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DEPLOYMENT OF TAGUCHI METHOD FOR OPTIMIZATION OF HEAT TREATMENT PROCESS PARAMETERS IN RAW UNCLEAN EDIBLE BIRD'S NEST

(Pelaksanaan Kaedah Taguchi untuk Pengoptimuman Proses Parameter Rawatan Haba Sarang Burung Walit Mentah Belum Bersih)

TAY GUO XUAN*, MAS NORDIANA RUSLI, KHAIRUL ANUAR MOHD ALI & ZAINOL MUSTAFA

ABSTRACT

Heat treatment process as one of the Critical Control Points (CCP) of raw unclean edible bird's nest processing. Main objective of the study was on the determination of optimal combination for the processing. The treatments were the combinations from orthogonal array and signal to noise ratio from Taguchi method with several control variables of conveyor belt speed (0.5, 1.0, 1.5 rpm), temperature of steam shrink tunnel (80, 90, 100 °C) and temperature sensors allocation (Base, Body, Head) were applied in heat treatment process. L_9 (3^3) orthogonal array was adopted in the study where 18 runs were performed with two replications. For this case study, "larger-the-better" approach was selected with the aim to minimize heat penetration time. Results displayed that the optimum condition for heat penetration duration was 11 seconds, where the conveyor belt speed, steam shrink tunnel temperature and temperature sensor allocation were 0.5 rpm, 90°C and head position respectively. Conveyor belt speed was the highest factor that affected heat penetration duration of raw unclean edible bird's nest.

Keywords: edible bird's nest; heat treatment; Taguchi's optimization

ABSTRAK

Proses rawatan haba sebagai salah satu Titik Kawalan Kritikal (CCP) pemprosesan sarang burung walet mentah belum bersih. Objektif utama kajian adalah untuk menentukan kombinasi optimum untuk pemprosesan. Rawatan tersebut adalah gabungan daripada tatasusunan ortogon dan nisbah S/N daripada kaedah Taguchi dengan beberapa pembolehubah iaitu kawalan kelajuan tali sawat (0.5, 1.0, 1.5 rpm), suhu terowong pengecutan wap (80, 90, 100 °C) dan peruntukan sensor suhu. (Asas, Badan, Kepala) digunakan dalam proses rawatan haba. Tatasusunan ortogon L_9 (3^3) telah diterima pakai dalam kajian di mana 18 larian dilakukan dengan dua ulangan. Untuk kajian kes ini, pendekatan "lebih besar-lebih-baik" telah dipilih dengan tujuan untuk mengurangkan masa penembusan haba. Keputusan analisis menunjukkan bahawa keadaan optimum untuk tempoh penembusan haba ialah 11 saat, di mana kelajuan tali sawat, suhu terowong pengecutan stim dan peruntukan sensor suhu adalah 0.5 rpm, 90°C dan posisi kepala. Kelajuan tali pinggang penghantar adalah faktor yang memberi pengaruh yang paling untuk tinggi kepada tempoh penembusan haba sarang burung walet mentah belum bersih.

Kata kunci: sarang burung walet; rawatan haba; pengoptimuman Taguchi

1. Introduction

Limited work has been performed in relation to the raw unclean EBN processing, no work has been conducted to address the process improvement of raw unclean EBN. In dealing with safety issues of RUC EBN lead us to further development and enhancement in heat sterilization technologies. As yet, there is no work and report in optimization of heat sterilization parameters and product quality in previous literature. Prolonged heat treatment causes protein modification which results in protein unfolding and exposure of altered protein (Teodorowicz *et al.* 2017). Hence, the current study is focusing on exploring optimized parameters for the heat sterilization process of raw unclean EBN. Research overview in this study will push the community to a new paradigm where the in-depth analysis of the processing of raw unclean EBN is remarkable and noteworthy for further discussion.

Outburst of Highly Pathogenic Avian Influenza (H5N1) back in 2004 highlighted the safety of cultivating edible bird's nests (Lim *et al.* 2012). One of the strategies proposed by Swayne (2006), stated that vaccination for at-risk birds. This statement remains controversial as vaccines did not totally prevent the reproduction of viruses in the gastrointestinal tract of poultry. Helmi *et al.* (2018) stated that EBN extract has the mechanism of action to hinder HPAI H5N1 virus infection by restraining the virus attachment to the cellular receptor.

Thus, proactive steps about optimization of the heat treatment process have to be taken into account. Taguchi optimization may be one of the approaches to get rid of Highly Pathogenic Avian Influenza H5N1 virus. By selecting the most favorable factor for the parameters of the heat sterilization process, it aids in efficient as well as the cost-effective working of heat sterilization process. Typical trial and error methods are not encouraged and adoption of a well-founded optimization technique is more preferable.

