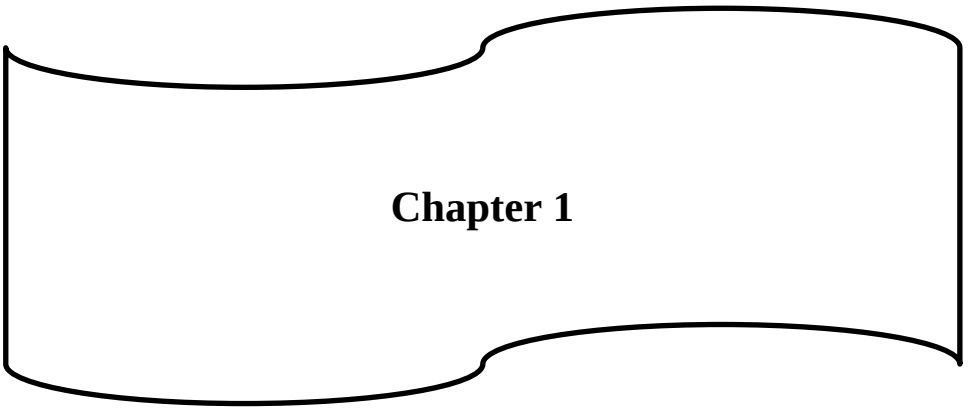
Chapter 1

1. Introduction

1.1 Background of the study

Rice is the second most consumed cereal after wheat and is a staple food for half of the world's population [1]. Harvested paddy or rough rice is treated almost in a similar manner all over the world. It is subjected to the drying process for safe storage or subjected to hydrothermal treatment for further processing to produce value-added products such as parboiled, puffed, flaked rice, etc. Parboiling is a hydrothermal treatment applied to paddy or sometimes brown rice. Processing conditions have a major impact on the quality of rice for consumption. The effect of processing conditions on rice has been reported in numerous studies related to rice processing. Higher temperatures generally increase the rate of moisture removal, leading to a lower equilibrium moisture content. In addition, lower humidity levels correspond to lower equilibrium moisture contents (EMCs), and at a condition when the drying temperature is above the gelatinization temperature the surface of the steamed rice changes from a rubbery state to a glassy state with a resultant drop in moisture diffusivity at the kernel that affects the cooking time and water absorption [2]. Parboiling of rice has been found to increase the cooking time as well as increase the nutritional content, and the structural changes enhance the textural properties. [3,4]. Treatment like instant controlled pressure drop has a significant impact on the quality attributes like less breakage during milling and higher water diffusion in soaking which is very desirable in terms of cooking quality. Pressure parboiling also has a beneficial effect on rice cooking quality [5]. When it comes to rice, in addition to processing parameters, rice ageing has a huge role to play in cooking properties, unlike other cereals. Ageing of rice induces distinctive characteristics to the cooking properties of rice. The major nutrient components like starch, protein, and fat change during ageing. Starch forms a more linear linkage, in protein lower molecular peptide changes to higher molecular weight due to disulfide linkages opening. Changes like free fatty acid content is found due to oxidation of lipids present in the rice [6].

Although rice ageing is hard to thoroughly understand, the noticeable factors need to be studied concerning eating and cooking quality for producing better quality rice. Pasting behavior, thermal properties, and texture are affected during ageing along with slight variations in rice composition and appearance [7]. The ageing process decreases the fast degradation of starch

into the residual cooking water, further confirming that the starch grains in the aged rice grains cause less hydration and swelling [8]. This property is desirable for rice, which is boiled, or pressure cooked before eating. However, in the case of *Komal Chaul (parboiled Chokuwa rice),* which is a soak-and-eat variety, these changes during ageing turn out to be disadvantageous.

Chokuwa rice of Assam is an indigenous variety to the state with a GI tag used in the production of *Komal Chaul* [9]. *Chokuwa* rice of Assam is a low amylose variety grown majorly in *Sali* season (Autumn-Winter). The word '*Komal*' means 'soft' and '*Chawal'* or '*Chaul'* means rice in Assam. *Komal Chaul* is prepared by parboiling *Chokuwa* paddy. The unique characteristic of this rice is its no cooking requirement [10]. It can be consumed by just soaking it in warm water at nearly about 60-70 ℃ temperature. This distinctive characteristic qualifies this rice in the ready-to-eat category, though cannot be categorized as instant food exactly because *Komal Chaul* takes at least 10-12 min to fully gelatinize/cook in warm water [11]. *Komal Chaul* is traditionally manufactured by soaking rice for 3-4 days to attain a desirable moisture content followed by draining the excess water placing it in fresh water and cooking over a wood fire until the grain splits out of the husk. The water is drained off again and the grains are dried in the sun on the same day. Drying is done on the same day to avoid retrogradation and maintain a soft structure [12]. The traditional method is weather dependent and unfavorable weather conditions result in delayed drying affecting the quality of the final product.

