Abstract

The study involves the development of a protocol for a non-destructive monitoring of the process conditions for manufacturing *Komal Chaul,* a special rice product, to ensure optimum quality. Also, a Near Infrared (NIR) based scientific methodology is developed for the assessment of the age of *Komal Chaul* during its storage. The product *Komal Chaul* is a kind of ready-to-eat rice that can be consumed by soaking in warm water. Adequate hydration from warm water-soaking to obtain a texture similar to the cooked rice even without actual cooking, is the typical feature of *Komal Chaul*. The quality of *Komal Chaul* is affected by the processing conditions. Additionally, changes that occur in the storage of the rice-product after production is another crucial factor that affects the hydration behavior. Accordingly, a non-destructive technique based on spectral data is attempted in this work to monitor the progress of processing and changes in the product during storage. Near Infrared Spectroscopy (NIRS) is used in this work because its instrumentation involves simple mechanics and robust sensors are available for online process analysis. Machine learning (ML) based mapping of spectral data to product features is found to be effective in food analysis applications of NIR technology. Therefore, an ML-supported and NIR sensor-integrated solution for evaluating the parboiling parameters during soaking, steaming, and drying and estimating the degree of ageing was taken up in this research. During this study, the production of *Komal Chaul,* was achieved by subjecting either brown rice or a de-husked form of low amylose rice known as *Chokuwa* to the parboiling process.

This work is divided into 4 work packages with specific objectives. The first task involves studying the kinetics of the parboiling process and finding the optimal parboiling conditions to obtain a good-quality *Komal Chaul*. The first objective's methodology was implemented by finding appropriate kinetic rate equations and spectral calibration. The second task was to develop a NIRS-based process analysis model for quality analysis of parboiling end points of the *Komal Chaul* manufacturing process. The second objective's methodology was implemented by applying the ML classification and regression tools. The third objective was to study the changes in the physicochemical characteristics of *Komal Chaul* during ageing and the effects of storage and ageing on eating and cooking qualities. The methodology for this objective was an experimental investigation of pasting, thermal, and molecular properties, and surface structure along with the cooking quality parameters for the characterization of aged and unaged *Komal Chaul*. Lastly, the fourth objective was to develop an NIR-based tool for predicting the time of ageing as well as calibrating NIR based sensing system for cooking quality. This methodology implemented the ML regression technique partial least square (PLS) to relate ageing time and ML-based classification for ageing time.

The findings include the changes in soaking, steaming, and drying processes occurring at different conditions and optimal parboiling parameters for the best rehydration property of *Komal Chaul*. Diffusion coefficient as a function of concentration, for Fick's diffusion model-based description of the movement of water from rice grain surface to core was used to characterize the isothermal soaking processes, which helped to identify the temperature dependence of hydration rates.

Steaming kinetics was studied using the first-order rate equation. The maximum changes were due to the increase in parboiling pressure as well as steaming time. Due to the temperature effect, the reaction rate constant showed a tendency to increase with parboiling pressure, and activation energy for the process was found to be 1.87×10^2 kJ/mol. Drying kinetics was studied using Fick's diffusion law. Also, a generalized drying equation relating changed moisture content to the drying time and drying temperature was developed using the master curve technique. Moving away from conventional models, a linear regression model combined with principal components was used for regressing moisture content during soaking with an R^2 of 0.695, and root mean squared error (RMSE) of 1.109 %. PLS for regression of NIR data with degree of gelatinization (DG) values worked well with an R^2 value of 0.843. The estimated highest and lowest relative percent differences (RPD) values for the test datasets were 19.79 and 0.94, respectively. For drying, an artificial neural network (ANN) performed well in the regression of moisture content with spectral profile, with cross-validation score of an R^2 of 0.66 and an RMSE of 7.03 %. Random Forest (RF) algorithm was used to identify soaked samples based on moisture content with a prediction accuracy of 0.895. The algorithm also worked well for dried product class classification with an accuracy of 0.941.

Studies on the tasks for the third objective revealed the pattern of textural and structural changes with storage and ageing, although the overall composition of *Komal Chaul* in terms of amylose, protein, and fat contents remains essentially unchanged after ageing. Storage at higher temperatures is identified to induce more changes in pasting behavior, the thermal properties, and the rehydration property of *Komal Chaul*. A PLS model was developed, based on a data set of NIR spectra of stored *Komal Chaul* during a storage period of 1 year, and was used to estimate the ageing time with a regression coefficient (R^2) of 0.897. The binary classification of a year-old spectral data showed better performance. According to the findings, the ageing process leads to a progressive strengthening and organization of rice due to the rearranging of the starch molecules, which affects its cooking and softening characteristics. The rate of hydration during soaking depends on the water temperature and soaking time. The steaming process is mostly affected by the steaming duration while a higher pressure facilitates quicker gelatinization. In the initial stages of drying, the moisture content abruptly decreases and gradually reaches saturation. Also, ML tools integrated with an NIR spectrum acquisition system can be used for process monitoring during the production of *Komal Chaul*. The use of NIR sensors for the estimation of rice ageing can be of great use to corporations involved in the distribution, procurement, and trading of rice.

Keywords: Non-destructive technique, Machine learning, *Komal Chaul*, gelatinization, parboiling, ageing, brown rice.