Taguchi merged existing Latin squares in a special way and formulated a method that accommodated different experimental conditions. All factor levels were weighted equally in orthogonal array (OA). Taguchi OA assumed the interaction effects among factors are minimal on the response. Even with minimal interaction between the factors, optimum conditions can be identified as well. Inner and outer arrays proposed by Taguchi to analyze the interaction of both noise and control factors. Inner array focused on the evaluation of control factors on the response while the outer array emphasized on the evaluation of noise factors on the response. Such arrays are also known as experimental design matrices, each combination in the inner array will run against the combinations in the outer array. Specifically, factors in the inner array are orthogonal to those in the outer array. In terms of factor interaction, no confounding effects were observed between control and noise factor. Despite having a large number of experimental runs, confounding effects among control factor effects and interactions where the outcome is influenced by the bias effect (Lochner & Matar 1990). Confounding effect, as one of the major drawbacks of Taguchi design which leads to failure in verification test and confidence level (Bours 2020). Accuracy of the performance estimate relied on the magnitude of factors interactions entanglement (Ghani *et al.* 2013).

Taguchi's approach has proven its effectiveness in process improvement but some Western statisticians disagreed with the method. Phadke (1989) stated that deployment of Taguchi method allowed the improvement in terms of cost and quality especially in automobile industries. Successful implementation leads the organization for optimized outcomes. His concept of optimum value inferred that continual improvement has a restraint that opposed Deming's fifth point. Taguchi received much criticism from other quality gurus. Deming contradicted the quantification of quality loss; Crosby denied the deployment of Taguchi's principles beneficial to American companies (Dobyns & Crawford-Mason 1991). The most remarkable critique found in a journal by Kackar (1985), brief summary of the criticism was listed below:

(1) Absence of data transformation techniques

(2) Lack of emphasis on the interaction effects
(3) Argument on usage of overall performance statistics
(4) Stepwise nature of investigation was not utilized

Hunter (1985) expressed that Taguchi's philosophy of incorporating quality into product design was exceptional but the analysis part remains an issue. Despite having plenty of criticisms, undoubtedly it is effective in cost and quality enhancement. Even though the acceptance rate was gradual, statisticians believed that Taguchi's method might have an impact on the product in the United States. Contributions of Taguchi towards the robust design philosophy were immense but certain restraints were associated with the method itself. Zang *et al.* (2005) addressed that OA does not lead to optimal results, introduction of non-linear optimization approaches enhances the reliability of the experiment outputs. Tsui (1992) realized that deployment of the Taguchi method was unable to identify appropriate solutions for the design problem associated with non-linear behavior. Otto and Antonsson (1993) conveyed the robust design along with constraints in the system with notable non-linear effect.

2. Methodology

The EBNs used as the sample were obtained from the birdhouse in Bandar Tun Razak, Jengka, Pahang. Selected sample was pre-sorted and graded by the supplier. The sample criteria used were white/beige swiftlet nests weighing from 12 to 23g with uniform cleanliness and composition and harvested from one birdhouse in September 2021. White swiftlet *Aerodramus fuciphagus* nesting were used for the study. The number of samples used were 12 EBN which will be used for different treatments. Temperature data loggers used for measurement as below. This equipment is calibrated and the test result is within the test limit.

Table 1: List of weights of raw unclean EBN used

No.	1	2	3	4	5	6	7	8	9	10	11	12
Test Weight (g)	23	16	17	12	14	17	12	18	19	23	21	16

(1) Master Equipment

- (i) Item and Manufacturer: Temperature Data Logger by MadgeTech
- (ii) Model and Serial Number: Oct Temp 2000 (Q27382/N78764)
- (iii) Calibration Date: 25 December 2021
- (iv) Traceability: MSRP20030478
- (v) Software: MadgeTech Secure Software
- (vi) Compliance: Software is complying to US FDA 21 CFR Part 11

(2) Test Equipment

- (i) Item and Manufacturer: Steam Shrink Tunnel by Shengzhou
- (ii) Serial Number and Reference Number: SZ SST200 (MAP9515)
- (iii) Calibration and validation were performed by METCAL Calibration Sdn. Bhd.