There are 17 varieties of this rice viz. *Boga Chokuwa, Boka Chokuwa-1, Boka Chokuwa-2, Bor Chokuwa, Bora Chokuwa, Chakuwa-6, Haru Chokuwa, Kagoli Chokuwa, Kalomdani Chokuwa, Lahi Chokuwa, Maju Chokuwa - 1, Maju Chokuwa – 2, Maibhog Chokuwa, Nepali Chokuwa, Sam Chokuwa, Saru Chokuwa,* and *Pozo Chokuwa* consisting of amylose content in the range of 9.12-16.02% [13]. The different rice varieties of Assam have different culinary applications consumed both as savory and sweet cuisines. The intermediate and high amylose rice, parboiled or non-parboiled are consumed as the staple for major meals while the low amylose rice is mostly consumed as snacks, breakfast cereals, and desserts like jalpan, pitha (rice cakes), puffed rice and so on.

The no cooking quality i.e., hydrating ability to create a texture like cooked rice without boiling is the preliminary or the foremost requirement of *Komal Chaul*. Previous reports or some unreported issues from consumers suggest that hydrating property gets affected and desirable quality of soft rice is not obtained always. During *Komal Chaul* preparation, processing

conditions like drying temperature during parboiling affect the rehydration property of the rice [14].

Scientific methods for the prediction of ageing of *Komal Chaul* will be helpful from a trading and purchasing perspective. Non-destructive techniques based on spectra and images are nowadays state-of-the-art methodologies in many disciplines. Near Infrared Spectroscopy (NIRS) is usually preferred for its non-destructive nature and can easily record spectra from solid and liquid samples without any pre-treatment [15]. The weak absorption nature of near-infrared (NIR) is advantageous in food analysis over other spectra as it yields a series of absorptions of divergent intensity over the wavelength range consisting of the same chemical information. Wider findings on proof of concept at the research level are more limited to research fields [16].

However, the NIR application is to yet expand extensively to the food industry with a larger scope of application in the future years for its non-destructive advantage. In the Indian context, the Indian Agricultural Research Institute has been carrying out extensive research on the application of NIR and other non-destructive techniques for the quality evaluation of fruits and vegetables [17, 18, 19].

Unlike other non-destructive techniques, NIR is preferred for its cost-effectiveness. Its instrumentation involves simple mechanics and robust sensors making it suitable for online process analysis [20]. The two types of NIR spectrophotometers concerning wavelength selection are discrete wavelength and whole spectrum. The former is a simple mechanism, as they irradiate samples with only a few wavelengths. Subsequently, they can be used only in applications with analytes absorbed in specific spectral zones.

Table 1.1 Key features and advantages of NIRS

Features	Advantages
○ Electromagnetic radiation in the range 780–2500 nm. ○ NIR spectra of foods comprise broad bands of overtones and combinations of vibrational modes involving C-H, O-H, and N-H chemical bonds. ○ Secondary method requiring calibration against a reference method.	○ Record spectra for solid and liquid samples. ○ No pre-treatment required. ○ Speedy characterization of samples. ○ Portable equipment can record spectra on site.

NIR absorption is formed due to the overtone and combination bands of vibrating molecules in the region (Fig. 1.1). The NIR spectra are quite dense and overlap heavily. In addition, the

number of physical, chemical, and structural variables can affect the spectra, making it difficult to obtain analytical information. Also, differences between samples can result in very subtle spectral differences that are difficult to see with the naked eye. For these reasons, NIR spectroscopy requires a technique to extract as much relevant information as possible from analytical data [21]. The key features or advantages of NIRS are highlighted in Table 1.1.

