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Optimization of Processing Conditions of Hand Operated Descaling Machine for Various Fish

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Abstract

ICAR-Central Institute of Fisheries Technology has developed a hand operated descaling machine of 3 kg capacity for easy and fast removal of scales in different fishes. This study was to optimize the loading capacity and duration of operation of hand operated descaling machine for various fishes. Effect of loading capacity and duration of operation on descaling efficiency was analysed using response surface methodology. Maximum descaling efficiency of 92.45, 77.24 and 85.78% in sardine, threadfin bream and tilapia, respectively were obtained at 2 kg loading and 9 min duration of operation. Also the highest descaling efficiency of 81.39% was observed at 1 kg loading and 9 min operation for pearl spot. The obtained optimum process variables will be helpful for the small scale fish vendors to use hand operated low cost, efficient descaling machine for quick and hygienic descaling process.

Keywords: Descaling, fishes, optimization, response surface methodology

Introduction

India is the second largest fish producing country in the world. In 2016-17, total fish production reported as about 11.41 million tonnes (Bodh, 2018). Indian fisheries sector attained significant importance due to its contribution to the overall socio-economic development. Fish is an important source of regular diet because it provides high quality protein and many vitamins and minerals to human (Hixson, 2014). Fish requires proper handling and preservation methods due to its highly perishable nature. Fish flavour and texture changes rapidly during storage. Hence fish preservation or pre-processing measures are required to increase the shelf life and maintain nutritional and quality characteristics (Ghaly et al., 2010).

Pre-processing of fish include removal of fish scales, deheading, cutting of fins and belly flaps, evisceration, slicing fish into steaks, filleting and skinning. (Bykowski & Dutkiewicz, 1996). Generally, fish scales are removed from skin by rubbing it against a rough surface. Small scale fish vendors and retailers remove the scales manually using different types of knives. Manual descaling of fish is reported to occupy around 50% of initial pre-processing time and it is labour intensive process (Bykowski & Dutkiewicz, 1996). Also, workers in small processing plants or retail shop vendors use sharp knife or any unsafe indigenous tools for descaling of fish. Usage of these small hand operating tools leads to the frequent injury of workers. Hence descaling demands automation and mechanization for efficient operations and maximum scales removal.

In the food processing industry, two types of descaling machines are commonly used *i.e.* drum machines and moving scrapers. Generally automatic descaling machines consist of a horizontal cylinder fabricated from horizontal metal bars or having rough internal surface (Harris, 1999). Current level of mechanization for processing of various fish is low due to the limited value addition, lack of economical and efficient mechanical equipment (Bykowski & Dutkiewicz, 1996). ICAR-Central Institute of Fisheries Technology, Cochin, has developed a low cost, hand operated descaling machine which can be used for descaling of fish in local fish markets and small scale processing industries (Zynudheen et al., 2017). It enables easy handling and efficient removal of scales, dirt and

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slime from fish, requires less maintenance and alleviates human drudgery. Hand operated descaling machine is safe to use for the targeted customers like fish retailers and road side vendors to remove the scales efficiently within short span of time.

This study aims to optimize the process variables of hand operated descaling machine such as loading capacity and duration of operation for various fishes using response surface methodology (RSM). RSM is an empirical modeling approach for determining the relationship between various process parameters (Mirhosseini et al., 2008). Also, it is an effective experimental design methodology, which can explore the interactions between independent variables and dependent variables and predict their responses under specified sets of conditions (Qin et al., 2016).

Materials and Methods

Fresh marine fish (small and medium size) Indian oil sardine (*Sardinella longiceps*, Chaala), Threadfin Bream (*Nemipterus japonicus*, Kilimeen) and brackish water fish Tilapia (*Oerochromis mossabicus*, Tilapia), Pearl spot (*Etroplus suratensis*, Karimeen) were purchased from local markets in Ernakulam, Kerala. Fishes were cleaned properly using potable water and kept at room temperature (25±2°C).

Experimental design for optimization of descaling process conditions was arrived at using response surface methodology (RSM). Three level factorial design of RSM was used for the optimization of variables (factors) loading capacity (X_1) and duration of operation (X_2) based on the response variable descaling efficiency (Y_1). Factors and the levels considered in this study are given in Table 1.