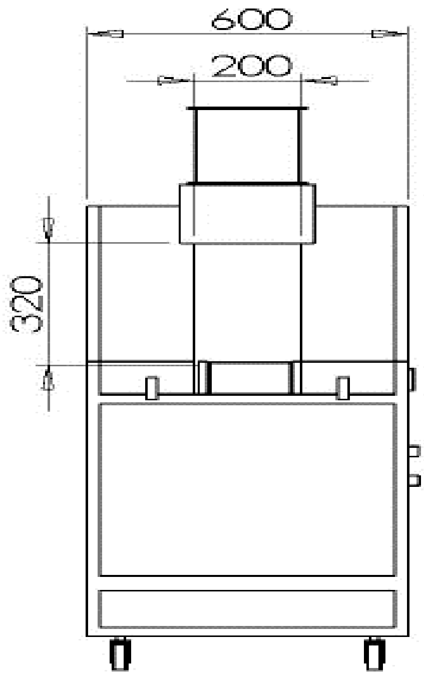

Figure 1: Inlet and outlet dimensions of steam shrink tunnel

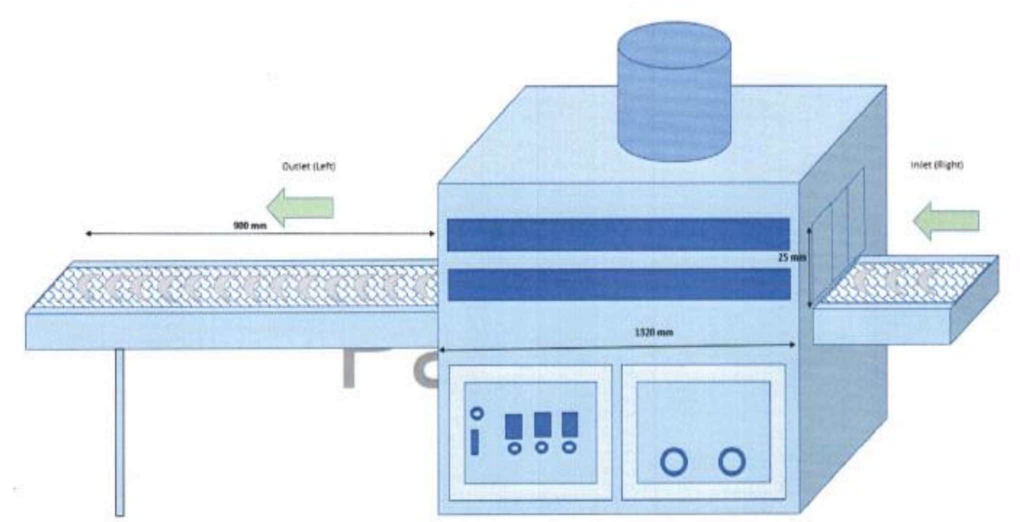

Figure 2: Schematic diagram of steam shrink tunnel

2.1. *Experimental procedure*

2.1.1. *Heat distribution of steam tunnel in loaded condition*

To ensure uniform heat distribution inside the steam tunnel, select 12 pieces of nest type raw unclean EBN which have body's weight near to maximum weight. Heaviest and largest size of EBN was selected to determine the longest holding time required to allow heat to penetrate into the core passing through the steam tunnel. 12 temperature sensors were arranged in a row at the center area of the conveyor. The tip of sensor was exposed to the air without coming in contact with the conveyor. 12 pieces of nest type raw unclean EBN were loaded on the conveyor in sequence with a 5cm gap between each EBN. Temperature sensors were fixed at the same height with the EBN loaded to stimulate a similar rate of steam exposure during the run. Duration of sensors achieved temperature ≥ 70°C after passing through the tunnel were identified accordingly. Cycle runs were repeated twice.

2.1.2. *Heat penetration of nest type raw unclean EBN's core*

Temperature sensors were inserted into each EBN's (Head, Body, Base). A total of 4 EBNs were inserted with sensors. EBNs selected were thickest and heaviest with weight near to the maximum weight as it would take longer time for heat to penetrate into the core passing through the tunnel. List of weights of EBN used can be referred to Table 1. 12 pieces of nest type raw unclean EBN were penetrated with sensors and loaded on the conveyor in sequence with a 5cm gap between each EBN. Sensors were attached to different zones of EBN based on the run order arrangement (Head, Body, Base). EBNs loaded continuously in a row on the center area of the conveyor to pass through the tunnel. The slowest sensor to achieve 70°C for 4 seconds after passing through the steam tunnel was the cold spot area within the EBN. Cycle runs were repeated twice.

2.2. *Design of experiment & process optimization*

2.2.1. *Define the problem and the selection of objective function*

This section explained systematically all the steps taken to carry out the optimization of the quality characteristic. The Taguchi method was first used to select the parameter, which tends to influence the quality characteristic or response significantly. It was often termed the fractional factorial method as little experimental data needs to be analyzed to improve product quality effectively. The main tools used were signal-to-noise ratio (SNR) and orthogonal arrays. The larger-the-better SNR was used to maximize the time required for heat to penetrate into the core of EBN regardless of the EBN thickness. ANOVA analysis often applied after the Taguchi method to determine each input parameter's significance on the final optimized output. Taguchi's optimization is performed using flowchart at Figure 3.

