^{i}
204	7.75±0.05^{a}	4.18±0.01^{b}	15.00±0.02^{a}	6.12±0.00^{fg}	7.44±0.56^{efg}	204	8.09±0.05^{a}	7.19±0.05^{b}	16.66±0.30^{a}	5.37±0.33^{n}	1.00±0.00^{i}

All values are mean standard deviation of three replicates.
$^{a–z}$ Means within a column with different letters are significantly different ($p<0.05$).
TAC, total aerobic count; Mal, malonaldehyde; VBN, volatile basic nitrogen.

(Tarladgis et al., 1960; Teets et al., 2008). In this study, lipid oxidation was determined according to the method described by Witte et al. (1970) and detected at 530 nm. The TBARS value of pork cutlet meat and pork lard are presented in Table 1, 2, 3, and 4. First, in case of cutlet meat, the TBARS value for M1 was 0.88±0.00 MDA mg/kg at day 0, and thereafter, samples

Table 2. The result of pork cutlet during storage at −1℃

Day	Total aerobic count	Malonaldehyde	Volatile basic nitrogen	pH	Sensory
0	2.87±0.03^{k}	0.88±0.00^{l}	8.68±0.02^{f}	6.45±0.04^{a}	9.00±0.00^{a}
1	3.11±0.09^{j}	1.07±0.08^{k}	9.80±0.07^{d}	6.42±0.00^{a}	8.75±0.25^{ab}
8	3.04±0.09^{j}	1.17±0.07^{j}	8.68±0.01^{f}	6.49±0.33^{a}	8.25±0.75^{abc}
15	3.40±0.05^{i}	1.20±0.07^{j}	9.24±0.03^{e}	6.51±0.24^{a}	8.50±0.50^{ab}
22	3.92±0.02^{h}	1.44±0.06^{i}	10.65±0.21^{c}	6.36±0.00^{a}	8.00±0.00^{bc}
29	4.14±0.06^{g}	1.59±0.05^{h}	10.65±0.35^{c}	6.30±0.00^{a}	7.58±0.42^{c}
36	4.57±0.03^{f}	1.75±0.01^{g}	10.93±0.13^{c}	6.32±0.00^{a}	5.50±0.50^{d}
43	5.22±0.02^{e}	1.91±0.05^{f}	10.65±0.30^{c}	6.30±0.08^{a}	5.33±0.67^{d}
50	5.22±0.01^{e}	2.52±0.06^{e}	10.93±0.28^{c}	5.81±0.06^{b}	4.75±0.25^{d}
57	5.44±0.07^{d}	2.62±0.03^{d}	10.93±0.45^{c}	5.76±0.09^{b}	4.92±0.08^{d}
64	5.87±0.01^{c}	3.70±0.06^{c}	11.49±0.12^{b}	5.15±0.01^{c}	3.50±0.50^{e}
71	6.09±0.03^{b}	4.92±0.03^{b}	12.05±0.20^{a}	4.92±0.02^{d}	2.42±0.58^{f}
78	6.31±0.03^{a}	5.42±0.06^{a}	11.77±0.45^{ab}	4.73±0.16^{d}	2.83±0.17^{ef}

All values are mean standard deviation of three replicates.
$^{a–l}$ Means within a column with different letters are significantly different ($p<0.05$).

were stored at different temperatures (−18°C, −6°C, and −1°C). Each sample was tested on every weekly sampling day over 204 days. The TBARS value of M1-18 was 4.18±0.01 MDA mg/kg at day 204, that of M1-6 was 7.19±0.05 MDA mg/kg at day 204, and that of M1-1 was 5.42±0.06 MDA mg/kg at day 78. Second, the initial TBARS value of the pork lard samples was 0.09±MDA mg/kg. This value was also measured in samples stored under each temperature condition. The TBARS value for L1-10 was 0.35±0.01 MDA mg/kg at day 204, that of L1-25 was 1.10±0.05 MDA mg/kg at day 204, that of L1-35 was 0.76±0.01 MDA mg/kg at day 78, and that of L1-45 was 1.22±0.05 MDA mg/kg at day 78. Significant difference was found between days 0 and 204 ($p<0.05$). Lipid oxidation showed a tendency to increase over the storage period as well; the higher the storage temperature, the higher the lipid oxidation. This result was similar with study of Lee et al. (2004).

