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Optimization of multiple performance responses of a fish feed pelletizer machine

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ABSTRACT

This study details the assembling of a prefabricated fish feed pelletizing machine and optimization of some operational parameters such as die thickness, number of die holes, shaft speed and feed rate to produce high-grade fish pellets. The Taguchi methodology and Grey relational analysis (GRA) have been utilized to evaluate the multi-objective functions of interest such as pelletizing efficiency, throughput, energy requirements and pellets bulk density (g/cm^3). The pelletizer machine performance evaluation test was carried at 3 levels of die thickness (8, 6 and 12 mm), number of die holes (30, 25, and 35), and feed rates (145, 130 and 160 g/h). The test for the performance indicators was conducted using L9 orthogonal array experimental design. The test data were analyzed using the Taguchi scheme employing the signal-to-noise ratio response with effects deduced. The GRA was utilized to assess multiple responses by fusing the Taguchi technique with the GRA. Thus the multi-objective optimization was transformed to a single equivalent objective function. The results of Taguchi optimization revealed that die thickness was the most influential parameter for the various control factors. In addition, optimum parameter combination was obtainable at medium die thickness (8mm), medium number of die holes (30), low shaft speed (200rpm) and medium feed rate of 145g/h. Analysis of variance for grey relational grade (GRG) reveals that die thickness and feed rate are the dominant parameters. The confirmation test performed shows that the GRG is enhanced by 2.19%.

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1. Introduction

The lack of adequate feed to meet the nutrient requirements of cultivable fish species has been a challenge to fish farming in Nigeria [1]. As a result of this factor, the cultivated fishes do not attain market size at the right age [2]. Omitoyin [3] stated that indigenous farmers rely on imported fish feeds to meet their feed requirements. This results in the astronomical cost of production due to the high cost of these imported feed given the devaluation of the naira and the attendant high foreign exchange rate.

It was reported in [4] that an estimated 46% of quality fish feeds are imported into the country. This invariably affects the profit accruing to the indigenous fish farmer. In trying to remain in production and business,

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the farmer translates this cost into the high prices of indigenously produced fish. The impact of this importation of quality fish feeds goes beyond the reduction of the profit margin of the fish farmer and the increase in the market price of indigenous fish. The local indigenous farmer is faced with competition from cheap imported fish. It is this foreign competition that constitutes the last straw. The indigenous farmers are hard hit by this vicious circle and only the development of low cost, indigenous engineering solutions that can support the fisheries in Nigeria by producing machines that guarantee the high quality of feeds needed by the farmers, can redress this problem and reverse this trend.

Presently, only large commercial feed millers have the financial wherewithal to use pellet mills. The most popular method of producing fish feed is through the method of pelletizing, which is economically and technologically advantageous. The performance of the fish pelletizer machine is determined by several operational variables, which impact on the quality characteristics of the pellets obtained.

A review of existing literature shows that several studies have been carried out, which are majorly focus on feed formulation and nutrition as it affects the growth of fish species. Studies on seawater [5] and fish farming sand systems [6], have been undertaken as it relates to the physical characteristics of feed pellets. However, there is an identified dearth of information on the use of Taguchi methodology in the evaluation of the parameters that affect the multi-objective machine performance responses, which invariably impact the quality of fish feed pellets employed in the industry. The design of the experiment, which employs the orthogonal array was developed by Taguchi et al. [7]. It method works by optimizing performance responses through the settings of the control factor and it minimizes the sensitivity of the system outcome [8]. Puri and Deshpande [9] identified the analysis and solutions of multiple performance parameters as a complex research challenge. It is worthy to note, that most of the published works on the Taguchi methods are centered on the optimization of single-objective functions.

Conversely, Deng [10] kick-started the grey system theory capable of handling unclear, uncertain, and incomplete information. The grey relational analysis was developed using the underlying theories of the grey system and it has been found to proffer an effective solution to complex inter-relationships among multiple objective functions. The mean of the grey relational coefficients is utilized to determine the relational grade, achieved by evaluating the degree of relationship between multiple responses [11]. The grey theory is be able to present a solution uncertain or inconclusive system models lacking in the relevant information. Besides the already mentioned benefits, it gives an efficient solution to uncertainty, multiplicity of inputs, and a discrete data problem.