Table 1. Variables and the levels used in three level factorial design of RSM

Factors	Levels		
	-1	0	+1
Loading capacity (X_1)	1	2	3
Duration of operation (X_2)	3	6	9

Experimental runs were conducted at different combinations of three levels of two factors listed in Table 2. Experimental run combinations were repeated for four fishes (Indian oil sardine, Threadfin Bream, Tilapia and Pearl spot) and descaling efficiency was calculated as response value.

Descaling experiments were carried out using hand operated fish descaling machine developed by Engineering division, ICAR-CIFT, Cochin (Zynudheen et al., 2017), to analyse its performance under various loading capacities (1, 2 and 3 kg) and duration of operation (3, 6 and 9 min). Hand operated descaling machine (Fig. 1) has the capacity of 3 kg and it is fabricated using stainless steel (SS 304). It consists of base frame, descaling drum and handle to rotate drum. Base frame is made of 25 mm square shaped SS tube and a hand pedal is fitted on one side of frame to rotate the descaling drum manually. Descaling drum is fabricated of outer smooth SS sheet and inner perforated sheet and has diameter and length of 270 and 270 mm, respectively. A leak proof door with lock is provided for loading and unloading purposes. Descaling is done by filling fish inside the descaling drum and by rotating the drum. Friction between the fishes and the rough interior surface of drum during the rotation of drum removes the scales. While rotating

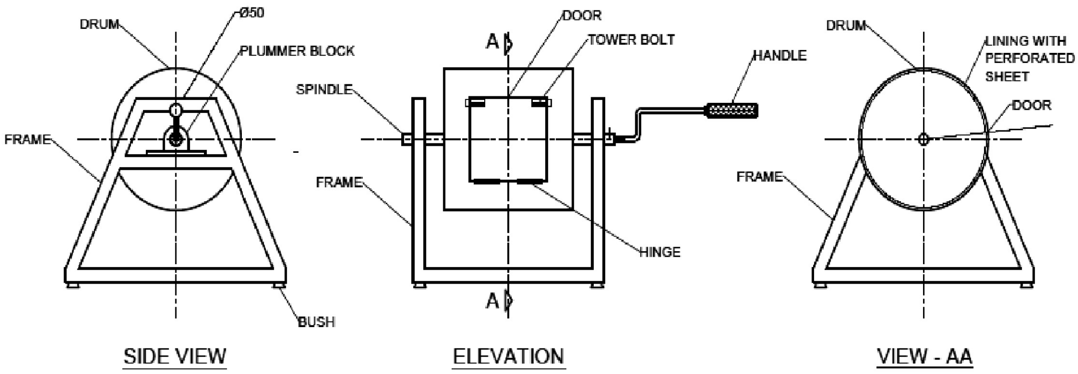

Fig. 1. Hand operated descaling machine

the drum fish will roll down gently through side walls. Downward sliding of fish will lead to the rubbing of fish against projected perforations and thus removing the scales.

Descaling of fishes was done at various loading capacities (1, 2 and 3 kg) and duration of operation (3, 6 and 9 min). Duration of operation of 9 min was selected as maximum since fish vendors in local market requires 10 – 15 min for descaling of one kg of fish (small and medium size fish) manually. Once fish is filled, the drum is rotated slowly (approximately 20 rpm) to make the contact between fish and perforations of drum. At the end of each experiment, amount of scales removed was recorded by noting down the weight of removed scales. The remaining scales on fish were removed manually using SS knife and weighed to know the total amount of scales on fish. Descaling efficiency was calculated using the following equation:

$$\text{Descaling efficiency \%} = \frac{\text{Weight of scales removed at time t (g)}}{\text{Total weight of scales on fish (g)}} \times 100 \quad \text{.....(1)}$$

The following second order regression equation was used to describe the relationship between factors and response:

$$Y_1 = b_0 + b_1x_1 + b_2x_2 + b_{11}X^2_1 + b_{22}X^2_2 + b_{12}X_1X_2 \quad \text{.....(2)}$$

Where b_0 is intercept, b_1 and b_2 are the linear effects, b_{11} and b_{22} are the quadratic effects and b_{12} is the interaction coefficient.