Volatile basic nitrogen (VBN)

VBN value has also been used as a good indicator of bacterial growth and protein deterioration and decomposition (Fanco et al., 2002; Kang et al., 2002; Vinci and Antonelli, 2002). One study (Field and Chang, 1969) has reported that enzymes and microorganisms in food decompose protein into peptides and amino acids. Therefore, VBN value was selected as an indicator and measurements were shown in Table 1 and 2. Samples pork cutlet (M) showed significant differences during the storage period ($p<0.05$). The initial value for pork cutlet (M) was 8.68±0.02 mg% and samples were kept at each experimental temperature during the 204 day study period, and then VBN values were measured once each week. VBN values of M1-18, M1-6, and M1-1 were 15.00±0.02 mg% at day 204, 16.66±0.30 at day 204, and 11.77±0.45 mg% at day 78, respectively. The results confirmed that VBN value is an appropriate proper measure for processed meat products.

pH

pH is a widely used estimate of the quality of food, including meat products (Jeremiah et al., 1991). Several studies have

Table 3. The changes of pork lard during storage at 10℃ and 25℃

Day/ 10℃	Malonaldehyde	Acid value	Peroxide value	Sensory	Day/ 25℃	Malonaldehyde	Acid value	Peroxide value	Sensory
0	0.09±0.06^{mn}	0.02±0.01^{q}	2.91±0.50^{r}	9.00±0.00^{a}	0	0.09±0.06^{r}	0.02±0.01^{s}	2.91±0.50^{r}	9.00±0.00^{a}
1	0.09±0.06^{mn}	0.02±0.00^{q}	2.97±0.11^{r}	9.00±0.00^{a}	1	0.11±0.08^{r}	0.02±0.01^{s}	2.97±0.10^{r}	9.00±0.00^{a}
8	0.10±0.07^{kmn}	0.02±0.00^{q}	3.00±0.30^{r}	9.00±0.50^{a}	8	0.11±0.00^{r}	0.05±0.01^{r}	2.80±0.10^{r}	8.50±0.50^{a}
15	0.11±0.06^{klmn}	0.04±0.00^{p}	3.13±1.30^{r}	9.00±0.50^{a}	15	0.11±0.00^{r}	0.07±0.01^{q}	4.53±2.60^{q}	9.00±0.00^{a}
22	0.11±0.00^{klmn}	0.06±0.01^{o}	3.62±0.13^{qr}	9.00±0.00^{a}	22	0.13±0.06^{r}	0.08±0.03^{q}	6.28±0.17^{p}	8.75±0.50^{a}
29	0.11±0.01^{klmn}	0.08±0.01^{n}	2.96±0.36^{r}	9.00±0.00^{a}	29	0.14±0.05^{r}	0.13±0.02^{op}	8.69±0.14^{o}	8.75±0.67^{a}
36	0.12±0.00^{jklmn}	0.10±0.01^{m}	4.20±0.10^{q}	9.00±0.00^{a}	36	0.17±0.05^{qr}	0.13±0.01^{op}	9.65±0.40^{o}	8.50±0.75^{a}
43	0.14±0.05^{ijklmn}	0.11±0.01^{lm}	6.15±0.11^{op}	8.75±0.25^{a}	43	0.19±0.11^{qr}	0.11±0.01^{p}	11.06±0.14^{n}	8.33±0.00^{ab}
50	0.14±0.01^{ijklmn}	0.11±0.01^{klm}	5.54±0.11^{p}	8.75±0.25^{a}	50	0.25±0.06^{pq}	0.14±0.01^{no}	14.04±0.14^{l}	8.33±0.50^{ab}
57	0.16±0.06^{hijklmn}	0.14±0.01^{hi}	6.71±0.10^{no}	8.75±0.25^{a}	57	0.32±0.06^{op}	0.13±0.01^{op}	9.29±0.40^{o}	7.58±0.75^{bc}
64	0.16±0.05^{hijklmn}	0.13±0.01^{hij}	7.08±0.11^{mno}	8.83±0.17^{a}	64	0.35±0.04 ^{nop}	0.14±0.01^{no}	10.92±0.14^{n}	7.58±0.33^{bc}
