Near Infrared based Solutions for Quality Assessment during Manufacturing and Storage of a Ready-to-Eat Rice

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Submitted by

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5. Summary and Conclusion

5.1 Summary

A study was conducted on a low-amylose variety of rice indigenous to Assam called *Chokuwa* rice that was used to produce traditional soak-and-eat rice called *Komal Chaul*.. The purpose of the study was to apply spectral based techniques, integrated with ML tools for feasibility of monitoring the process of manufacturing of *Komal Chaul* from brown (de-husked) form of the *Chokuwa* rice, and monitoring the changes in its quality during storage. These were accomplished by fulfilling the 4 objectives:

The first objective was studying the kinetics of the parboiling process and finding the required conditions for desirable parboiling parameters to produce *Komal Chaul*. The kinetic study of three processes gives us an insight of the changes occurring, while a handy process analysis is required for easy and quick estimation. For soaking kinetics Peleg's equation performed well and the activation energy for the process was calculated to be 42.28 kJ/mol, and the estimated soaking time from the predicted model for attaining 30 % moisture content (wb) were 185, 135, and 110 min at 40, 50, and 60°C, respectively. Steaming kinetics was studied using a first order rate equation, the maximum changes were due to the increase of steaming time and with increasing pressure, the reaction rate constant showed a tendency to increase. The D_{eff} values obtained at 0, 0.05, 0.1, 0.15 and 0.2 MPa were 1.76, 3.52, 5.28, 7.04, and 8.8 $\times 10^{-8}$ m^2/s respectively. The time required to reach 99% gelatinization at 0, 0.05, 0.1, 0.15, and 0.2 MPa was estimated to be 21, 17, 12, 10, and 6 respectively. The activation energy of the steaming process was calculated to be 18.7×10^2 kJ/mol. Drying kinetics was also studied using Fick's diffusion law and using the Cranks solution, the D_{eff} was estimated to be 7.77×10^{-9} m^2/s - 2.60 $\times10^{-9}$ m^2/s. Page model fitted the best and the estimated time for reaching 13% m.c. (wb) was found to 185, 165, and 150 min at 40, 50, and 60 °C respectively. The activation energy calculated for the drying process using the diffusion coefficient was found to be 2.49×10^{-7} kJ/mol. Generalization of the temperature and time for moisture absorption and desorption in soaking and drying, respectively using the Midili Kucuk equation and a time shift factor. And it worked well for both the processes with maximum RMSE of 0.006 for measured and predicted values. Therefore, it can be said that the hydration rate of brown rice during soaking depends on the water temperature and soaking time, the steaming process is mostly affected by the steaming time while a higher pressure facilitates quicker gelatinization. The moisture content abruptly decreases during the initial stages and later tends towards saturation while drying.

The second objective was development of a spectral based system for process analysis of parboiling threshold end points by integrating with ML tools for monitoring the process of parboiling of *Chokuwa* rice for producing *Komal Chaul*. The overall methodology for implementation of process analysis in the parboiling system involved forming a spectral database by acquiring spectrum at each processing conditions of soaking, steaming, and drying. PCR worked for soaking spectra regression; PLS for the purpose of regression of NIR data with 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 dataset were 19.79 and 0.94, respectively. Artificial Neural Network mapped the drying spectral data well. Random forest classifiers worked well for prediction of moisture classes for both soaking and drying processes. Class imbalance problem was handled well using an ensemble technique like Random Forest. Overall, classification models worked well in comparison to regression models for spectral data which was due to the better handling of discrete labels by ML model and over time classification models are extensively applied and optimized.

The third objective was to study the changes with ageing of *Komal Chaul.* The cooking time or softening time of *Komal Chaul* increased as storage time increased causing the rice to uptake less water. This can be related to the increase in pasting temperature of the RVA plot. The increase in the peak and setback viscosity could be attributed to the change of the physical structure of rice, which could be justified by the rise in crystallinity during the process of ageing. As rice ages, the rice loses moisture from the grain due to the process of retrogradation, and the surface of the rice becomes hardened, restricting it to penetrate water during cooking. The thermograms and surface scans using SEM gave us ideas about the changes that could have occurred due to storage temperature. The difference in the compositional values like fat, amylose and protein were not higher but there were significant changes, and these changes could have happened due to the interaction of starch protein and amylose. The FTIR plot gave us a minimal idea about the bonds. Rice ageing is a complicated process, the extrinsic properties and intrinsic properties relation and their mapping may require years of study.