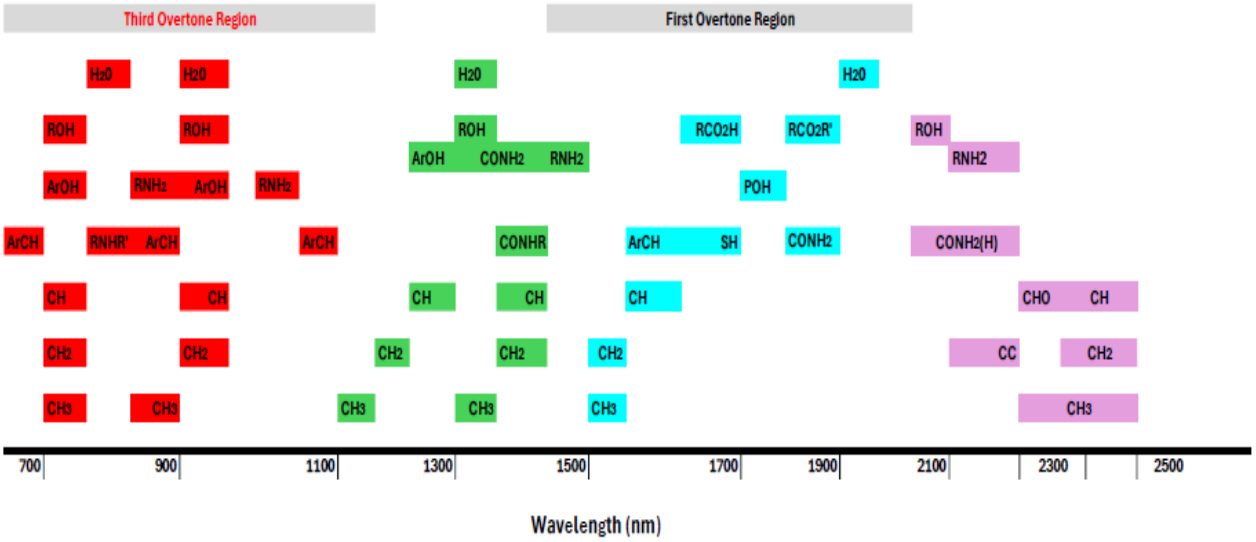

Fig 1.1: Major analytical bands and relative peak positions for prominent near-infrared absorptions (Image Source reference: Metrohm).

Machine Learning (ML) is one such technique that can be used to extract information from such spectral bands. ML is a state-of-the-art technique that learns from data. The scope of ML as a calibration and validation technique has made non-destructive techniques like NIRS a feasible method for the analysis of materials. The NIRS technique has several applications in food analysis. ML is an effective tool to provide a mapping of NIRS-based measurements to perceivable extrinsic measures of food quality. There are advancements in the technologies for instrumentation and it has resulted in the manufacturing of portable spectrophotometers that can quickly provide spectra for real-time analysis [21]. ML simply teaches our computer to learn how to extract information from the data provided. In a brief statement, ML does descriptive, predictive, and prescriptive analytics in data. In simpler terms, we can describe ML as a part of artificial intelligence that learns from data and enables the computer to perform different tasks based on data. ML models are broadly classified into three categories supervised, unsupervised, and reinforcement learning as explained in Fig. 1.2.

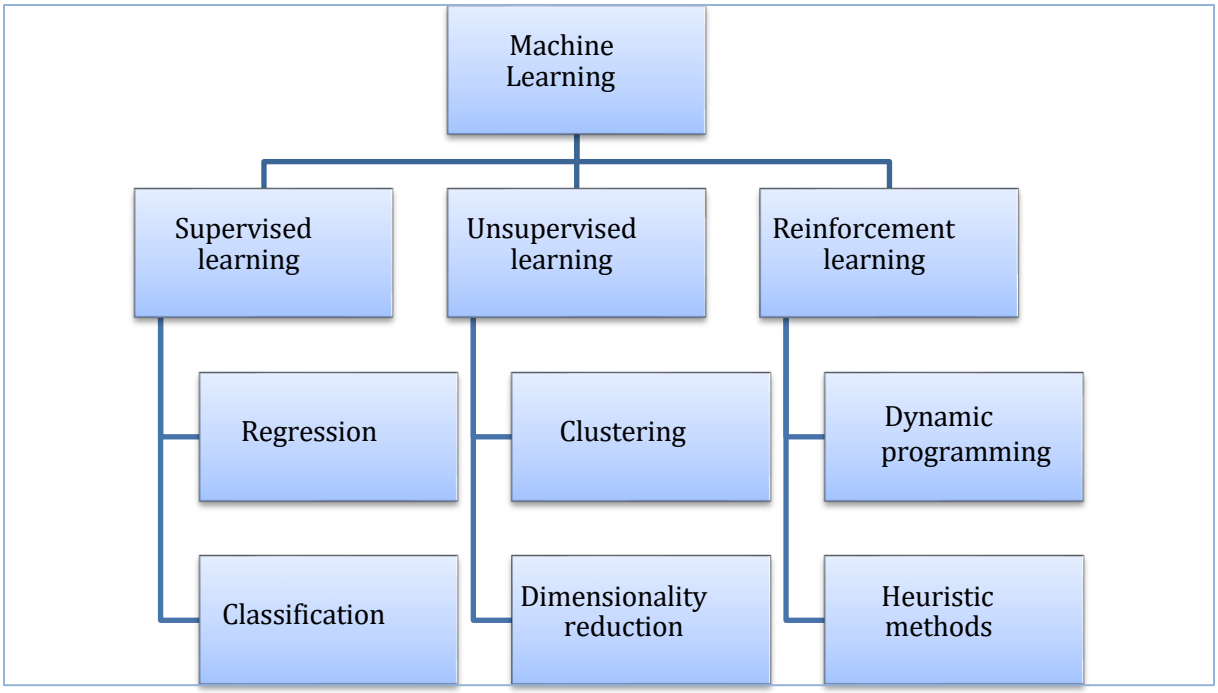

Fig. 1.2: Types of ML (Image reference: www. Towardsdatascience.com)