71	0.17±0.02^{ghijklm}	0.13±0.01^{ijk}	7.88±0.11^{klmn}	8.83±0.17^{a}	71	0.36±0.02^{mno}	0.14±0.01^{no}	12.54±0.40^{m}	7.58±0.75^{bc}
78	0.19±0.01^{fghijk}	0.14±0.01^{gh}	7.88±0.10^{klmn}	8.58±0.42^{a}	78	0.43±0.05^{klmn}	0.15±0.01^{n}	14.16±0.14^{l}	7.58±0.00^{bc}
85	0.17±0.06^{ghijklmn}	0.10±0.01^{gh}	7.31±0.20^{mn}	8.67±0.33^{a}	85	0.40±0.06^{lmno}	0.32±0.01^{m}	22.49±0.50^{k}	7.58±0.25^{bc}
92	0.18±0.06^{fghijkl}	0.11±0.01^{lm}	7.63±0.50^{lmn}	8.67±0.35^{a}	92	0.43±0.08^{klmn}	0.48±0.01^{i}	24.14±0.14^{j}	7.58±0.75^{bc}
99	0.19±0.07^{fghijk}	0.12±0.01^{jkl}	7.31±0.24^{mn}	8.67±0.40^{a}	99	0.46±0.00^{klm}	0.38±0.01^{l}	25.79±1.30^{i}	7.58±0.14^{bc}
106	0.19±0.06^{fghijk}	0.11±0.02^{lm,}	7.63±0.10^{lmn}	8.50±0.25^{a}	106	0.48±0.00^{jkl}	0.42±0.00^{k}	24.66±0.40^{j}	7.25±0.50^{cd}
113	0.20±0.05^{efghij}	0.13±0.01^{hij}	7.94±2.60^{klm}	8.50±0.50^{a}	113	0.51±0.08^{ijk}	0.45±0.00^{j}	22.27±0.20^{k}	7.25±0.67^{cd}
120	0.23±0.05^{cdefgh}	0.16±0.01^{efg}	8.26±0.14^{jklm}	8.50±0.50^{a}	120	0.62±0.07^{jhi}	0.48±0.01^{i}	23.90±0.32^{j}	7.25±0.25^{cd}
127	0.21±0.06^{defghi}	0.14±0.02^{gh}	8.57±0.40^{ijkl}	8.25±0.75^{ab}	127	0.57±0.07^{hij}	0.51±0.01^{h}	29.97±0.32^{g}	7.00±0.67^{cd}
134	0.22±0.00^{cdefghi}	0.15±0.01^{fg}	8.89±0.20^{hijk}	8.50±0.50^{a}	134	0.60±0.06^{hi}	0.54±0.01^{g}	27.14±0.40^{h}	7.00±0.00^{cd}
141	0.28±0.02^{abcde}	0.16±0.01^{ef}	9.20±0.50^{ghij}	8.38±0.56^{ab}	141	0.85±0.05^{bc}	0.57±0.01 ^{f}	33.51±0.17^{e}	6.67±0.50^{d}
148	0.26±0.00^{bcdef}	0.18±0.00^{cd}	9.52±0.36^{fghi}	8.25±0.50^{ab}	148	0.74±0.01^{def}	0.54±0.01^{g}	30.39±0.24^{g}	6.67±0.00^{d}
155	0.24±0.06^{cdefgh}	0.17±0.01^{de}	9.83±0.10^{efgh}	8.54±0.67^{a}	155	0.68±0.05^{fgh}	0.54±0.01^{g}	32.01±2.60^{f}	6.67±0.00^{d}
162	0.25±0.00^{bcdefg}	0.18±0.00^{cd}	10.15±0.14^{defg}	8.50±0.75^{a}	162	0.71±0.05^{efg}	0.54±0.01^{g}	33.63±0.17^{e}	6.50±0.00^{d}
169	0.27±0.05^{abcde}	0.19±0.00^{c}	10.46±1.30^{cdef}	8.50±0.67^{a}	169	0.79±0.11^{cde}	0.54±0.01^{g}	35.25±0.14^{d}	5.67±0.00^{e}
176	0.28±0.01^{abcde}	0.17±0.00^{de}	11.09±0.13^{abcd}	8.33±0.52^{ab}	176	0.82±0.06^{bcd}	0.60±0.01^{e}	43.90±0.40^{c}	5.00±0.00^{f}
183	0.29±0.06^{abcd}	0.22±0.01^{b}	10.78±0.36^{bcde}	7.58±0.52^{bc}	183	0.88±0.12^{bc}	0.67±0.02^{d}	44.12±0.32^{c}	4.75±0.00^{fg}
190	0.33±0.03^{ab}	0.24±0.01^{a}	11.41±0.14^{abc}	7.25±0.67^{c}	190	1.04±0.04^{a}	0.70±0.01^{c}	45.89±0.32^{b}	4.25±0.00^{gh}
197	0.30±0.02^{abc}	0.21±0.01^{b}	11.72±0.32^{ab}	8.35±0.65^{ab}	197	0.90±0.02^{b}	0.76±0.01^{b}	57.39±0.10^{a}	4.00±0.00^{h}
204	0.35±0.01^{a}	0.22±0.01^{b}	12.04±0.10^{a}	7.00±0.92^{c}	204	1.10±0.05^{a}	0.92±0.02^{a}	57.39±0.24^{a}	3.88±0.00^{h}