2.2.2. *Identification of factors, testing condition & quality characteristic*

Outline all feasible parameters with the aid of brainstorming and Ishikawa diagram. Risk determination was critical for food safety and encompassed as part of HACCP development. Implementation of Ishikawa diagram for CCP (Heat Treatment) in raw unclean EBN processing was provided. Factors influencing the issues in the heat treatment process were identified by the means of verification. Later step will be determining the actions needed to prevent recurring issues in the heat treatment process (Jha *et al.* 2013). Panjaitan and Jamhari (2019) stated that formation of Ishikawa diagram is according to the following 5 steps:

(1) Recognize the major issue
(2) Allocate the major issue at the right side of the diagram
(3) Pinpoint the major cause as the source of variation and categorize under main cause
(4) Determine the minor cause as the source of deviation and categorize under main problem
(5) Assess the diagram to resolve the real cause of deviation

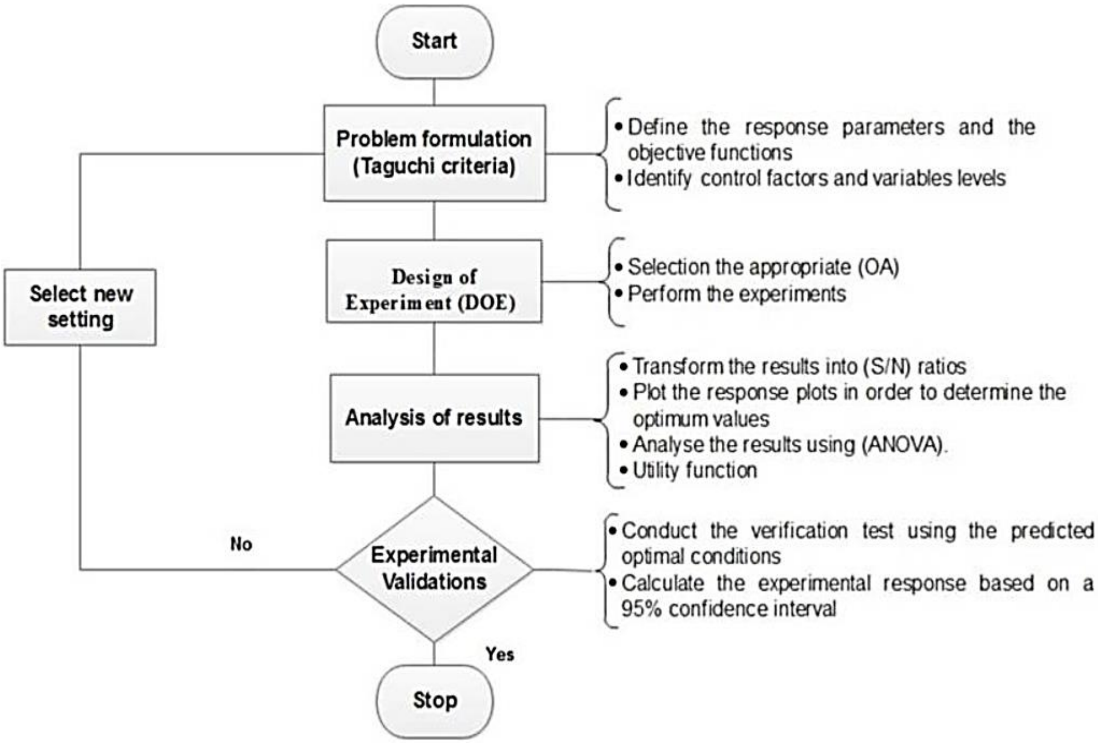

Figure 3: Flowchart for Taguchi's optimization (Phadke 1989)

In terms of the reference parameter, 4M1E (Man, Machine, Materials, Methods, Environment) were used to determine the likelihood of factors that cause problems in the process. Layout of the Ishikawa diagram was displayed in Figure 4.