The fourth objective was to develop an NIR based tool for predicting the degree of ageing that can be a solution for such quality assessment of *Komal Chaul*. PLS Regression technique with optimal variable selection method worked well for predicting NIR spectral data. Therefore, the classification comparison suggests that *Komal Chaul* that are spectra obtained from apparently age groups of 6 months, were showing better predictability. The classification of 1-year spectral data using ageing time grouped into 1 month interval, 3 months and 6 months interval showed that SVM and RF models performed the best. The predictability on the basis of accuracy and F1_score showed that 6 months classification was better. Therefore, ML supported and NIR sensor integrated solution for the estimation of degree of ageing of rice can be useful for corporations dealing with distribution, procurement, and trading of rice.

5.2 Conclusion

Following conclusions were made regarding NIR based assessment of the progression of various stages of processing during the manufacturing of *Komal Chaul*. This rice is a unique rice as it softens on warm water soaking and can be consumed without conventional cooking. The feedstock for this rice is the low-amylose rice variety named *Chokuwa*. These conclusions may pave a way for having a better understanding and monitoring of the process of *Komal Chaul* production by the brown rice parboiling method.

1. The duration of the soaking step of parboiling to attain a grain moisture level of 30% (wet basis) for *Chokuwa* brown rice is around 100-110 minutes when the soaking water is maintained at 60^oC. The duration almost doubles when a soaking temperature of 40^oC is used. The concentration-dependent diffusion coefficient of hydration process in this soaking temperature range is 2.83×10^{-11} m^2/s - 7.92×10^{-11} m^2/s. NIR spectral profiles of soaked grains capture the changes in grain moisture with a decreased reflectance value near the water bond region with an increase in the moisture level.
2. A regression ML model like PCR works well for mapping the change in moisture level during soaking with the NIR spectral values of sampled grains. At the same time, an ensemble technique such as RF classifier, known to reduce overfitting and improve generalization performance, maybe more preferred for the purpose of endpoint detection, as it gives a very good classification of soaked grain based on a target moisture value of 30%.

3. When *Chokuwa* brown rice with 30% (wet basis) moisture is subjected to steaming, time requirement for adequate gelatinization in open steaming is around 20 minutes. It reduces to around 12 minutes upon pressure parboiling at 1 atm (gauge), at laboratory scale processing. The first order reaction rate constant for the progression of percentage DG was in the range of between 0.003 to 0.001 s^{-1}. A regression model like PLS performs well in estimating the percentage of degree of gelatinization during steaming of brown *Chokuwa* rice.
4. The time estimated for hot air drying of the steamed brown rice in thin layers to a moisture content of 13% is around 180-200 minute when a drying temperature of 40°C is used. The drying time reduces to 140-150 minutes when the drying temperature is raised to 60°C. The concentration dependent diffusion coefficient of air-drying process in this temperature is in the range of in the range of 2.60×10^{-9} to 7.77×10^{-9} m^2/s. The decrease in moisture during drying results in an increase in the value of spectral absorbance of sampled grains.
5. A regression model like ANN performed well in estimating the percentage of moisture removal during drying. The accuracy for end point moisture class determination gives better performance than the regression model suggesting reliable class prediction.
6. The changes in the composition and the crystallinity percentage are pre-dominantly affected by processing conditions rather than the duration of ageing. Therefore, no significant compositional changes occur in ageing of *Komal Chaul*. However, the textural and pasting behavior of the product changes significantly due to ageing.
7. Storage at refrigeration temperature helps preserve the rehydration property of *Komal Chaul better*. Change in the surface morphology is more for the product when stored at warmer conditions (temperature around 37 °C) than for refrigerated ones. There are evidence of starch globules swelling and settling on storage at higher temperatures.
8. The PLS model works well for multicollinearity relationships of NIR spectral data for estimation of ageing time of stored *Komal Chaul*. Optimal variable selection performs well in reducing the number of features for the PLS model for the prediction of ageing time from NIR spectral data. The spectral classification of data based on ageing time shows higher accuracy for classification of 6 months rather than 1 month classification of 1 year ageing data of *Komal Chaul* which is because the former being a binary class performs better than multi class classification.

5.3 Scope for future work

1. Development of real-time solutions for analyzing the quality of rice that can be helpful for traders and procurement agencies using nondestructive spectra-based solutions.

2. Quantitative Structure-Activity Relationship for relating physicochemical properties of *Komal Chaul* with consumer perception.