Design-expert software (6.0.8, Statease Inc., Minneapolis, USA,) was used for the experimental design formulation and to perform statistical analysis. Statistical significance was analysed by analysis of variance (ANOVA) and goodness of fit of models were determined by coefficient of determination (R^2) values. Interaction between factors and response were determined by graphical analysis and represented by three dimensional response surface plots. Optimum condition for descaling of each fish was identified by the numerical optimization method.

Cost analysis

Operation cost of descaling machine was calculated to compare with the manual descaling cost. Total operating cost was calculated using the following equation:

$$\text{Total operating cost/hour} = (\text{Maintenance cost/hour}) + (\text{Labour cost/hour}) \quad \text{.....(3)}$$

Where maintenance cost (INR/h) = (percentage of maintenance × price of machine) / (100 × annual hours of use) (Lotfie et al., 2013). The percentage of maintenance is taken as 15% of machine cost (Obinna & Oluka, 2016).

Results and Discussion

Descaling optimization was done by three level factorial design and the combinations of experimental runs and response values are given in Table 2. Experimental values of descaling efficiency were fitted in second-order regression equation (Eq. 2). The corresponding R^2 values of descaling efficiency of various fishes were found to be high (>0.99) and indicating a good fit of models to response and the high proportion of variability was explained by experimental results. Coefficient of variation less than 5% showed that the reliability of models were high.

ANOVA was conducted to check the significance of models and model fitting. Results showed that the models are highly significant ($p<0.01$) for descaling efficiency of all fishes. Lack of fit is not significant for all responses which indicate that models adequately explain the data. Graphical representation of effect of factors on responses is shown in three dimensional response surface plots (Fig. 2 - 5).

Descaling efficiency of Indian oil sardine varied from 27.03 to 92.45% for the loading capacity of 1 to 3 kg and duration of 3 to 9 min (Table 2). Interaction effect of both factors on descaling efficiency of Indian oil sardine is shown in Fig. 2. It is observed that increasing the loading capacity from 1 to 2 kg increased the descaling efficiency from 70.4 to 92.45%, however further increase from 2 to 3 kg reduced the descaling efficiency to 69.3%. Reduction in descaling efficiency may be due to the lack of exposure of fish to internal projections of drum at higher loading capacity. Descaling efficiency was increased with increasing duration of operation from 3 to 9 min due to the increased exposure time of fish to drum. Extended exposure of fish to projections in drum facilitated the rubbing of fish and thus more scales were removed during descaling. In sardine fish maximum scales about 92.45% has been removed within the duration of operation of 9 min. This may be due to the presence

Table 2. Experimental run combinations and response value of descaling process

Loading capacity (kg), X_1	Duration of operation (min), X_2	Descaling efficiency (%), Y_1			
		Indian oil sardine	Threadfin Bream	Tilapia	Pearl spot
3.00	6.00	63.22	29.7	40.51	37
1.00	3.00	27.03	12.74	18.37	23.25
3.00	9.00	69.3	48.02	69.42	62
2.00	9.00	92.45	77.24	85.78	62.34
2.00	6.00	80.9	59.54	56.34	36.36
1.00	9.00	70.4	49.98	69.39	81.39
2.00	6.00	80.75	58.67	57.54	35.45
2.00	3.00	48.17	36.45	28.44	16.88
2.00	6.00	80.45	59.23	58.57	36.78
2.00	6.00	79.52	58.45	59.02	34.67
2.00	6.00	79.25	59.43	58.45	36.98
3.00	3.00	32.43	8.54	15.44	17
1.00	6.00	58.24	34.64	40.82	50.46

of small and fine scales in sardine rather than hard scales in other fishes.

