The Design of Experiment in the Optimization of the Expiration Date for Sealed Takoyaki of Takoya-mie Hauz

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Abstract – **Takoyamie-Hauz was established during the pandemic as Takoyaki with a menu of different flavors. The CEO expanded its products by offering packaged takoyaki that can be stored in the refrigerator. Due to the desire of the Takoyamie Hauz family to bring their customers the first-hand experience of 'Do-It-Yourself' (DIY) takoyaki, the researchers plan to predict and optimize the storage convenience and prolongation of the takoyaki shelf span. This study focused on optimizing the expiration date of packaged Takoyaki. The researchers' response variable is the expiration time and date, which are very important for food quality and safety. Five (5) factors were considered in the design of experiments, which are: temperature, humidity, alcohol concentration, methane and storage time. The data will be recorded with the use of food monitoring device for two weeks. The researchers will make use of a 2^5 full factorial experimental design. For the evaluation of results, Minitab was used to analyze and visualize the data gathered. The results showed the predicted and optimized results for the expiration date of minimum in 8 days for minimum factor values.**

Keywords – **Takoyaki, expiration, food quality, 2k full factorial, Minitab**

I. INTRODUCTION

Foods are organic compounds that are eaten to provide nutrition. Foods come from either plants or animals and are composed of moisture, protein, lipids, carbohydrates, minerals, and other organic compounds. Foods can get spoiled through microbiological, chemical, or physical processes. Foods are subject to spoiling in terms of their nutritional value, color, texture, and palatability [1]. As a result, foods must be preserved if they are to maintain their quality over an extended length of time. The procedures or methods used to maintain both internal and exterior elements that could lead to food decomposition are referred to as food preservation. The main goal of food preservation is to prolong its shelf life while preserving its original nutritional composition, color, texture, and flavor [2]. Traditional food preservation techniques are widely utilized all throughout the world. Drying, freezing, chilling, pasteurization, and chemical preservation are examples. However, scientific advances and improvements are influencing the evolution of existing technologies and the development of new ones, such as irradiation, high-pressure technology, and hurdle technology. Growing, harvesting, processing, packing, and distribution have all become part of the food processing process. As a result, an integrated food preservation strategy would be advantageous during the food manufacturing and processing stages [3].

A. Background of the Study

The food preservation and processing industry has been rapidly increasing to accommodate rising consumer demand [2]. One of these food industries and businesses is the Takoyamie-Hauz which specializes in creating Takoyaki dish. This mini business originated in Quezon City, Philippines which started during the pandemic era. According to the CEO, the original idea was only a menu during their afternoon snack or merienda and this gave an idea to start a small business which the menu started as a party order with 15 pieces to 30 pieces of Takoyaki balls per order. Little by little, the business started to grow with several resellers and business partners. As the demand continue to increase, the CEO created a DIY Takoyaki which is sealed through frozen vacuum sealed packs. Takoyaki tastes best when it's hot and fresh, but it's important to store and preserve the food if the customer wants or plans to eat in other time or day [4]. Freezing method was used during the storing time for the Takoyaki dish. Due to the desire of the CEO to give the customers the best food experience and quality, this paper initializes the best practices to store the takoyaki in the best way. According to the CEO, it is important for the business to put an expiration date of the sealed Takoyaki just like other products normally seen in the supermarket.

B. Statement of the Problem

The main problem of this study is the need to predict and optimize the expiration date for the DIY sealed Takoyaki for the Takoyamie-Hauz using the design of experiments. This is essential to ensure the product's quality and safety, especially considering the desire to provide customers with a DIY Takoyaki experience. This specifically concerns what are factors that influence the time of expiration of sealed Takoyaki. This also specify what are the optimal conditions to predict and optimize these factors for storage convenience and shelf span of packaged Takoyaki with the time as the response. Lastly, this requires to answer how can the researchers evaluate and validate the results. Achieving an optimal expiration date is vital to meet customer expectations for freshness and taste. This is to establish standardized conditions for packaging and storage that result in longer expiration periods while ensuring the product's safety.