This paper seeks to proffer a way out of the challenge of providing quality feed for the indigenous fishing industry, through the optimization of multiple performance responses of a fish feed pelletizer machine. The basic framework of this study is center on the optimization of multiple- objective functions and examination of the impacts of various levels of screw speed, number of die holes, feed rate, and die hole thickness on the fish pelletizer machine performance responses. It is expected that the results of this study would provide relevant information on the impact of the outline input parameters on the machine performance of the pelletizer machine. This invariably would assist in the future industrial scale-up of the machine to meet the feed needs of the local fish farmer based on optimum parameter settings.

2. Materials and Methods

2.1. Materials

The following equipment and consumables were used for the experimental test performance and measurements:

(a) fish feed comprising wheat offal, maize, groundnut and soybean cake, full-fat soya, limestone, bone and fish meal, premix, salt, palm oil, and gelatinized starch;

(b) speed of screw conveyor or shaft determined by employing three pulleys of different diameter and use of a digital tachometer;

(c) electrical balance–digital electric balance of 7kg was used for the evaluation of the mass of samples with an accuracy of 0.0001g;

(d) bags – plastic bags were used to collect samples; and

(e) stopwatch – the time needed for the experimental run was measured using a stopwatch with an accuracy of 0.01s.

2.2. Methods

A. Machine description and operation

The basic pelletizer machine consists of the following parts as displayed in Fig.1.

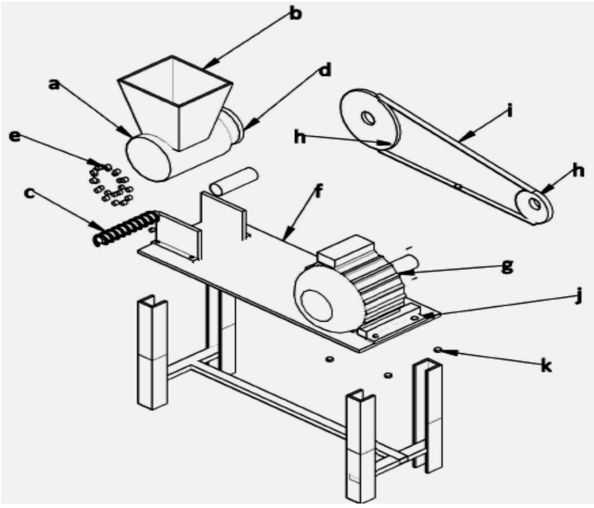

Fig. 1 Assembly drawing of the pelletizer machine component parts

The parts include (a) barrel, which houses a screw conveyor (auger); (b) a sheet metal hopper welded to a cylindrical base; (c) a screw conveyor shaft fixed within the barrel that feeds the material into granular form; (d) a screw conveyor terminating at the die plate, which compresses the feed into a semi-solid pellet mass; (e) a drive pulley at the opposite end of the screw conveyor; (f) a machine frame on which the entire components are mounted; and (g) an electric motor that drives a pulley system via a belt. The principle of operation of the machine entails feeding the machine with a homogenous feed through the hopper. The feed material is conveyed and compressed by screw within the barrel leading to a rise in temperature and pressure. In the presence of water and high temperature, gelatinization and stretching of the starchy components of the feed material take place. The screw conveyor moves the gelatinized feed to the pelletizer disc and the feed is forced through the pelletizer plate disc holes by the screw conveyor to produce cylindrical shape pellets.

B. Pelletizer machine assembling

The assembling of each part of the pelletizer machine was completed on schedule and the various parts of the pelletizer were coupled as follows: firstly the hopper was welded to the cylindrical barrel base at the upper end. Thereafter a screw conveyor was embedded into the barrel opening. The inner bearing was clamped to the shaft screw conveyor with a pulley fixed at the end of the screw shaft. These assembled parts were welded on two supports at the two ends of the barrel before they were finally welded to the constructed frame. The material used for the frame was angle iron. The small pulley was attached to the electric motor mounted on the frame, while the larger pulley was kept in fix position attached to the shaft. A V-belt was fixed to each of the pulley grooves.

C. Determining pellet response

The following independent controlled process parameters affecting the machine output performance responses are die thickness (mm), no of die holes, shaft speed (rpm), and feed rate (g/h). The responses considered for the study were pelletizing efficiency (%), throughput (g/h), energy requirements (Wh/kg), and pellets bulk density (g/cm^3) adopted from the study [12]. The pelletizer efficiency, *PE* (%) refers to the ratio of the pelleted quantity of feed realized to the total feed inputted [13]-[15], expressed as follows:

$$\text{PE} = (W_P/W_M) \times 100 \quad (1)$$

Where W_P is the weight of output pelletized feed (kg), and W_M is the weight of total feed input (kg).