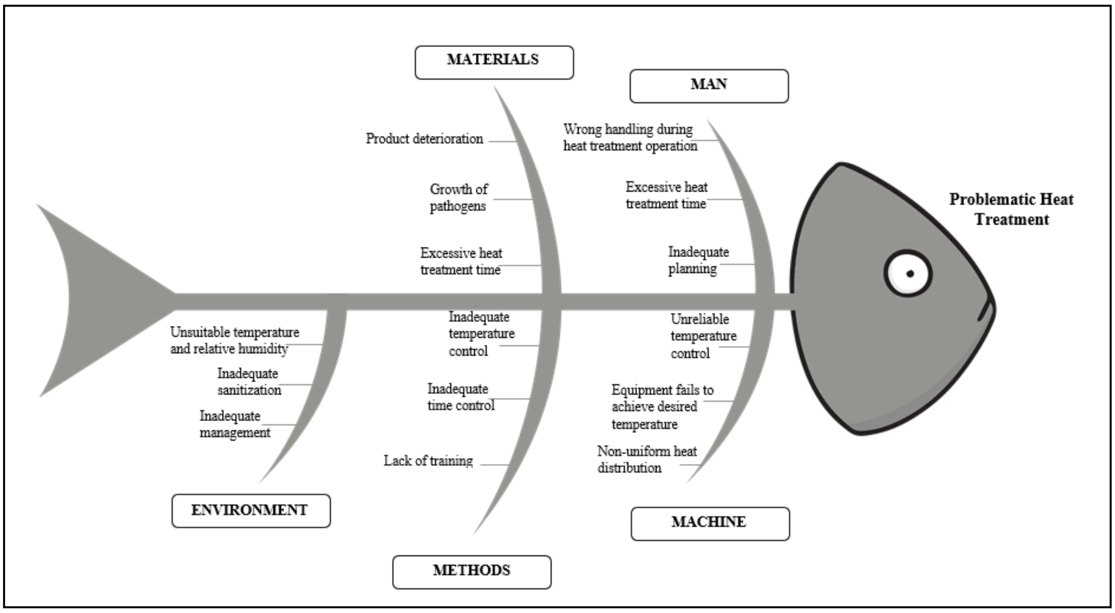

Figure 4: Ishikawa diagram for heat treatment process of raw unclean EBN (Tay *et al.* 2023)

2.2.3. *Selection of processing parameters & orthogonal array*

Components affecting quality characteristics including signal, interference and control factors. The signal factor (input) was the raw unclean EBN; selection of control factor influenced the quality characteristics' optimization. In this study, control factors include the conveyor belt speed, temperature of steam shrink tunnel and temperature sensors' allocation. Interference factor or uncontrolled parameter, is represented by heat loss and humidity changes. Signal factor and response value are in input-output association.

Appropriate selection of orthogonal array (OA) as one of the critical steps in the Taguchi method. Ahead of the OA selection, total degree of freedom of control factors were computed first. As aforementioned, three parameters selected were conveyor belt speed, temperature of steam shrink tunnel and cold spot of EBN. Two responses were analyzed using different DOE techniques. Experimental design was applied to identify the heat penetration duration of nest type EBN's core. The purpose of determining heat distribution is to identify the duration of temperature sensors to heat up above 70°C by passing through the steam tunnel in loaded condition. As for heat penetration, the main objectives were to verify core temperature of nest type EBN in the steam tunnel capable of reaching 70°C and above for at least 4 seconds during heat sterilization and cold spot within the nest type EBN's core were determined. The chosen factors, notation, symbols and units were presented in Table 2 and 3.

Table 2: Control factors and their levels

Notation	Factors	Unit	Level		
			1	2	3
A	Conveyor Belt Speed	Rpm	0.5	1.0	1.5
B	Temperature of Steam Shrink Tunnel	°C	80	90	100
C	Temperature Sensors Allocation	N/A	Base	Body	Head

For experimental design, three factors and three levels for each factor, an L_9 (3^3) orthogonal array was selected. In this scenario, 18 runs were conducted (two repetitions at each trial condition). The DOE planning matrix for the L_9 orthogonal array was displayed in Table 3. The experiments were carried out in a randomized order. Weight of raw unclean EBN used were preconditioned and used in the experimental runs. This action ensures that EBN selected are thickest and weights close to maximum weight (23g) to capture the longest time required to sterilize EBN.