All values are mean standard deviation of three replicates.
$^{a–s}$ Means within a column with different letters are significantly different ($p<0.05$).

reported that microorganisms degrade protein and produce organic sulfides and amines that increase pH during storage (Brown et al., 1998; Devine et al., 1993; Gregory, 2005; Hambrecht et al., 2003). Therefore, pH was selected as an indicator of freshness and pH measurements for the samples appear in Table 1 and 2. The pH of the M1 was measured over 204 days

Table 4. The changes of pork lard during storage at 35℃ and 45℃

Temperature	Day	Malonaldehyde	Acid value	Peroxide value	Sensory
35℃	0	0.09±0.06^{e}	0.02±0.01^{j}	2.91±0.50^{i}	9.00±0.00^{a}
	1	0.14±0.06^{de}	0.12±0.01^{i}	2.84±0.20^{i}	9.00±0.00^{a}
	8	0.15±0.05^{de}	0.14±0.01^{i}	3.10±0.12^{i}	8.50±0.75^{a}
	15	0.16±0.06^{de}	0.16±0.01^{h}	5.82±0.20^{h}	8.50±0.50^{a}
	22	0.16±0.03^{de}	0.19±0.03^{g}	7.26±0.32^{g}	8.50±0.75^{a}
	29	0.21±0.01^{cde}	0.22±0.02^{f}	10.16±0.32^{f}	8.25±0.92^{ab}
	36	0.22±0.06^{cde}	0.26±0.01^{e}	17.99±0.10^{e}	7.58±0.00^{bc}
	43	0.24±0.17^{bcde}	0.29±0.02^{d}	17.99±0.18^{e}	7.58±0.50^{bc}
	50	0.35±0.01^{abcd}	0.29±0.01^{d}	29.43±0.20^{d}	7.08±0.00^{cd}
	57	0.43±0.05^{abc}	0.31±0.01^{c}	29.54±0.18^{d}	7.00±0.08^{cd}
	64	0.47±0.06^{ab}	0.34±0.02^{b}	32.96±0.20^{c}	6.50±0.17^{de}
	71	0.57±0.06^{a}	0.34±0.01^{b}	43.28±0.18^{a}	6.00±0.33^{e}
	78	0.76±0.01^{a}	0.54±0.02^{a}	41.35±0.20^{b}	5.92±0.58^{e}
45℃	0	0.09±0.06^{g}	0.02±0.01^{l}	2.91±0.50^{j}	9.00±0.00^{a}
	1	0.16±0.11^{fg}	0.08±0.01^{k}	2.99±0.15^{j}	8.75±0.25^{ab}
	8	0.21±0.06^{ef}	0.11±0.02^{j}	3.00±0.25^{j}	7.58±0.42^{c}
	15	0.26±0.00^{e}	0.21±0.01^{i}	12.54±0.50^{i}	8.25±0.75^{bc}
	22	0.27±0.05^{e}	0.23±0.02^{h}	16.67±0.24^{h}	7.58±0.42^{c}
	29	0.47±0.05^{d}	0.24±0.01^{g}	34.79±0.46^{g}	6.75±0.25^{d}
	36	0.52±0.01^{d}	0.28±0.01^{f}	34.56±0.40^{g}	6.83±0.17^{d}
	43	0.53±0.05^{d}	0.34±0.01^{c}	42.01±0.34^{f}	5.75±0.25^{e}
	50	0.64±0.06^{c}	0.32±0.01^{d}	57.86±0.15^{e}	5.25±0.50^{ef}
	7	0.84±0.07^{b}	0.30±0.00^{e}	62.93±0.34^{d}	4.75±0.75^{fg}
	64	0.91±0.01^{b}	0.34±0.01^{c}	63.97±0.15^{c}	4.50±0.25^{gh}
	71	1.16±0.00^{a}	0.39±0.01^{b}	85.95±0.34^{b}	3.88±0.50^{hi}
	78	1.22±0.05^{a}	1.48±0.01^{a}	115.10±0.15^{a}	3.50±0.00^{i}