The rate of pellet production by the machine is known as the machine throughput. The throughput, *T* (kg/h) was evaluated as the weight of a given pellet sample per time of production as defined as follows:

$$\text{T} = (W_P/T_p) \quad (2)$$

W_P is the weight of pelleted feed (kg) and T_p is the time required to produce a given quantity of pellet feed in hours (h).

The pellet bulk density (PBD) refers to the degree of compactness of the pellets per unit volume. According to Okoli et al. [16], it's an expression of fraction of the mass of the extrudates occupying a given bulk volume shown in Equation (3); where W_P is pellet sample mass (g) and V_d is the volume (cm^3) of pellets sample.

$$\text{PBD} = (W_P/V_d) \quad (3)$$

The PBD was obtained using a 100 ml cylindrical container, which was weighed empty; thereafter sifted pellets were poured into the cylinder being leveled, to remove the surplus, using the edge of a ruler. The weight was also taken after this exercise. The fish feed pellet bulk density was obtained using the water displacement method. The mass and density were recorded. The energy requirements, ER (Wh/kg) is deduced as:

$$\text{ER} = \text{Power required/Throughput} \quad (4)$$

D. Machine performance test procedures

Design of experiment: The experiments were performed based on the Taguchi design procedures [17]. Taguchi's L_9 orthogonal array was employed in the design for machine performance evaluation with three factors and levels. The array design of the experiment was used to assign values of input parameters. The given input parameters selected for the experiment were die thickness (mm), number of die holes, die speed (rpm), and feed rate (g/h). The designation of levels to different factors and the input parameters utilized are shown in Table 1. The design of the experiment for L_9 orthogonal array is given in Table 2.

Table 1 Input parameters and their levels

Control Factors	Symbol	Levels		
		1	2	3
Die thickness (mm)	A	8	6	12
Number of die holes	B	30	25	35
Shaft speed (rpm)	C	250	200	300
Feed rate (g/h)	D	145	130	160

Table2. Orthogonal array with control factor

Experiment no	Control Factors			
	Die thickness (mm) A	Number of die holes B	Shaft speed (rpm) C	Feed rate (g/h) D
1	8	30	250	145
2	8	25	200	130
3	8	35	300	160
4	6	30	200	160
5	6	25	300	145
6	6	35	250	130
7	12	30	300	130
8	12	25	250	160
9	12	35	200	145

Experimental test of performance of machine: Tests were conducted on the pelletizing machine using the outline design of the experiment based on the orthogonal array for control factors in Table 2. The tests were conducted with 1kg of un-pelleted feeds. An adequate amount of feed was mixed in proportion to water as the binder. The weight of the feed to be pelletized was noted and the record was taken to be 280g. The time required to pellet the feed was also recorded using the stop-watch to determine the capacity of the machine. The performance evaluation was performed using the Taguchi orthogonal experimental design L_9. The values pelletizing efficiency (%), through-put (kg/h), energy requirements (Wh/kg) and pellets bulk density (g/cm^3) evaluated are discussed in section 3.

E. Single response optimization procedure

The single response optimization procedure is employed to evaluate the maximum value or minimum value of a given response under consideration. The Taguchi method computes the signal-to-noise (S/N) ratio as logarithmic functions of the preferred output, which serves as an objective function in the optimization problem.

The machine performance indicators are converted to S/N ratios with the Minitab 17 statistical software. The influential control parameters were indicated from the delta statistics available in S/N ratios response table. The properties of S/N ratio can be subdivided into the following classes: smaller (better), larger (better), and nominal (best) when the features are continuous. These characteristics are chosen based on the objective function under consideration. Computation is carried out by the use of the following equations for nominal (best), smaller (better) and larger (better), respectively:

$$S/N = 10 \log \quad (5)$$

$$S/N = - 10 \log \quad (6)$$

$$S/N = - 10 \log \quad (7)$$

The plots of the effects are utilized to deduce the optimum arrangement of processing parameters at a specified level with the highest average response.