C. *Objectives of the Study*

The main goal of this study is to predict and optimize the expiration Date for DIY sealed Takoyaki of Takoyamie Hauz using the design of experiments. The researchers specifically aim the following:

1) To determine the factors that influence the time of expiration of sealed Takoyaki
2) To identify the idea and optimal conditions for predicting and optimizing the factors for storage convenience and shelf life of packaged Takoyaki
3) To evaluate and validate the experiments using the 2k full Factorial.

D. *Scope and Limitations*

The research focuses on improving the expiration date of packaged Takoyaki produced by Takoyamie-Hauz. Temperature, humidity, MQ3 alcohol content, MQ4 CH4 (methane) levels, and storage period are all the factors considered in experiment design. Data will be collected for two weeks utilizing food monitoring device with the use of the internet of things in both open and closed environment. The data will be validated using the 2^6 full factorial design of experiments. Minitab will be used for data analysis and visualization. While the study's goal is to provide insights into improving Takoyaki's shelf life, it does not investigate other areas of food manufacturing or delivery. Furthermore, any specific legal and regulatory concerns about food safety and labeling will not be addressed in depth within the scope of this study.

II. RELATED LITERATURE

According to Jiyoung Kim, the mean kinetic temperature (MKT) is a predictor of food quality used in the approach for determining remaining shelf life based on food temperature history. It has been shown effective for low-temperature pasteurized milk and packaged chicken, and it could be used for other foods [5]. On the other hand, just like any other food, Takoyaki can also be spoiled if it doesn`t store in a cold place like the fridge or freezer, However, those storage have a time limit before the takoyaki goes bad, two days in the fridge and a month in the freezer [6]. In order to determine the shelf life of food products, the research contrasts regression approaches with maximum likelihood estimation (MLE) methodologies. In particular for smaller percentiles, MLE has stronger coverage, better bias characteristics, and lower mese values. The initiative emphasizes the significance of temperature in shelf-life investigations and provides useful insights into experiment design and food shelf-life estimation [7]. The storage process of frozen foods involves various modes of deterioration, necessitating the use of various prediction methods to determine their shelf life. Proper documentation and a clear margin of safety are crucial for ensuring the safety of these products [8]. The authors propose a smart system that uses gas, humidity, and temperature sensing mechanisms to keep track of the quality of food and alert the user about the quality of food and the time spans of its deterioration [9]. From the point of view of food safety, the shelf life of the food depends on four main factors: formulation, processing, packaging and storage. It is important to do it in a complementary way to establish the best by date of a product [10]. Sensory differential ratings, initial analytical moisture values and storage moisture values generated by changes in package weight provide important insight into the moisture tolerance of foods [11]. Foods with a water activity of 0.6 will lose water when the relative humidity is below 60% and absorb water when it is above 60%. ERH is an indicator of what chemical reactions may occur during distribution and how much packaging protection a product needs to have to give it the shelf life it needs. It is a valuable tool for food and packaging development [12]. Detection of gases such as methane, ammonia, and ethylene, which are naturally released during food spoilage, can be used to detect food spoilage. Using sensors to detect the presence of these gases in food can detect food spoilage early and prevent the consumption of spoiled food [13]. Detecting naturally emitted gases such as Methane, Ammonia and Ethylene as foods decay can be used to detect food spoilage. Using sensors to detect the presence of these gases among foods can help detect food spoilage early and prevent consumption of spoiled food [14]. One of the articles discuss also the importance of monitoring temperature and humidity in food packaging. For example, the article describes the use of critical time temperature indicators (TTI) to monitor frozen food products. By monitoring temperature and humidity in real time, smart packaging can helps ensure food is stored and transported in optimal conditions, improving food safety and reducing food waste [15]. It was also been discussed by Rinika Paul & Sanketh Prabhu that food grains can spoil due to humidity, precipitation, and temperature to maintain food quality requirements, an effective food spoilage tracking and warning system are essential. Their device was implemented in an FPGA and the sensors detect if methane levels in the food are beyond a threshold alerting initial stages of spoilage as well as if the food contains moisture [16]. Another article cites different gas sensors like MQ3 and MQ4 to detect food spoilage [17]. Food is the primary necessity of humans but a lot of factors affect food quality like temperature. However, In the food industry, humidity and gas concentrations help the post-harvest quality of horticultural products along with its proper monitoring, from shelf-life and evaluation of losses due to its storing and transportation [18]. The design made by Fera Anugreni and et. Al made use of the MQ3 sensor for alcohol content detection in the food spoilage process. With five days of testing in a row, the author tested the results and recorded the percentage of alcohol content, which averaged 22%, 39%, 46%, 57%, and 67% [19]. Another study provides and includes fundamental environmental factors like temperature, moisture, alcohol location, and light exposure. The device's construction makes use of Arduino UNO. A device that is linked to the Arduino board. a variety of detectors, such as the DHT-11 The MQ4 monitors temperature and moisture. which gauges the location of methane [20]. In order to assess the freshness of food, electrical and biosensors are used. a sophisticated technology that can determine whether common household foods like dairy, meat, and fruit is still fresh. A smart food freshness detector that employs pH, moisture, and gas sensors to decide whether to eat or discard food can help you find and select fresh food [21]. Another journal cites that early detection of gases from various foods, such as ammonia, methane, etc., can help in the fight against gases. Sensors that detect gas emissions from food even before visible signs of spoilage appear. The author of this journal recommends to incorporate different other sensors like pressure, temperature and moisture [22]. Another article implements a user-friendly and cost-effective microsystem that detects whether food is spoiled by monitoring the gases emitted by solid foods, detecting the pH of liquid foods with sensors, and transmitting data via wireless communication. Monitoring of solid foods is done using an MQ-4 gas sensor and monitoring of liquid foods is done using a pH sensor [23]. A multiple nonlinear regression model (MNLR) is proposed to relate temperature and other sensors and maximum storage period [24].