Table 3: Taguchi orthogonal array (L_9) with three factors and three levels

Standard Run	Run Order		Factors and Their Levels		
	Rep. I	Rep. II	A	B	C
1	1	9	0.5	80	Base
2	2	8	0.5	90	Body
3	7	3	0.5	100	Head
4	3	7	1.0	80	Body
5	4	6	1.0	90	Head
6	8	2	1.0	100	Base
7	5	5	1.5	80	Head
8	6	4	1.5	90	Base
9	9	1	1.5	100	Body

2.2.4. *Perform experimental run*

The experiment was conducted based on the matrix as per OA and records the responses from each trial. To avoid discrepancies during experiment runs, the trials were observed closely. Minimum of one run per experiment condition was required but it did not reflect the variability of the results. Repetition trials in experiments diminished the effect of error, as the frequency of runs increases, the accuracy of conclusion is magnified. Additional data obtained was analyzed for variance around the mean. The moment the noise factors were assessed at designated level or combination, repetition is accomplished. Repetition was linked with the cost of implementation, in the case where the interference cost is high, the number of repetitions should be decided by means of an expected outcome for added cost (Roy 1990). Repetition enables the identification of a variation index known as SNR. The greater the value, the smaller the variance around the mean.

2.2.5. *Statistical analysis & SNR calculation*

Data analysis was performed by analyzing the outputs of measured responses. Taguchi prescribed SNR concept to seize the dispersion dependencies in single estimation and it generated methods to maximize process performance with reduction of variation effect. The average mean of the response for each level of the factors was calculated. The average mean of the response for level 1 of a factor was calculated by taking the average of the mean value of the response of treatments which included the level 1 of a particular factor. Likewise, the average SNR was also calculated for each level of all factors. Minitab 20 statistical software was utilized for evaluation of Taguchi experiments by fulfilling the following objectives:

(1) Determine how each factor influence each other
(2) Identify optimum performance parameters
(3) Estimate or predict the optimate at optimal settings

SNR was used to investigate the optimum design of factors and factor levels. The signal has desirable output characteristics. The noise represents the undesirable output characteristics. The S/N ratio was calculated and Taguchi optimization was done through Minitab and Microsoft Excel. SNR depends on the criterion for the response variable to be optimized. The SNR were divided into three different categories and data sets, the larger-the-better, the smaller-the-better and the nominal-the-best. Higher values of the SNR indicate control factor settings that minimize the effects of the noise factors. SNR selection always depends on the goal of the experiment. Process robustness can be attained via SNR metrics due to the consideration of noise factors. Regardless of the nature of quality characteristic, SNR should be maximized as long as the transformation was induced.

For our case study, the “larger-the-better” approach is capable of minimizing heat penetration time in order to achieve core temperature of 70°C and above. As the response variability was reduced where the SNR will increase. Therefore, the “larger-the-better” was selected for the optimization of parameters as described in Eq. (1) below.

$$\frac{S}{N} = 10 \log \frac{\mu^2}{\sigma^2} \left(\Sigma_{i=1}^{n} Y_i^2 \right) \tag{1}$$

where, y_i is the value of the i experiment in each group; n is the frequency of experiment in each group (Tseng *et al.* 2013).

For the identification of best parameters, SNR, mean response effect and standard deviation were evaluated to choose the adequate level to attain robustness concept of the process. Data analysis was performed in 2 phases:

(1) Observing response graphs of each response
(2) Assigning statistical significance via ANOVA treatment

For the assessment of statistical significance of factor interactions, ANOVA was applied. In order to determine the relative importance of the factors, ANOVA was employed by calculating the sum of squares (SS), degrees of freedom (df), mean of square (MS), associated F-test of significance (F) and percentage contribution (P%). Significance level of 0.05 was selected in current study. If the P value of the parameter is less than 0.05, the factor is statistically significant at 95% confidence level. Factors that significantly affect the performance characteristics are identified from the ANOVA outputs. No specific requirements were set by Taguchi in terms of interactions prediction, it was focused on the measurement of each factor's variance effect with means.

2.2.6. *Establish optimal condition and performance prediction*

Optimal parameters that yield desirable performance were obtained from ANOVA outputs. Control parameters that generate the highest S/N ratios were known as optimal conditions where the process was optimized under these conditions. Followed by the prognosis of performance under these conditions. Predicted optimum performance was illustrated using the following formula.

$$Y_{opt} = T + \Sigma_{i=1}^{k} (T_i - T) \quad (2)$$

where, Y_{opt} = Predicted Optimum Performance; T_i = Mean of experimental runs at optimum level for factor i; T = Absolute average for all experimental runs; k = Number of factors affecting the heat sterilization process (Kaladhar *et al.* 2011).

95% confidence interval for verification experiment (CI_{CE}) must be assessed at designated error level with reference to following expression:

$$CI_{confirm} = \sqrt{F_{\alpha}(1, f_e) \times V_e \times [\frac{1}{n_{eff}} + \frac{1}{R}]} \quad (3)$$

where, α indicates 0.2, f_e denotes F-ratio degree of freedom, n_{eff} represented number of experiment n/(1 + average degree of freedom of significant factor), R stands for test number, $F_{\alpha}(1, f_e)$ = 2.07 (Tseng *et al.* 2013).

n_{eff} is the effective sample size calculated as:

$$n_{eff} = \frac{N}{1 + (\text{DOF of all factors used to estimate the mean})} \quad (4)$$

where N is the number of experiments, R represents the number of repetitions, and MS_e is the error variance (Kaladhar *et al.* 2011).