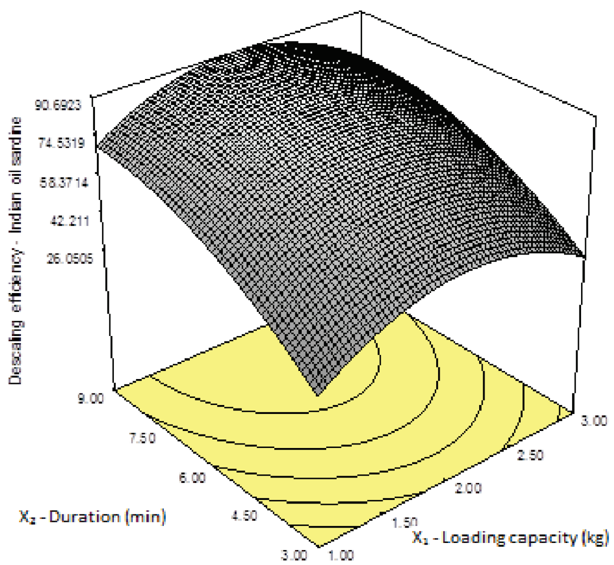

Fig. 2. 3D plot for descaling efficiency in Indian oil sardine

Descaling efficiency values of Threadfin bream fish ranged between 8.54 and 77.24% (Table 2). Descaling efficiency increased with an increase in duration of operation. Increasing loading capacity from 1 to 2 kg increased the efficiency from 49.98 to 77.24%, further increase in loading decreased the efficiency to 48.02% (Fig. 3). Descaling efficiency (77.24%) was much less than other fishes may be due to the presence of more scales in Threadfin bream.

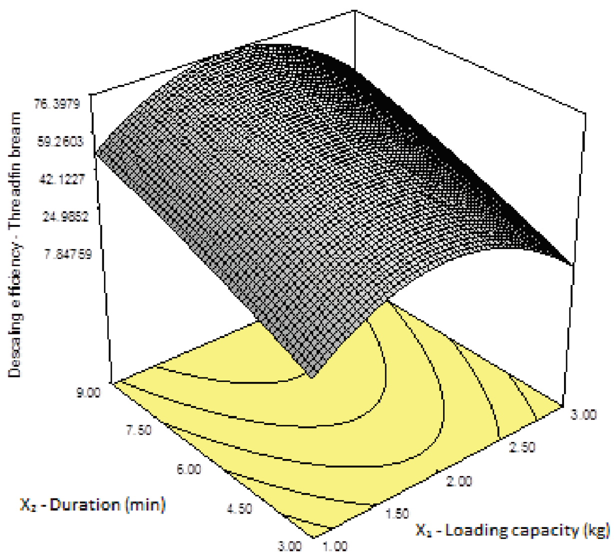

Fig. 3. 3D plot for descaling efficiency in Threadfin bream

Table 2 shows the descaling efficiency of Tilapia fish which ranged from 15.44 to 85.78%. Fig. 4 shows the effect of loading capacity and duration of operation on descaling efficiency of Tilapia fish and observed that an increase in duration of operation increased the efficiency. Also descaling efficiency was increased with increasing loading time up to 2 kg and further increase to 3 kg decreased the efficiency. Maximum of 85.78% scales were removed after 9 min of rotation due to the slight hardness of scales in Tilapia fish.

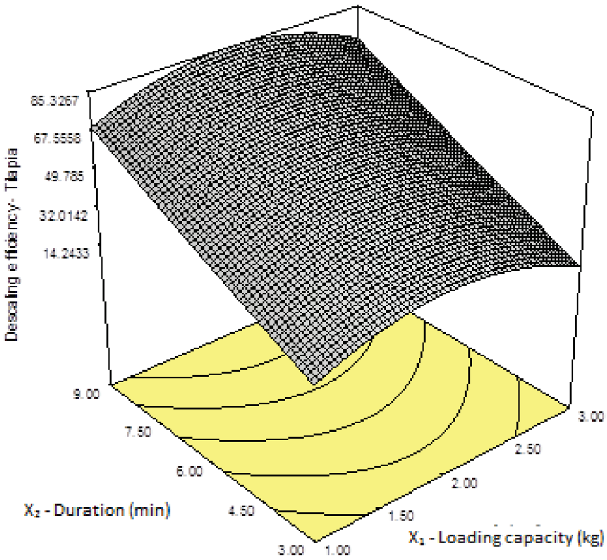

Fig. 4. 3D plot for descaling efficiency in Tilapia

Experimental values of descaling efficiency of Pearl spot fish was observed between 16.88 and 81.39% (Table 2). Response surface plot in Fig. 5 shows the interaction between loading capacity, duration of operation and descaling efficiency of Pearl spot fish. Efficiency increased from 17 to 62% when duration of operation was increased from 3 to 9 min at 3 kg loading. Maximum descaling efficiency of 81.39% was obtained at 1 kg loading capacity and 9 min duration of operation. Maximum efficiency of 81.39% is only possible because of the presence of scales near the gills and tail of the fish which were more intact and couldn't be completely removed.