III. METHODOLOGY

A. *Research Design*

This research follows a design of experiments that will guide the researchers to obtain a feasible and accurate result. The article about the design of experiments in the service industry cited a useful quality technique that was incorporated into Motorola's Six Sigma methodology. Experimentation strategies adopted by organizations in these sectors include the classical DoE full factorial. Then, Taguchi used orthogonal. The Response Surface Method used the CCD. Screening used the Plackett-Burman design type. These strategies demonstrate the potential advantages of DoE in the service sector. It has been determined that additional research is required to evaluate the potential of DoE to improve service delivery and performance. Researchers and practitioners can use these trends to develop new methods and strategies for implementing DoE in the service industry [25]. The researchers will incorporate the full factorial design of experiments.

B. *Conceptual Framework*

This part demonstrates how the researchers used the IPO Chart for designing the study, collecting and analyzing data, and interpreting the results.

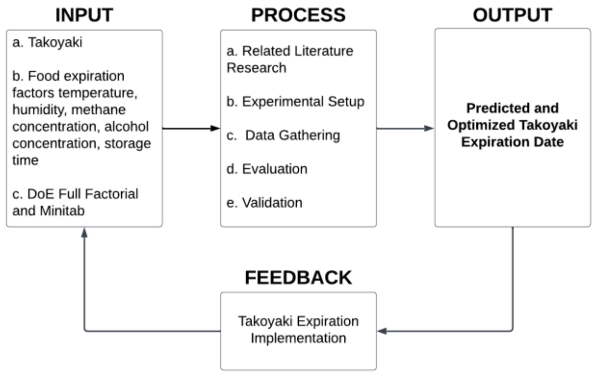

Fig. 1. Input Process Output (Conceptual Framework)

The figure above shows the IPO chart. The input of the researchers is the Takoyaki menu by Takoyamie-Hauz. Knowledge about Takoyaki and food expirations, including temperature, humidity, methane concentration, alcohol concentration, and storage time, is needed in order to implement this study. The researcher also needs to know the Minitab software and implement the full-factorial design of experiments. In the process part, the researchers put up related literature research, which serves as the main body of ideas and knowledge for implementing this study. After that, an experimental setup is initiated with the help of a food monitoring device. During the experiment, data gathering procedures are monitored. Evaluation and validation of the data gathered from the factors of this study are implemented in Minitab. Then this results in the predicted and optimized expiration times for the Takoyaki. The feedback cited was to implement the expiration date for the sealed Takoyaki.