All values are mean standard deviation of three replicates.
$^{a–l}$ Means within a column with different letters are significantly different ($p<0.05$).

on every weekly sampling day. The initial pH value of was 6.45±0.04; these values decreased significantly during the storage period ($p<0.05$). The pH values of the individual samples (M1-18, M1-6, and M1-1) were 6.12±0.00 at day 204, 5.37±0.33 at day 204, and 4.73±0.16 at day 78, respectively.

Acid value (AV) and peroxide value (POV)

Lipid oxidation, one of the most important determinants of shelf life, occurs during food production and storage (Castro et al., 2007; Baggio and Bragagnolo, 2006). POV is one of the most widely used methods to evaluate lipid oxidation in processed meat products and represents the content of the primary oxides that form during oxidation. AV is also a popular method with which to measure lipid oxidation. AV is generally associated with lipase activity originating from

microorganisms. The quality changes in AV and POV for pork lard under the experimental storage conditions are shown in Table 3 and 4. We observed that the values rapidly increased in all samples. Total samples were divided in accordance with the temperature conditions, and those samples were assessed over 204 days. The initial AV was 0.02±0.01 mg KOH/g, and initial POV was 2.91±0.50 meq/kg. AVs and POV for pork lard samples increased markedly during overall storage. For the temperature conditions of L1-10, L1-25, L1-35, and L1-45, AV values were 0.22 mg±0.01, 0.92±0.02, 0.54±0.02, and 1.48±0.01 mg KOH/g, respectively, at day 204. Respective POV was 12.04±0.10, 57.39±0.24, 41.35±0.20, and 115.10±0.15 meq/kg. The results showed that AV and POV gradually increased without exception under all temperature conditions during overall storage. However, measured POV and AVs of samples stored at higher temperature were higher than those of samples stored at lower temperatures. The results of this study are similar to those of López-Duarte and Vidal-Quintanar (2009). In their research, although POV values were studied in various samples, POV were increased significantly during the storage period. In particular, POV increased significantly with temperature.

