IMPROVEMENT OF NUTRITIONAL QUALITY OF FISH DURING CONVENTIONAL FRYING PROCESS: A NOVEL APPROACH USING ARTIFICIAL INTELLIGENCE

A Thesis Submitted in Partial Fulfilment of the Requirements

for the Degree of

Doctor of Philosophy

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May, 2022

ABSTRACT

Fish is an excellent human diet worldwide due its rich source of "essential" fatty acids (FA), especailly the long chain ω-3 polyunsaturated fatty acids (PUFA). It prevents the prevailing nutrient deficiencies and associated diseases. The overall FA profile of a fish has a great impact on human health. Scientists have defined various nutritional quality indices (NQI) related to FA profile and recommended their value in diet to evaluate the nutritional benefit of food for human.

The consumption of raw fish of any species either in fresh or frozen condition is rare and therefore the information about nutrient constituents of raw fish may have limited value for their food quality. Fish is usually consumed after different culinary preparations to improve its palatability, digestibility and sensory attributes. Among several culinary processes, frying with edible oil is a common, easy and economic method used globally. It promotes the physical and chemical changes in the product that may be beneficial and/or detrimental to overall nutritive value. The nutritive value of fried food depends on a number of interfering factors. Among those, the most effective and controllable process variables of traditional frying techniques are frying temperature, time, oil amount used, oil variety, and number of times of this oil use.

Therefore, the effects of the frying process on the overall nutritional and sensory quality of fish are interesting and worthy of investigation. There is dearth of data in the literature about the effect of different cooking processes on freshwater major carps, associated biochemical aspects and their implication towards human health. From the nutritional point of view, it is essential to recommend an optimized frying condition that preserve the maximum nutritional benefits and healthy attributes of fish. For optimizing the process, it is of particular concern to determine the effect of most influencial process variables on the nutritional value of fish. There is no phenomenological method available in the literature on the modelling purpose that support a unified correlation between the frying conditions and NQI, nor any comprehensive experimental study is available on optimization. It is of great advantage also if the optimized frying condition can simultaneously improve all the conflicting objectives (NQI) along with satisfying the sensory attributes (flavour, colour & appearance, and taste) of consumers while reducing cost and waste.

In light of the above-mentioned research gaps, this work particularly aims to propose a modelling and optimization methodology based on the experimentations for the

improvement of the nutritional quality of fish during the conventional frying process by a novel application of artificial intelligence. The thesis has been organised into the following chapters.

Chapter 1: Introduction and literature review

The introductory chapter includes the reviews of significant previous and present work done related to the necessity of processing of fish, their favourable and adverse effects on the FA profile, nutritional quality along with the impact on sensory attributes. It explores the difficulties and research gaps about the development of methodology for optimization of the frying condition to improve the overall nutritional value of fish as well as satisfying the sensory attributes and multi-objective proposal (beneficial for health, time-saving, economic, and waste minimizing). Based on these considerations, aim and objectives followed by the work plan of the present research have been proposed and discussed.

Chapter 2: Effect of conventional frying on the nutritional quality of major carps

This chapter describes the consequence of conventional frying with mustard oil on the proximate compositions, FA profiling and associated NQI of fresh and frozen major carps (*Catla catla, Labeo rohita, and Cirrhinus mrigala*) along with multivariate analysis. From the results it may be concluded that frying directly asserts positive effect on human health because of the decrease in index of atherogenicity (IA), index of thrombogenicity (IT) values along with rise in hypocholesteromic/hypercholesteromic (HH) value and PUFA/SFA ratio. In contrast, other important nutritional parameters such as ω-3/ω-6 FA ratio, cis/trans FA ratio deteriorated significantly on frying. But how each process parameters of frying affect different NQI is of fundamental interest for optimization purpose of cooking process to minimize the thermal alteration as well as nutritional deterioration.

Chapter 3: Modelling of frying process: An approach with ANN

This chapter is an endeavour to develop the empirical relationship between the inputs (frying temperature, frying time and oil amount used for frying) of frying process parameters and NQI. Here, an artificial intelligence system, artificial neural network (ANN) was developed by an exhaustive search of various algorithms, activation functions and nodes in hidden layer automatically. The developed ANN was successfully applied to predict the non-linear functional correlation between the independent inputs and dependent outputs. Very high R^2, low RMSE and performance value of optimized neural network topology for all the outputs proved the fitness, accuracy and reliability of the developed

model. Sensitivity analysis revealed that frying time had the greatest impact on the nutritional profile compared to other two factors.