C. Software Flowchart

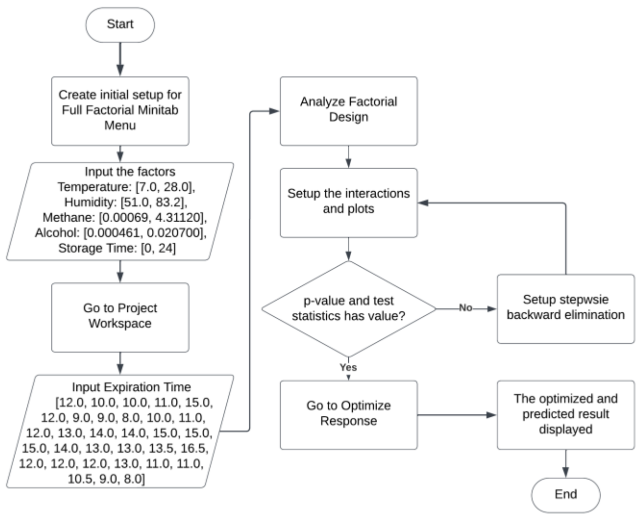

Fig. 2. Minitab Software Setup Flowchart

This figure above shows how the researchers' setup for input factors and responses to the Minitab software for getting the test statistics, plots and graphical representations of the interactions, prediction and the optimization of the data.

IV. DESIGN OF EXPERIMENTS AND DATA ANALYSIS

A. *Food Monitoring Setup*

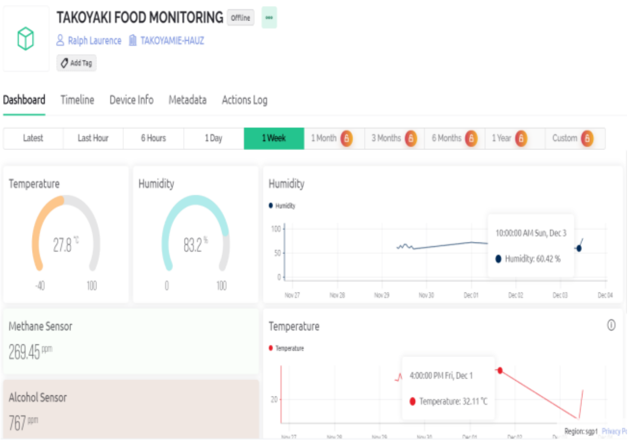

Fig. 3. Blynk Webserver Takoyaki Monitoring Dashboard

The figure above shows the Takoyaki monitoring that was implemented in Blynk Webserver. The values for the temperature, humidity, methane concentration, alcohol content with their charts was created for the monitoring. By monitoring, the researcher was able to get the low and high values needed for each factor. The methane concentration and alcohol concentration were implemented in ppm and converted to mg/L during the Minitab setup. The temperature was measured in degree Celsius and the humidity was measured in percent (%).

B. *Minitab Setup*

Factor	Name	Type	Low	High
A	Temperature	Numeric	7	28
B	Humidity	Numeric	51	83.2
C	Methane	Numeric	0.00069	4.3112
D	Alcohol	Numeric	0.000461	0.0207
E	Storage Time	Numeric	0	24

Fig. 4. Factors Low and High Setup

This figure shows how the researcher put the values of the factors in Minitab for full factorial design of experiments. As demonstrated the temperature ranges from low 7.0°C to high 28.0°C, humidity ranges from low 51.0% to high 83.2%, Methane concentration ranges from low 0.00069 mg/L to high 4.31120 mg/L, alcohol concentration from low 0.000461 mg/L to high 0.020700 mg/L, and storage time ranges from low 0 hour to 24 hours.