Sensory evaluation

Sensory evaluation is a useful tool with which to judge the quality of food. Numerous studies have used sensory evaluation as an indicator of food quality (Ambrosiadis et al., 2004; Bovolenta et al., 2008; Lu et al., 2011). Changes in the sensory evaluation of pork cutlet and pork lard are presented in Table 1, 2, 3, and 4. Sensory analysis was performed using a 9-point hedonic scale. The evaluation criteria were defined such that the initial quality level was 9 points, and the quality limit was 5 points. The relationship between storage period and sensory quality was analyzed using a linear regression equation. Sensory assessments decreased significantly during the experimental period and decreased more rapidly at higher storage temperature ($p<0.05$).

Estimate of the shelf life for pork cutlet and pork lard

Cutlet meat product with frozen distribution was selected and kept at −18℃, −6℃, and −1℃ for 204 days. Pork lard was also selected and kept at 10℃, 25℃, 35℃, and 45℃ for 204 days. Accelerated shelf life tests are used because these selected samples have a long shelf-life, assessing their characteristics over time requires comparatively higher costs and more time. Quality indicators were selected according to the characteristics of processed meat products. The selected microbiological indicators were TAC and coli form count, and the selected physicochemical indicators were TBARS, VBN, pH, AV, POV, and Sensory evaluation. Experimental data for pork cutlet and pork lard were analyzed using zero- and first-order reactions, Arrhenius equation, and Q_{10}. Initially, quality changes displayed linear regression according to the zero- and first-order equations, and then reaction order was selected based on higher r^2. Activation energy and Q_{10} were calculated using the constant k applied to the Arrhenius equation. Other quality limits were calculated and analyzed using correlated linear regression of sensory evaluation with experimental data.

In this result of estimated shelf-life analysis, the quality limits of cutlet, M1-18, M1-6, and M1-1 were reached at 12.36–13.91, 1.99–3.67 and 1.48–1.97 months (Table 5). And in case of pork lard, L1-10, L1-25, L1-35 and L1-45 were reached 10.17–36.34, 5.76–7.48, 3.21–4.07 and 1.57–2.94 months, respectively (Table 6).

Conclusion

The purpose of this study was to analyze the quality changes associated with various temperatures in processed meat products and provide more easily used processes for establishing shelf life using various quality indicators (legal indicators

Table 5. Estimated shelf life of pork cutlet (M) according to storage temperature using the Arrhenius equation

Quality indicator	Temperature (T)	Reaction order	Constant $k^{1)}$	r^2	$Ea^{2)}$ (kcal/mol)	Q_{10}	Estimated shelf life (mon)
TAC	255	Zero	0.0265	r^2=0.9701	3.70	1.32±0.021^{a}	12.89±4.09^{a}
	267		0.0282	r^2=0.8958		1.29±0.02^{ab}	3.67±0.63^{b}
	272		0.0458	r^2=0.9841		1.27±0.02^{b}	1.90±0.27^{b}
TBARS	255	Zero	0.0165	r^2=0.9339	8.77	1.92±0.78^{a}	12.36±1.90^{a}
	267		0.0305	r^2=0.9387		1.82±0.70^{a}	2.34±0.49^{b}
	272		0.0515	r^2=0.8472		1.78±0.66^{a}	1.48±0.03^{b}
VBN	255	Zero	0.0284	r^2=0.9669	2.33	1.19±0.32^{a}	12.59±0.45^{a}
	267		0.0365	r^2=0.9783		1.17±0.28^{a}	3.45±0.20^{b}
	272		0.0373	r^2=0.8241		1.17±0.26^{a}	1.97±0.32^{b}
pH	255	Zero	0.0018	r^2=0.9749	18.69	4.02±1.16^{a}	13.91±0.42^{a}
	267		0.0056	r^2=0.9606		3.57±0.97^{a}	1.99±0.30^{b}
	272		0.0216	r^2=0.8131		3.41±0.89^{a}	1.58±0.10^{b}
Sensory	255	Zero	0.0101	r^2=0.8402	17.22	3.60±0.25^{a}	13.54±1.55^{a}
	267		0.0431	r^2=0.9663		3.23±0.17^{b}	2.94±0.20^{b}
	272		0.0867	r^2=0.9517		3.09±0.15^{b}	1.62±0.08^{b}

All values are mean standard deviation of three replicates.
^{a,b} Means within a column with different letters are significantly different ($p<0.05$).
$^{1)}$ Rate constant.
$^{2)}$ Activation energy in kJ/mol.
TAC, total aerobic count; TBARS, thiobarbituric acid reactive substances assay; VBN, volatile basic nitrogen.