F. Multi response optimization processing of parameters

When multi-objective optimization functions are considered in, the limitation of the Taguchi method becomes inherent, thus the integration of the Taguchi-based scheme with other techniques becomes necessary. Therefore, parameters optimization involving multiple performance indicators of the pelletizing process using the Grey relational analysis (GRA) is employed in this paper. The test of performance which was based on L_9 Orthogonal array was first conducted. The performance responses were then normalized (range of response values from 1 to 0) and employed to compute the values of the grey coefficient and grades based on GRA. The optimal process parameters simultaneously leading to higher pelleting efficiency (%), throughput (kg/h), and lower energy requirements (Wh/kg) and pellets bulk density (g/cm^3) were verified through a confirmation test. A description of the procedures are given in the following subsections.

Normalization of experimental procedures: data pre-processing required in GRA, arise from the fact that the range and unit in a particular data sequence may be at variance with others. Data pre-processing entails transforming the original sequence into an equivalent sequence. Data normalization of experimental outcomes falls between the range of zero and one. Pelletizing efficiency and throughput is the dominant response in pelletizing processing that determines the performance characteristics of the machine.

The pelletizing efficiency and throughput capacity are the variables with which the original sequence to be normalized for the "larger-the-better" criterion, as:

$$x_i^*(k) = \frac{x_i(k) - min x_i(k)}{max x_i(k) - min x_i(k)} \quad (8)$$

where $x_i^*(k)$ and $x_i(k)$ are the sequences after the data pre-processing and comparability sequence respectively, k=1 for pelletizing efficiency and throughput; i (=1, 2, …, 9) represents experimental runs.

The energy requirements and pellet bulk density are also important indicators of pelletizing machine performance. To obtain optimum cutting performance, the "smaller-the-better" quality properties were used for minimizing the energy requirements and pellets bulk density. In this case, the original sequence can be normalized as:

$$x_i^*(k) = \frac{max\, x_i(k) - x_i(k)}{max x_i(k) - min x_i(k)} \quad (9)$$

The x_i^* (k) for pelleting efficiency is calculated for experimental runs with (8). The deviation sequence, $\Delta_{oi}(k)$ of the reference sequence $x_o^*(k)$ is computed using

$$\Delta_{oi}(k) = |xo*(k) - xi*(k)| \quad (10)$$

Grey relational coefficient (GRC): the GRC is computed with the pre-processed sequence. This coefficient shows the correlation between the ideal and actual normalized results; being expressed as:

$$\xi_i(k) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{oi}(k) + \xi\Delta_{max}} \quad (11)$$

Where Δ is the deviation sequence of the reference sequence. The parameters are given equal consideration, hence it is taken as 0.5.

Computation of Grey relational grade (GRG): When considering the GRA, the performance of the multi-objective optimization process is dependent on the GRG values. This value is computed with appropriate consideration to the mean values of the GRC equation:

$$Y_i = \frac{1}{n}\sum_{k=1}^{n}\xi_I(K) \quad (12)$$

Where, *n* is the number of objective functions, ξ_I is the GRC and *k* (= 1, 2, 3, …) is the number of responses.

3. Results and Discussion

3.1. Single Response Optimization Results

A. Pelletizing Efficiency (PE)

The response plots effects and parameters for pelletizing efficiency against die thickness (mm), number of die holes, shaft speed (rpm) and feed rate (g/h), are shown in Fig 2 and Table 3, respectively. The trend exhibited by the plot was used to evaluate the optimum control factor combination to obtain a higher pelletizing efficiency. As observed (Fig. 2), it is obvious that optimal combination of process parameter for higher pelletizing efficiency entails a die thickness of 12mm, no of die holes of 25, shaft speed of 250rpm, and a feed rate of 145g/h.

The highest value of delta was assigned the first rank and represents the influential factor affecting pelletizing efficiency. Table 3, reveals that the delta value of each parameter A, B, C, and D, are 2.85, 0.91, 0.74, and 2.52 respectively. Based on the delta value of each parameter, it is observed that for pelletizing efficiency the most dominant parameter is die thickness. This followed by feed rate, no of die holes, and lastly the shaft speed.