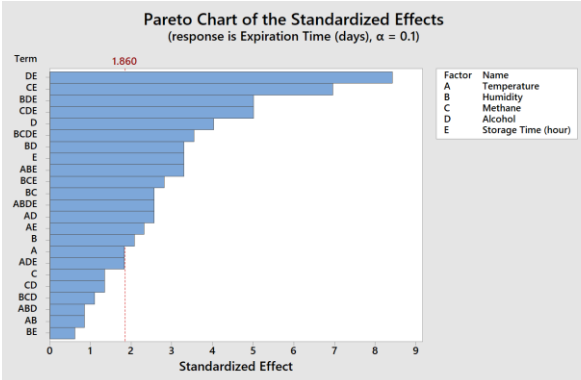

Fig. 5. Pareto Chart for the Factors and Interactions

In the figure represented the pareto chart for the standardized effects in response for the expiration time in days at alpha 0.1. The factors that reaches the red line 1.860 is significant while the factor which not touches the red line is not significant.

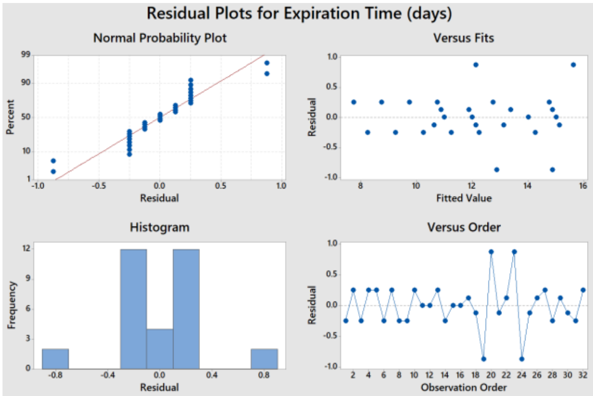

Fig. 6. Residual Plots

The versus fits plot shows that the residual points do not appear to be randomly distributed about zero. There are outliers that indicates variances of the residuals are unequal. This suggest that the researchers should investigate to determine this cause of inequality. The versus order plot shows that the trends in the points may indicate that residuals near each other may be correlated, and not independent in the observation order. As a result, look into the cause. In the normal probability plot does not follows the straight line and there is evidence of nonnormality, outliers, or unidentified variables. The residuals are not normally distributed.

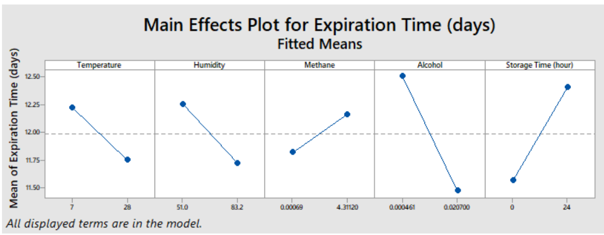

Fig. 7. Main Effects Plot

In the figure above shows the main effects plot for the expiration time of the sealed takoyaki. All the factors affects the response because the line is not horizontal which corresponds to their respective low value and high value.

