Abstract

Micronutrient malnutrition, particularly iron deficiency anemia, is becoming a worldwide nutritional disorder affecting individual health. Globally, approximately one-third of the population is affected by IDA. The issue can be solved by providing the required quantity of iron, vitamin B_9, and vitamin B_{12} to the body. Food-to-food fortification is an emerging technology with the potential to carry out the required operation for mitigation of micronutrient deficiency. It only requires dense micronutrient-rich natural fortificants (NF) and a potential food vehicle. In the current study, a novel formulation was developed through linear programming (LP) covering the maximum limit of iron, vitamin B_9, and vitamin B_{12} through herbs and skim milk powder (SMP). The choice of formulation was done using fuzzy logic and a 9-point hedonic scale. Standardization of extrusion process parameters was done by varying the feed moisture content (MC) (30-40% wb), screw speed (SS) (80-100 rpm), feeder screw speed (FSS) (10-20 rpm), and the die head temperature (DHT) (max 130°C). The minimum limit of DHT was found using steady shear analysis (SSA). The extrusion optimization was done using a graphical multi-response optimization technique (GMOT) and a multi-objective genetic algorithm (MOGA) with the responses being the cooking and texture characteristics of fortified rice noodles (FRN). Three different drying techniques viz., hot air drying (HAD), vacuum drying (VD) and microwave drying (MWD) were applied with variation in processing conditions. The drying kinetics using twelve empirical models and four machine learning (ML) models were done. The drying optimization was done using MOGA after the development of regression models for HAD, VD, and MWD with responses selected using principal component analysis. The effect of hydrocolloids (xanthan gum, guar gum, sodium alginate) and gelatinized rice flour (GRF) for improving the FRN quality and cooking time was done at different levels and optimum concentration was found out. The sorption study at 40, 50, 60, and 70°C was done with regression analysis using sorption and ML models followed by characterization, sensory analysis, and cost calculation.

The results showed the optimum LP formulation having rice flour of 92.53 g/100g, marjoram powder of 4.13 g/100g, and SMP of 3.34 g/100g providing 4.25 mg/100g of iron, 14.76 μg/100g of vitamin B_9, and 0.13 μg/100g of vitamin B_{12}. The developed FRN using the optimized formulation had the highest sensory appeal suggested by sensory analysis. The minimum limit of DHT obtained through SSA was 90°C. MOGA provided the best optimal solution of feed MC of 32-33% wb, DHT of 115-120°C, SS of 85-87 rpm, and FSS of 12-13 rpm. All the drying techniques showed the presence of a falling rate region with better performance of ML models viz., gaussian process regression and artificial neural network. The optimal drying process was HAD with the optimal condition of 60°C temperature with 1 m/s air speed obtained using MOGA. The improvement in cooking and textural properties of FRN was obtained through the 5% addition of GRF. FRN adsorption isotherms indicated higher MC with increased relative humidity, and lower MC with rising temperature. The GPR model was the optimal model in predicting sorption of noodles. The FRN have iron, vitamin B_9, and vitamin B_{12} under the prescribed FSSAI 2018 limits with the cost of Rs. 150 per kg, balancing both economic feasibility and high sensory acceptance evidenced by favorable evaluations in color, texture, aroma, and overall acceptability.

Keywords: Fortified rice noodles; Extrusion, Drying; Hydrocolloids; Machine learning