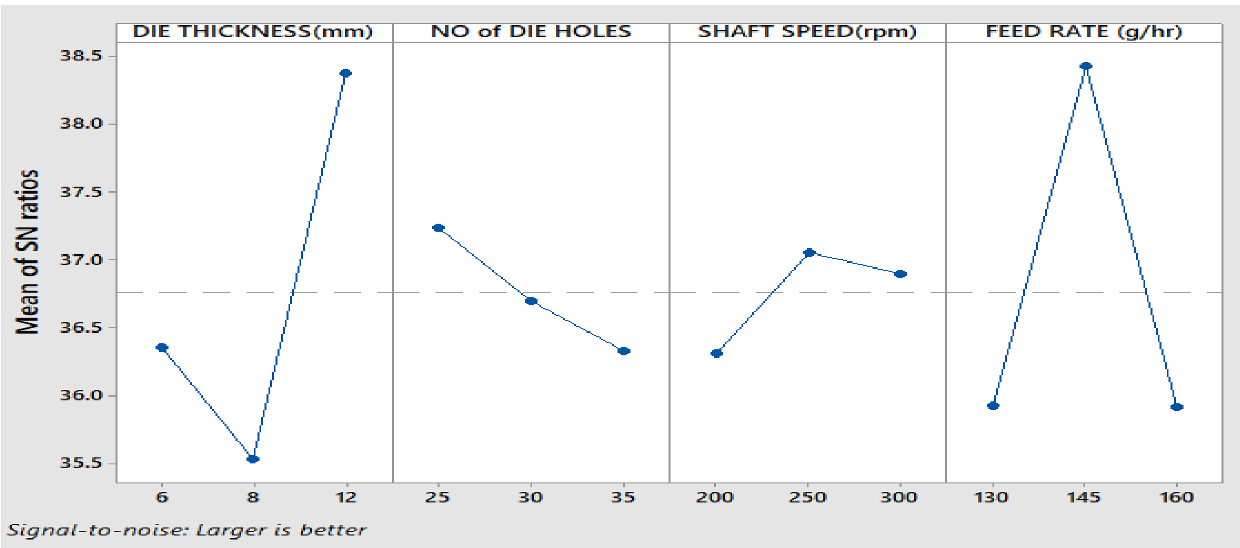

Fig. 2 Effects of S/N ratio for pelletizing efficiency versus die thickness (mm), number of die holes, shaft speed (rpm) and feed rate (g/h)

Table 3 Response table of S/N ratio for pelletizing efficiency

Level	Die thickness (mm) A	Number of die holes B	Shaft speed (rpm) C	Feed rate (g/h) D
1	36.36	37.24*	36.31	35.92
2	35.53	36.69	37.06*	38.43*
3	38.38*	36.33	36.90	35.91
Delta	2.85	0.91	0.74	2.52
Rank	1	3	4	2

*Level for optimum pelletizing efficiency

B. Throughput (T_p)

The main effects of the throughput and input parameters obtained are presented in Table 4 and Fig. 3. As observed (Fig. 3) higher throughput is achieved at an optimum combination of die thickness (8mm), number of die holes (30), shaft speed (300rpm), and a feed rate (145g/h) respectively. Table 4 was used to determine the most influential control factor, which shows that the value of delta for each parameter A, B, C, and D to be 6.30, 1.06, 1.97, and 3.51 respectively. The delta values show that die thickness is the most dominant operational parameter on the throughput. This is followed by feed rate, shaft speed, and number of die holes.

C. Energy Requirement (ER)

Fig. 4 and Table 5 show the effect of S/N energy requirement against the control factors. To obtain a lower energy requirement from the machine, the plot reveals that this can be obtained at an optimum combination of die thickness (6mm), no of die holes (25), shaft speed (250rpm), and feed rate (160g/h) respectively.

Table 4 Response of S/N ratio for throughput

Level	Die thickness (mm) A	Number of die holes B	Shaft speed (rpm) C	Feed rate (g/h) D
1	12.54	15.22	15.97	14.84
2	18.84*	16.28*	14.50	17.80*
3	15.55	15.42	16.47*	14.29
Delta	6.30	1.06	1.97	3.51
Rank	1	4	3	2

*Level for optimum throughput

The values of delta for A, B, C, and D, are 6.30, 1.05, 1.97 and 3.50 for lower energy requirements indicated (Table 5). Arising from the delta values, it can be seen that die thickness has the most dominant effect on minimum energy requirements. This is followed by feed rate, shaft speed, and number of die holes.

D. Pellet Bulk Density (PBD)

Fig. 5 shows the optimum parameter values for the pellet bulk density. An optimum combination of each control factor leads to a minimum pellet bulk density. This was achieved at a die thickness (12mm), no of die holes (35), shaft speed (250rpm), and feed rate (160g/h). Table 6 shows the response.