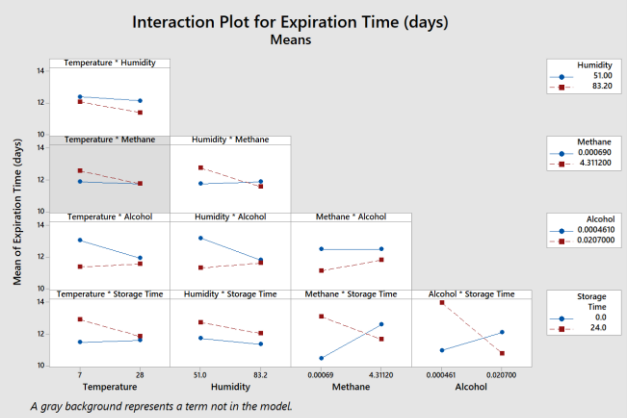

Fig. 8. Interaction Plot for Expiration Time

This graph represents the interaction plot for each factors. The gray color interaction represents that this factor is not significant and included to the interaction effects to the response expiration time.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	23	147.555	6.4154	12.26	0.001
Linear	5	19.164	3.8328	7.32	0.007
Temperature	1	1.758	1.7578	3.36	0.104
Humidity	1	2.258	2.2578	4.31	0.071
Methane	1	0.945	0.9453	1.81	0.216
Alcohol	1	8.508	8.5078	16.25	0.004
Storage Time (hour)	1	5.695	5.6953	10.88	0.011
2-Way Interactions	9	79.508	8.8342	16.88	0.000
Temperature*Humidity	1	0.383	0.3828	0.73	0.417
Temperature*Alcohol	1	3.445	3.4453	6.58	0.033
Temperature*Storage Time (hour)	1	2.820	2.8203	5.39	0.049
Humidity*Methane	1	3.445	3.4453	6.58	0.033
Humidity*Alcohol	1	5.695	5.6953	10.88	0.011
Humidity*Storage Time (hour)	1	0.195	0.1953	0.37	0.558
Methane*Alcohol	1	0.945	0.9453	1.81	0.216
Methane*Storage Time (hour)	1	25.383	25.3828	48.49	0.000
Alcohol*Storage Time (hour)	1	37.195	37.1953	71.06	0.000
3-Way Interactions	7	38.867	5.5525	10.61	0.002
Temperature*Humidity*Alcohol	1	0.383	0.3828	0.73	0.417
Temperature*Humidity*Storage Time (hour)	1	5.695	5.6953	10.88	0.011
Temperature*Alcohol*Storage Time (hour)	1	1.758	1.7578	3.36	0.104
Humidity*Methane*Alcohol	1	0.633	0.6328	1.21	0.304
Humidity*Methane*Storage Time (hour)	1	4.133	4.1328	7.90	0.023
Humidity*Alcohol*Storage Time (hour)	1	13.133	13.1328	25.09	0.001
Methane*Alcohol*Storage Time (hour)	1	13.133	13.1328	25.09	0.001
4-Way Interactions	2	10.016	5.0078	9.57	0.008
Temperature*Humidity*Alcohol*Storage Time (hour)	1	3.445	3.4453	6.58	0.033
Humidity*Methane*Alcohol*Storage Time (hour)	1	6.570	6.5703	12.55	0.008
Error	8	4.188	0.5234		
Total	31	151.742			

Fig. 9. ANOVA Result

In the ANOVA result shows the factors and the interactions that are significant to the response with a p-value < 0.1. On the other hand, the rest also show the factors and the interactions that are not significant to the response with a p-value > 0.1. Overall, the linear, 2 way interations, 3 way interaction and 4 way interactions were significant at 0.1.

Term	VIF
Constant	
Temperature	1.00
Humidity	1.00
Methane	1.00
Alcohol	1.00
Storage Time (hour)	1.00
Temperature*Humidity	1.00
Temperature*Alcohol	1.00
Temperature*Storage Time (hour)	1.00
Humidity*Methane	1.00
Humidity*Alcohol	1.00
Humidity*Storage Time (hour)	1.00
Methane*Alcohol	1.00
Methane*Storage Time (hour)	1.00
Alcohol*Storage Time (hour)	1.00
Temperature*Humidity*Alcohol	1.00
Temperature*Humidity*Storage Time (hour)	1.00
Temperature*Alcohol*Storage Time (hour)	1.00
Humidity*Methane*Alcohol	1.00
Humidity*Methane*Storage Time (hour)	1.00
Humidity*Alcohol*Storage Time (hour)	1.00
Methane*Alcohol*Storage Time (hour)	1.00
Temperature*Humidity*Alcohol*Storage Time (hour)	1.00
Humidity*Methane*Alcohol*Storage Time (hour)	1.00

Fig. 10. Coded Coefficient

In the figure shows the VIF is 1 means there is no multicollinearity among the factors.