Table 6. Estimated shelf life of pork lard (L) according to storage temperature using the Arrhenius equation

Quality indicator	Temperature (T)	Reaction order	Constant $k^{1)}$	r^2	$Ea^{2)}$ (kcal/mol)	Q_{10}	Estimated shelf life (mon)
AV	283	First	0.0099	r^2 =0.4893	6.35	1.47±0.13^{a}	10.17^{a}
	298		0.0160	r^2 =0.8431		1.42±0.10^{a}	5.76^{b}
	308		0.0258	r^2 =0.6243		1.39±0.24^{a}	4.07^{bc}
	318		0.0331	r^2 =0.6978		1.36±0.49^{a}	2.94^{c}
POV	283	Zero	0.0439	r^2 =0.9496	17.21	2.84±0.41^{a}	36.34^{a}
	298		0.2263	r^2 =0.9355		2.57±0.63^{a}	7.48^{b}
	308		0.5503	r^2 =0.9405		2.42±0.42^{a}	3.22^{c}
	318		1.2760	r^2 =0.9403		2.29±0.71^{a}	1.57^{d}
TBARS	283	Zero	0.0011	r^2 =0.9593	12.69	2.16±0.30^{a}	15.16^{a}
	298		0.0046	r^2 =0.9615		2.01±0.52^{a}	6.04^{b}
	308		0.0071	r^2 =0.8652		1.92±0.28^{a}	3.21^{c}
	318		0.0138	r^2 =0.9572		1.84±0.66^{a}	1.67^{c}

Table 6. Estimated shelf life of pork lard (L) according to storage temperature using the Arrhenius equation (continued)

Quality indicator	Temperature (T)	Reaction order	Constant $k^{1)}$	r^2	$Ea^{2)}$ (kcal/mol)	Q_{10}	Estimated shelf life (mon)
Sensory	283	Zero	0.0070	r^2 =0.7390	11.70	2.03±0.93[a]	18.50[a]
	298		0.0220	r^2 =0.8930		1.90±0.80[a]	6.49[b]
	308		0.0400	r^2 =0.9700		1.82±0.32[a]	3.42[c]
	318		0.0690	r^2 =0.9730		1.76±0.44[a]	1.87[d]

All values are mean standard deviation of three replicates.
[a–d] Means within a column with different letters are significantly different ($p<0.05$).
[1)] Rate constant.
[2)] Activation energy in kJ/mol.
AV, acid value; POV, peroxide value; TBARS, thiobarbituric acid reactive substances assay.

and non-legal indicators). Quality changes were analyzed using zero- and first-order kinetic equations, Q10, and Arrhenius equation in ground meat kind of pork cutlet and pork lard (Coliform group counts were excluded as an indicator). The limits of quality indicators were established according to their correlation with the results of sensory evaluation tests. The shelf life of processed meat products was determined using microbiological, physicochemical, and sensory indicators at various temperatures. The results generally showed that temperature affects the shelf life of these products during storage. Finally, the shelf life of pork cutlet was suggested with shortest 12.36 months at −18℃, 1.99 months at −6℃, and 1.48 months at −1℃. Also, the shelf life of pork lard was suggested with shortest 10.17 months at 10℃, 5.76 months at 25℃, 3.21 at 35℃, and 1.57 months at 45℃. This study primarily offered a process through which to establish shelf life and calculate quality limits. It provides useful basic information for predicting and estimating the quality of processed meat products under various temperature conditions. Further studies will be conducted for the validation of this developed model.

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