The values of delta (Table 6) for each parameter are A (10.7), B (0.81), C (1.22), and D (0.15). It can be stated that with regards to pellet bulk density, that the most dominant parameter that influences lower pellet bulk density is die thickness. This parameter is followed by shaft speed, number of die holes and feed rate.

Fig. 3 Effects of S/N ratio for throughput versus die thickness (mm), number of die holes, shaft speed (rpm) and feed rate (g/h)

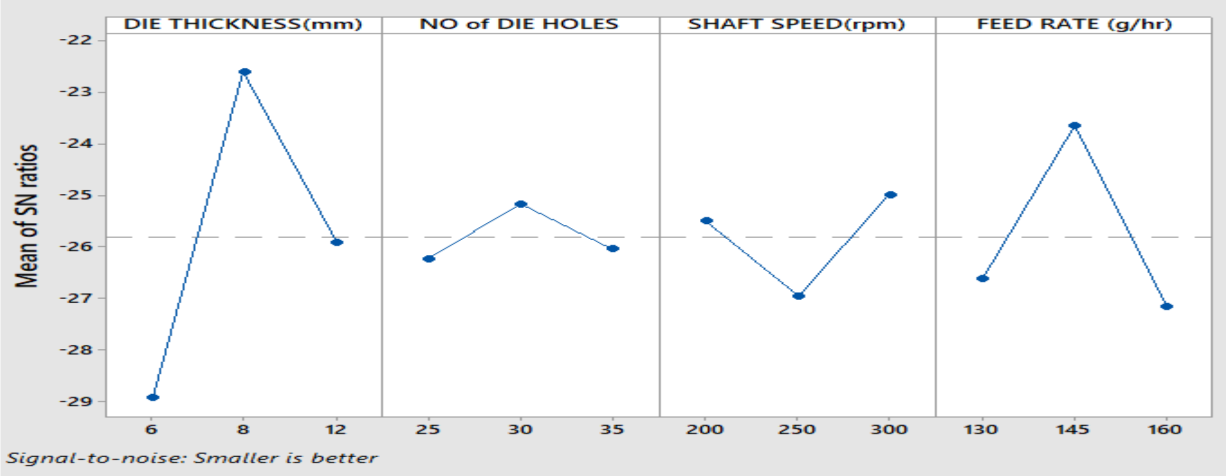

Fig. 4 Effects of S/N ratio for energy requirements versus die thickness (mm), number of die holes, shaft speed (rpm) and feed rate (g/h)

Fig. 5 Effects of S/N ratio for pellet bulk density versus die thickness (mm), number of die holes, shaft speed (rpm) and feed rate (g/h)

Table 5 Response for energy requirement

Level	Die thickness (mm) A	Number of die holes B	Shaft speed (rpm) C	Feed rate (g/h) D
1	-28.92*	-26.23*	25.49	-26.62
2	-22.62	-25.18	-26.62*	-23.66
3	-25.91	-26.04	-24.99	-27.16*
Delta	6.30	1.05	1.97	3.50
Rank	1	4	3	2

*Level for optimum energy requirement

Table 6 Response for pullet bulk density

Level	Die thickness (mm) A	Number of die holes B	Shaft speed (rpm) C	Feed rate (g/h) D
1	4.8090	6.0883	6.1157	5.6032
2	11.3034	5.3438	4.8962*	5.6291
3	0.6024*	5.2828*	5.7029	5.4826*
Delta	10.7010	0.8055	1.2195	0.1465
Rank	1	3	2	4

*Levels for optimum pellet bulk density

3.2 Analysis of GRG with Multi Responses

Table 7 shows the GRG obtained based on the GRA. The higher GRG signifies that the corresponding experimental result is in close proximity with the ideal normalized value. Experiment 1 can be deemed to have produced the best outcome given the fact that it has the highest value of GRG. The multi–response parameter has been converted into a single response characteristics with the objective function been the grade relational.

It possible achieved an optimal parameter combination based on higher values of mean GRG, which maximizes the overall response. Table 8 shows that optimal grey relational grade exist at A1B1C2D1. Therefore optimal machine performance settings for the production of good quality pellets is obtainable at medium die thickness of 8mm, medium number of die holes of 30, low shaft speed of 200rpm and medium feed rate of 145g/h.