Chapter 4: Optimization of frying condition to satisfy multi-objective proposal

4.1 Performance of selected metaheuristic algorithms for optimization purpose

In this chapter, Simulated Annealing (SA), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Differential Evolution (DE) were selected among the "classical" and "new generation" algorithms, namely, Firefly Algorithm (FFA), Krill Herd (KH), Grey Wolf Optimization (GWO), and Symbiotic Organism Search (SOS) were chosen. Their performances were tested and compared for the solution of a number of selected benchmark problems that are used in the literature for algorithm testing purpose. Among all, SOS and KH showed the most promising results within short execution time against most of the selected complex problems. DE, and PSO also effectively attained the optimal solution which were very close to the best one. Therefore, no firm conclusion can be taken regarding a possible universal best algorithm. Their performance may vary for different benchmark problems. This study provided some insights to use SOS and KH as best performing algorithms to the novice user who can easily get lost by the large number of optimization algorithms.

4.2 An application of hybrid 'modelling-optimization' techniques for tuning the combination of frying process to improve nutritional value

In this chapter, a hybrid robust process approach integrating the developed ANN model with selected algorithms was employed to optimize the unique cooking condition for improving all the NQI of fish after frying up to the recommended limit. All the hybrid "modelling-optimization" topologies were able to tune the frying condition successfully within and beyond the experimental limit to attain the recommended values of NQI. But two main disadvantages of this formalism were that they failed to achieve the same optimized condition for all of the conflicting objectives (NQI) simultaneously and in many cases the selected optimized conditions recommended for high temperature, time or required oil amount can possibly enforce adverse effect on health, economy and the sensory attributes of consumers.

4.3 An approach with MOGA for simultaneous optimization of all the conflicting objectives as well as satisfy multi-objective proposal

According to nutritional guidelines, ω-3/ω-6, PUFA/SFA, cis/trans FA ratios need to be maximized, while, IA value need to be minimized in the food. In this chapter, a novel approach was implemented to integrate the ANN model with multi-objective genetic algorithm (MOGA) to find out the Pareto optimal data set to improve all the conflicting NQI of the fried fish simultaneously. The main advantage of this formalism is that users can choose the optimal solution from the Pareto set according to their preferences to the competitive objectives from a practical point-of-view. Finally, the selected optimized condition (temperature- 140.01℃, time- 7.62 min, oil amount- 47.87 ml/kg of fish) simultaneously improved the ω-3/ω-6 FA, PUFA/SFA, cis/trans FA ratio and IA value up to 74.44%, 4.39%, 100.58% and 82.98%, respectively than the conventional frying along with satisfying the multi-objective proposal. Experimental verification demonstrated that the maximum relative error of the modelling was lower than 10% and thus proved the accuracy and reliability.

Chapter 5: Consumers' sensory attributes analysis using MCDM tool

Finally, sensory evaluation was performed for the selected optimized cooking conditions. However, practically, it is not possible to maintain the optimum values of temperature with such precision in real experimental condition. Therefore, values for this input parameter (Temperature) were rounded off to integer numbers to perform the experiment. The data were analysed using two well-known multi-criteria decision making (MCDM) strategies, analytical hierarchy process (AHP) and fuzzy logic technique to remove the subjectivity. Among the three most important quality attributes, taste was most preferable one for the fried fish samples followed by colour & appearance, and flavour, consecutively. From both the results of AHP and fuzzy logic analysis, it may be concluded that the sample fried with the optimized condition (a combination of 140℃ temperature, 7.62 min time and 47.87 ml oil/kg of fish) was the most accepted one in terms of all perspectives. Therefore, this tuned combination of frying process may be implemented as standard condition in domestic and industrial purpose.

Chapter 6: Concluding remarks and Future scope

The novelty of the present work was to develop a generic methodology that is a combination of experimentation, ANN modelling, metaheuristic optimizations and MCDM approach. The finally selected optimized process conditions for frying of fish simultaneously and successfully improved all the NQI up to the recommended limit along with satisfying the multi-objective proposal. Therefore, this tuned combination of frying

process may be implemented as standard condition in domestic and industrial purposes. Further research in this regard constitutes the future scope of the present work. The generic modelling technique and hybrid robust process approach will be very useful also for a novice user to select the best model automatically and optimize the process condition of any experiments.