Numerical optimization applying desirability function was used to identify the optimum conditions for descaling of fishes. Criteria chosen for factors and response are in the range. Optimum loading capacity and duration of operation for fishes such as Indian oil sardine, Threadfin bream and Tilapia were 2 kg and 9 min with the desirability values of 0.973, 0.988 and 0.994, respectively. For Pearl spot fish 1 kg and 9 min were found to be optimum with

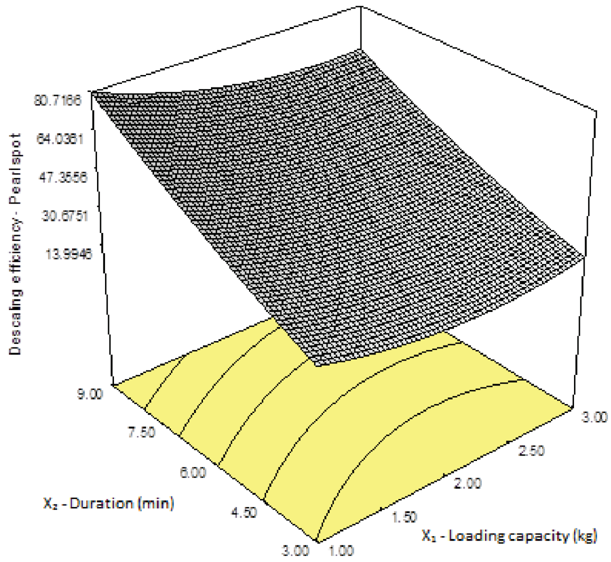

Fig. 5. 3D plot for descaling efficiency in Pearl spot

the maximum desirability of 0.990. Descaling experiments (n=3) were conducted using optimum variables for validation. Predicted and experimental values of descaling efficiency of all fishes under optimum conditions were found to be in agreement with each other (Table 3). Thus the obtained optimum process variables were validated and it can be used to obtain maximum descaling efficiency for all fishes. The maximum descaling efficiency of Indian oil sardine, Threadfin bream, Tilapia and Pearl spot under optimum process variables were observed as 89.45, 75.39, 86.78 and 81.53, respectively.

Fishes were observed for the physical damage at the end of each descaling experimental run. No physical damage was observed in Tilapia and Pearl spot

Table 3. Predicted and experimental values at optimum conditions

Response	Predicted value	Actual value (n=3)
Descaling efficiency – Indian oil sardine	90.69	89.45±1.34
Descaling efficiency – Threadfin Bream	76.40	75.39±0.16
Descaling efficiency – Tilapia	85.32	86.78±2.12
Descaling efficiency – Pearl spot	80.72	81.53±1.03

fishes after descaling for duration of 3, 6 and 9 min at 1,2 and 3 kg loading. Skin softness and belly burst was observed in Indian oil sardine and Threadfin bream when loading capacity was 3 kg and duration of operation were 6 and 9 min. This may be due to the softness of fish tissues and full capacity loading leading to congestion.

According to local fish market survey at Cochin, manual descaling of one kg of fish requires Rs.15/-. Operating cost of descaling machine was calculated as Rs.4.76 kg^{-1} (in case of Sardine, Tilapiaand Threadfin bream) and Rs. 9.52 kg^{-1} (for Pearl spot). In comparison, descaling using hand operated descaling machine could save Rs. 5.5/- than manual descaling.

Optimization of descaling process conditions in hand operated descaling machine for various fishes were done using response surface methodology. Loading capacity and duration of operation of 2 kg and 9 min were obtained as optimum conditions for Indian oil sardine, Threadfin bream and Tilapia with the maximum descaling efficiency of 89.45, 75.39 and 86.78%, respectively. Optimum condition for descaling of Pearl spot was found to be 1 kg and 9 min with the descaling efficiency of 81.53%. This study gives an idea of optimum loading capacity of fish and duration of operation for various fishes and it will be helpful for the small scale vendors and retailers.

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