Table 7 Analysis of grey relational grade with multi-responses

Experiment no	Grey relational coefficient				Grey Relational Grade	Rank
	Pelletizing Efficiency, PE (%)	Throughput, T_p (kg/h)	Energy Requirements, ER (Wh/kg)	Pellet Bulk Density, PBD (g/cm^3)		
1	0.5376	1.0000	1.0000	0.8572	0.8487	1
2	0.3459	0.5750	0.7641	1.0000	0.6713	2
3	0.3333	0.5880	0.7765	0.8999	0.6494	4
4	0.3568	0.3579	0.4062	0.5294	0.4126	8
5	0.7888	0.4267	0.5621	0.5538	0.5829	5
6	0.3748	0.3333	0.3333	0.4737	0.3788	9
7	0.5627	0.4691	0.6337	0.3396	0.5013	6
8	0.6918	0.3662	0.4290	0.3333	0.4551	7
9	1.0000	0.5643	0.7528	0.3529	0.6675	3

Table 8 Response for Grey relational grade

Level	Die thickness (mm) A	Number of die holes B	Shaft speed (rpm) C	Feed rate (g/h) D
1	0.7231*	0.5875*	0.5609	0.6997*
2	0.4571	0.5698	0.5838*	0.5171
3	0.5413	0.5652	0.5779	0.5057
Delta	0.265	0.0233	0.0229	0.194
Rank	1	4	3	2

Minitab17 statistical software was used for the analysis of variance (ANOVA) of the multi-objective optimization; the result (Table 9) for GRG contains all the required information on the analysis of variance. According to Sawyer [18], the ANOVA is used to highlight the distinctions between the experimental group averages (means). It accounts for the influence of each independent parameter on a single dependent variable. The statistic is useful in determining the significant percentage contribution of a given parameter to the variable studied. A large F-value shows a parameter that has a significant effect on the multi-objective responses.

Table 9 clearly shows that die thickness and feed rate are the dominant parameter that affects GRG and hence contributes to maximizing pelleting efficiency and throughput while minimizing the energy requirements and pellet bulk density. The multi-objective optimization problem was changed into a single equivalent objective optimization problem using Grey relational analysis.

3.3. Validation Test

The level of the optimum process parameters was determined in the final step of grey relational analysis. Based on the grey relational analysis, the maximum grey relational grade is the optimal pelleting parameters of the work. From the examination of Table 10 based on the ranking level, A1B1C1D1 has the largest grey relational grade. This gives optimal experimental test performance response parameters of pelletizing efficiency of 74.5%, the throughput capacity of 10.58kg/h, energy requirements of 11.18W/h, and pellet bulk density of 0.30g/cm^3 respectively.

After the optimal level of the machine responses (A1B1C2D1) has been chosen, the final aspect of this study entails the verification of the enhancement of the pelleting machine performance indicators using the grey relational grade. A verification test was conducted to evaluate the level of optimal parameter settings improvement obtained from Table 8. The purpose of the validation is to verify the performance improvement in the responses in terms of the GRG. For the grey confirmation test, the predicted GRG calculated as follows:

$$\bar{y} = Y_m + \sum_{i=1}^{q}(\bar{Y}_i - Y_m) \quad (13)$$

Where, Y_m is the total average GRG, Y_i is the average GRG at the optimal testing parameter level and *q* the number of design parameters.

Table 9 Analysis of variance for Grey relational grade

Source	DF	Seq SS	Adj SS	Adj MS	F-value	Contribution (%)
Die thickness (mm)	2	0.110228	0.110228	0.055114	130.94	60.23
Feed rate(g/h)	2	0.071097	0.071097	0.035549	84.46	38.85
Error	4	0.001648	0.001684	0.000421		0.92
Total	8	0.183009				100