2.2.7. *Verification experiment*

A verification or validation experiment was the final step in any DOE as a proof of methodology used. Therefore, in this study, a test including all combinations at optimum conditions of noise factors and their levels in response to different signals of quality loss was conducted in order to validate the Taguchi approach during the heat treatment process. Confirmation experiments were carried out in triplicates for each quality attribute. The optimal combination applied resulted in significant minimization in variation of performance attributes which on the other hand proved that the selected factors and levels generate favorable results. If the values obtained for predicted and observed value are approaching, we can infer that the applied model is adequate and characterize the factors' effect on quality components.

3. Results and Discussion

The objective of the present work is to achieve the target value that satisfies customer needs. The values away from the target value are not preferred. Heat penetration duration shall meet the requirements set by Department of Veterinary Services Malaysia (DVSM); EBN core temperature shall achieve 70°C and above for at least 3.5 seconds. To reach the intended target (smaller-the-better), the determination of the optimal factor level is the result of the test that approaches the heat penetration to the core of EBN able to achieve 70°C and above for 4 seconds during sterilization. So that, Taguchi method is adopted for the optimization of significant factors by experiment. Current study applied L_9 orthogonal array with 3 factors, each with 3 levels. Outputs from the analysis are evaluated individually.

Table 4: Experimental responses of the Taguchi OA (L_9) for two repetitions of each trial (R1, R2)

Trials (L_9)	**Factors (Parameter)**			**Responses**		**S/N ratio (dB)**
	A	**B**	**C**	**Heat Penetration Duration (second)**		
	Conveyor Belt Speed (rpm)	**Temperature of Steam Shrink Tunnel (°C)**	**Temperature Sensors' Allocation**	**R1**	**R2**	
1	0.5	80	Base	5	6	14.807
2	0.5	90	Body	11	11	20.828
3	0.5	100	Head	10	11	20.424
4	1.0	80	Body	5	4	13.064
5	1.0	90	Head	7	7	16.902
6	1.0	100	Base	4	5	13.064
7	1.5	80	Head	3	4	10.881
8	1.5	90	Base	3	3	9.542
9	1.5	100	Body	2	3	7.959

After the computation of SNR, the information retrieved is used to generate a response table and response diagram plotting. Magnitude of factors influence on the system can be calculated by adopting SNR value in Table 4 and response table and diagram formation can be accomplished. SNR response value for each factor is calculated using Eq. (1) and the computed data are display in Table 5.

Table 5: Response value of SNR

Average SNR for Factor A (Conveyor belt speed setting)	
A1	14.8073 + 20.8279 + 20.4238 = 56.0589
A2	13.0643 + 16.9020 + 13.0643 = 43.0305
A3	10.8814 + 9.5424 + 7.9588 = 28.3826
Average SNR for Factor B (Temperature of steam shrink tunnel)	
B1	14.8073 + 13.0643 + 10.8814 = 38.7529
B2	20.8279 + 16.9020 + 9.5424 = 47.2722
B3	20.4238 + 13.0643 + 7.9588 = 41.4468
Average SNR for Factor C (Temperature probe attachment)	
C1	14.8073 + 13.0643 + 10.8814 = 38.7529
C2	20.8279 + 13.0643 + 7.9588 = 41.8509
C3	20.4238 + 16.9020 + 10.8814 = 48.2071

Table 6: Integration results of responses from Taguchi experiments

Level	**A** **Conveyor Belt Speed (rpm)**	**B** **Temperature of Steam Shrink Tunnel (°C)**	**C** **Temperature Sensors' Allocation**
1	56.0589	38.7529	38.7529
2	43.0305	47.2722	41.8509
3	28.3826	41.4468	48.2071
Effect	27.6763	8.5193	9.4542
Rank	1	3	2

Selected quality characteristic is the larger-the-better, therefore, as the SNR of the experimental result is larger than zero, it indicates better quality characteristic. With reference to Table 6, optimal conditions are A1 B2 C3. Speed of conveyor belt is 0.5 rpm, temperature setting of steam shrink tunnel is 90 °C and temperature probe attachment to the head position of EBN. Table 6 outlines the magnitude of parameter contribution to the process. Based on the result, degree of contribution ranging from parameter A > C > B. Both main effect plots and response table displayed similar result in term of significance ranking of the factor.