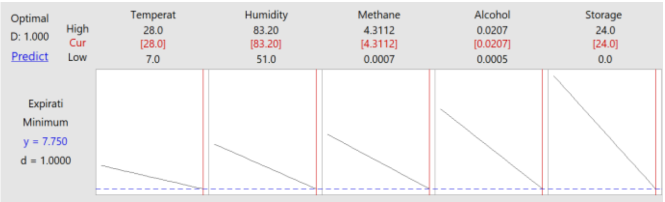

Fig. 11. Optimization Plot

In the figure shows the minimum optimization for the expiration date for sealed takoyaki. At temperature of 28°C, Humidity of 83.20%, Methane concentration of 4.3112 mg/L, Alcohol concentration 0.0207 mg/L and storage time of 24 hours, the minimum date of expiration is at least 8 days after putting it outside the cold container.

Multiple Response Prediction

Variable	Setting
Temperature	28
Humidity	83.2
Methane	4.3112
Alcohol	0.0207
Storage Time (hour)	24

Response	Fit	SE Fit	95% CI	95% PI
Expiration Time (days)	7.750	0.627	(6.305, 9.195)	(5.543, 9.957)

Fig. 12. Response Prediction

The figure shows the accompanying statistical metrics provide additional insights into the reliability. The "Fit" value indicates the goodness of fit for the model, with a value of 7.750 days. The "SE Fit" (Standard Error of the Fit) is 0.627, providing an estimate of the variability of the predicted values. The 95% Confidence Interval (CI) ranges from 6.305 to 9.195 days, indicating the range within which the true expiration time is likely to fall, while the 95% Prediction Interval (PI) spans from 5.543 to 9.957 days, offering a broader prediction range.

Settings

Variable	Setting
Temperature	7
Humidity	51
Methane	0.00069
Alcohol	0.000461
Storage Time (hour)	24

Prediction

Fit	SE Fit	90% CI	90% PI
14.875	0.626561	(13.7099, 16.0401)	(13.0953, 16.6547)

Fig. 13. Predicted Results for Different Factor Values

In this figure, a different predictive model has been employed to estimate the expiration time of Takoyaki, based on specific input settings. It shows that the sealed takoyaki was put in a closed container. The settings include a Temperature of 7 degrees, Humidity at 51%, Methane concentration of 0.00069, Alcohol concentration of 0.000461, and a Storage Time of 24 hours. The predictive model generates a forecasted expiration time of 14.875 days. Or 15 days. The "Fit" value, representing the goodness of fit for the model, is 14.875 days. The "SE Fit" (Standard Error of the Fit) is 0.626561, present an estimate of the variability in the predicted values. The 95% Confidence Interval (CI) ranges from 13.4301 to 16.3199 days, suggesting the likely range within which the true expiration time lies. Additionally, the 95% Prediction Interval (PI) spans from 12.6680 to 17.0820 days, providing a broader prediction range that accounts for potential variations.

V. CONCLUSION

Based on the results of the design of the experiments, the researchers were able to identify and determine the factors that influence the time of expiration of sealed Takoyaki. Through the related research of the study, this states that the temperature, humidity, methane, alcohol and storage time were these factors. The researchers also identified idea and optimal conditions for predicting and optimizing the factors for storage convenience and shelf life of packaged Takoyaki with temperature ranges from low 7.0°C to high 28.0°C, humidity ranges from low 51.0% to high 83.2%, Methane concentration ranges from low 0.00069 mg/L to high 4.31120 mg/L, alcohol concentration from low 0.000461 mg/L to high 0.020700 mg/L, and storage time ranges from low 0 hour to 24 hours. The expiration time were observed and tested by the customers so that the researchers would be able to get the observed time were the sealed Takoyaki would expire when stored inside the refrigerator. As the result of the 2^5 full factorial design of the experiments, The settings include a Temperature of 7°C, Humidity at 51%, Methane concentration of 0.00069 mg/L, Alcohol concentration of 0.000461 mg/L, and a storage Time of 24 hours. The predictive model generates a forecasted expiration time of 14.875 days or 15 days. At temperature of 28°C, Humidity of 83.20%, Methane concentration of 4.3112 mg/L, Alcohol concentration 0.0207 mg/L and storage time of 24 hours, the minimum date of expiration is at least 8 days after putting it outside the cold container. Therefore it is concluded that the sealed takoyaki can last until 15 days inside the cold container and 8 days outside the cold container.

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