Table 10 Analysis of the Taguchi experiment design and grey relational analysis

					Experimental multiple responses				Grey Relational Coefficients (GRC)					
Exp. no.	A (mm)	B	C (rpm)	D (g/h)	PE (%)	T_p (kg/h)	ER (Wh/kg)	PBD (g/cm^3)	PE (%)	T_p (kg/h)	ER (Wh/kg)	PBD (g/cm^3)	GRG	Rank
1	1	1	1	1	74.5	10.58	11.18	0.30	0.5376	1.0000	1.0000	0.8572	0.8487**	1
2	1	2	2	2	54.6	7.89	14.99	0.24	0.3459	0.5750	0.7641	1.0000	0.6713	2
3	1	3	3	3	52.5	8.03	14.73	0.28	0.3333	0.5880	0.7765	0.8999	0.6494	4
4	2	1	2	3	56.3	4.05	29.21	0.56	0.3568	0.3579	0.4062	0.5294	0.4126	8
5	2	2	3	1	85.7	5.69	20.79	0.53	0.7888	0.4267	0.5621	0.5538	0.5829	5
6	2	3	1	2	58.9	3.3	35.85	0.64	0.3748	0.3333	0.3333	0.4737	0.3788	9
7	3	1	3	2	76.1	6.46	18.31	0.94	0.5627	0.4691	0.6337	0.3396	0.5013	6
8	3	2	1	3	82.5	4.28	27.6	0.96	0.6918	0.3662	0.429	0.3333	0.4551	7
9	3	3	2	1	91.1	7.77	15.23	0.9	1.0000	0.5643	0.7528	0.3529	0.6675	3

Table 11 Confirmation Test Values

	Initial parameter settings	Optimal Conditions		Improvement (%)
		Prediction	Experimental	
Level	A1B1C1D1	A1B1C2D1	A1B1C2D1	
Pelletizing efficiency (%)	74.5		76.5	
Throughput (kg/h)	10.58		11.08	
Energy requirements (Wh/kg)	11.18		10.73	
Pellet bulk density (g/cm^3)	0.30		0.28	
Grey relational grade	0.8487	0.8714	0.8673	2.19

A value of Y_m = 0.8715 was obtained as the predicted value of GRG. The values of the performance responses and GRG obtained are summarized in Table 11. This shows that the optimal parameter combination has enhanced the grey relational grade to a value of 0.8673 which gives a percentage improvement in the performance of 2.19 %.

4. Conclusion

The overall focus of this study was the optimization of selected control factors that impact on the operation of a fish pelletizer machine to produce high-quality pellets. This was achieved by an experimental test analysis of multiple performance responses such as pelletizing efficiency (%), throughput (kg/h), energy requirements (Wh/kg), and pellets bulk density (g/cm^3). Based on the results obtained from the single optimization of the various performance indicator using the Taguchi methodology, the following deduction was drawn up.

Considering pelletizing efficiency: the paper found out that the most influential parameter for higher pelletizing efficiency is die thickness and this was followed by feed rate, no of die holes, and shaft speed respectively. The best parameter combinations for high pelletizing efficiency are: die thickness (A) at level 3 (12mm), number of die holes (B) at level 1 (25), shaft speed (C) at level 2 (250rpm) and feed rate (D) at level 2 (145g/h) respectively. In the case of throughput (kg/h), the most dominant parameter for higher throughput was found to be the die thickness. This was followed by feed rate, shaft speed, and no of die holes. The best parameter combinations for a high level of throughput are available at a die thickness (A) at level 2 (8mm), no of die holes (B) at level 2 (30), shaft speed (C) at level 3 (300rpm) and feed rate (D) at level 2 (145g/h).

In considering the energy requirements (Wh/kg), it was discovered that the most significant parameter for lower energy requirements was die thickness, and this parameter was followed by feed rate, shaft speed, and no of die holes. The best parameter combinations for minimum energy requirements was achieved at die thickness (A) at level 1 (6mm), no of die holes (B) at level 1 (30), shaft speed (C) at level 2 (250rpm) and feed rate (D) at level 3 (160g/h). Lastly, the results of the analysis of pellets bulk density (g/cm^3) reveal that the most effective parameter for lower pellet bulk density was die thickness, which was trail by shaft speed, no of die holes, and feed rate. The best parameter combinations for lower pellet bulk density are: die thickness (A) at level 3 (12mm), no of die holes (B) at level 3 (35), shaft speed (C) at level 2 (250rpm) and feed rate (D) at level 3 (160g/h). Considering the multiple optimization processes based on the ANOVA for the GRG, the study reveals that the most dominant parameter on the selected responses was the die thickness and feed rate. It is worthy to note that the optimal parameters combination for the multiple responses is achievable at a medium die thickness (8mm), medium number of die holes (30), low shaft speed (200rpm) and medium feed rate of 145g/h. Finally, the confirmation test was performed to verify the enhancement in the performance of the multiple responses. The confirmation test performed shows that the GRG is enhanced by 2.19%.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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