The purpose of ANOVA is to examine the experimental errors where the F-ratio approach is effective to determine the weight of each factor on the process (Torng *et al.* 1999). If the F-ratio is larger than the smallest F-ratio in terms of confidence level, the designated factor is considered as statistically significant. Parameter with F-ratio smaller than the minimum value is subjected to experimental errors pooling. SNR response value for each factor is computed by the degree of freedom error (dof_e), variance sum of square (SS), total variance SS that include (Sum of square of individual variance and variance error), error of variance, F-ratio and lastly the percent contribution (Roy 2010). Calculated data are presented in Table 7.

Table 7: ANOVA for SNR

Source	**Df**	**SS**	**F**	**P**	**P (%)**
A	2	127.809	28.47	0.034	77.7
B	2	12.641	2.82	0.262	7.7
C	2	19.620	4.37	0.186	11.9
Residual Error	2	4.490	-	-	2.7
Total	8	164.560	-	-	

Minimum value for F-ratio shall not be below 4 as the confidence level drop below 95 %. F-ratio of 4.46 and below is considered as pooled errors as tabulated in Table 8. Based on Table 8, temperature of steam shrink tunnel is pooled error at confidence level below 95 %. Statistically significant factor is the conveyor belt speed setting.

Table 8: ANOVA for SNR after error pooling

Source	Df	SS	F	P
A	2	127.809	28.47	0.034
B		Pooled		
C		Pooled		
Residual Error	6	36.751	-	-
Total	8	164.560	-	-

During confirmation test, confidence interval approach is applied on Taguchi's method with the aim to rectify the optimal factor level. Both predicted and actual value of confidence level are acquired for the optimal parameter. Overlapping of two intervals indicate that the proposed optimal factor level from Taguchi experiment is confident and valid.

Optimal factor level combination is predicted can be from the outputs from response table. As referred to Table 6, optimal condition is achieved by combination A1B2C3. SNR is analyzed from the result of predicted optimal combination in which the SNR of larger-the-better is selected for optimal combination computation. Factor optimization reliability is examined at confidence interval of 80 % and below (Torng *et al.* 1999). For confirmation experiment, experimental parameter level is assessed at 80% confidence interval.

Refer to Table 9, SNR for the predicted value is 22.1856, and SNR of the actual value is 21.5836. The experiment was repeated thrice to obtain the mean value for actual value. Actual value is greater than zero in each experiment which indicate the designated factor level capable of minimizing variation. Table 10 shown that the overlapping of predicted and actual value confidence interval. Hence, combination A1B2C3 is verified as the factor level that generate optimal condition.

Table 9: Comparison of actual and predicted value for A1B2C3

Value	Optimum Parameters	SNR	Heat Duration (sec)
Predicted	A1, B2, C3	22.1856	11.44
Actual		21.5836	12.00

Table 10: Summary of optimal conditions for heat penetration studies

Response	Optimal Conditions	Predicted Value	95% CI_{CE}	Actual Value	% Deviation
Heat Penetration Duration	A1, B2, C3	11.44	$11.39 \leq Y \leq 11.93$	12.00	4.67

4. Conclusion

Conveyor belt speed (Level 1), temperature of steam tunnel (Level 2) and allocation of temperature sensors (Level 3) found to be the best combination of parameters for heat penetration of raw unclean EBN through Taguchi approach. Under the optimal settings, the study displayed how to make core temperature of raw unclean EBN achieved a temperature ≥ 70°C for more than 3.5 seconds, the longest time of heat penetration is preferrable to ensure that EBN of different thickness capable to meet the designated requirement.

Acknowledgments

The study was part of the validation study for heat treatment process of raw unclean EBN.

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Bio Life Neutraceuticals Sdn Bhd
No. 9, Jalan P4/8B
Bandar Teknologi Kajang
43500 Semenyih
Selangor DE, MALAYSIA
*E-mail : briangx95@gmail.com**

Department of Accounting
Faculty of Business and Economics
University of Malaya
50603 Kuala Lumpur
Federal Territory of Kuala Lumpur, MALAYSIA
E-mail : annarusli@um.edu.my

UKM-Graduate School of Business (UKM-GSB)
Universiti Kebangsaan Malaysia
43600 UKM Bangi
Selangor DE, MALAYSIA
E-mail : kabma@ukm.edu.my

Centre for Modelling and Data Analysis (DELTA)
Department of Mathematical Sciences
Faculty of Science and Technology
Universiti Kebangsaan Malaysia
43600 UKM Bangi
Selangor DE, MALAYSIA
E-mail : zbhm@ukm.edu.my

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[*]Corresponding author