The scope of such real-time cost-effective techniques in the rice industry will subsequently increase with Industry 4.0 becoming popular in the industrial sector to improve working conditions, operational efficiency, and machine lifetime. NIRS has shown to have a major scope in the food industry for its efficiency in process monitoring [22]. Process Analytical technology in the food industry can enhance process efficiency and product quality by improving the control of manufacturing processes. However, the majority of assessments have been performed on a lab scale, and there are not many industrial uses yet [23]. With increasing computational advancement, Artificial Intelligence has been able to solve many complex problems. ML techniques have been applied as an alternative technique over conventional modeling for solving complex problems [24].

1.2 Research gap

Komal Chaul, being an indigenous variety of Assam with a GI tag and possessing a unique characteristic of no cooking requirement has many scopes for marketability. Though, it is not fully commercialized there is a potential for its application in ready-to-eat food section. One issue with *Komal Chaul* is its rehydration property after processing gets affected. Ageing of the rice also results in lesser hydration. Moreover, there is neither a standard protocol nor any device developed for estimating rehydration quality with respect to ageing. So, a handy tool can prove to be a reliable solution to this.

There are not many reports citing application of NIR techniques for PAT in industrial settings. Many reports are available on laboratory study and on-site application for the detection of adulteration, identification, proximate analysis, storage quality and for postharvest analysis. There is a greater potential for NIRS in process analytical technology in the food industry. It can not only increase the process efficiency but can also automate the whole system [23]. NIR-based PAT needs much more exploration for an wider industrial application. There are very limited numbers of reports found on the application of PAT using NIR for rice processing. Since, parboiling of rice involves three primary steps namely soaking, steaming, and drying, and each step has crucial end-point parameters to be estimated, therefore, an NIR-based application to find its feasibility for on-site practices of rice parboiling is justified for investigation.

1.3 Justification

Previously cited gaps gave us a valid reason to work on finding a scientific methodology based on the determination of the age of *Komal Chaul*. The reason was that the cooking quality as well as the storage quality of *Komal Chaul* is highly affected by ageing. The degree of ageing mapped with pasting behavior and, rehydration percentage and cooking time could serve as an indicator of the shelf life of *Komal Chaul* products. A smartphone-operated, ML-supported, and NIR sensing device integrated solution for the estimation of the degree of ageing of rice.

As mentioned earlier, NIR-based PAT needs much exploration for better industrial application. There have been no reports found on the application of process analytical techniques using NIR for rice processing. Our target was to find a solution to estimate the saturation point in the parboiling process. Since parboiling involves time-dependent and temperature-controlled processes viz. a monitoring sensing that indicates the desired stopping point for each step was thought to be helpful.

The scope of ML as a calibration and validation technique has made non-destructive techniques like NIRS a feasible method for the analysis of materials. The NIRS technique has proven to be an effective tool for providing a mapping of NIRS-based measurements to perceivable extrinsic measures of food quality. Due to the advancements in the technologies for instrumentation, portable spectrophotometers are also available nowadays besides the benchtop spectrometers, which are capable of providing spectra in a quick way for real-time analysis [21]. In another context, governmental agencies like the Department of Food and Public Distribution under the Ministry of Consumer Affairs, Food and Public Distribution are looking for real-time scientific.

solutions for determining the age of parboiled rice [25]. In addition, recent studies have shown the application of NIRS for ageing of rice [26-27].

The cited reasons justify the need to work towards finding a scientific methodology for the assessment of *Komal Chaul* based on the determination of its age. Also, a protocol for non-destructive monitoring of process conditions is necessary to retain the quality of the product at its best. These reasons were the motivation to carry out the research on Near Infrared solutions for quality assessment during the processing and storage of *Komal Chaul*, through fulfillment of the following objectives:

1.4 Objectives

1. **To develop a kinetic model and analyze the progression of hydration, gelatinization, and dehydration during different stages of parboiling of brown rice for *Komal Chaul* production**
2. **To develop machine learning-based mapping of spectral data to target parameters to analyze the process of parboiling of *Komal Chaul***
3. **To study the effects of storage and ageing on the cooking quality of *Komal Chaul* and physicochemical characterization of aged and unaged rice**
4. **To develop an ML model based on NIRS for indicating the time of ageing in *Komal Chaul* and its respective cooking quality**

1.5 Arrangement of thesis

The thesis is divided into five chapters for an orderly and logical presentation of the work done and its findings.

Chapter 1: This chapter already discussed above gives a summary of the introductory view of our proposed idea and brief literature supporting the work. The chapter extends to a discussion on the research gap, including a section on its scientific justification, followed by the objectives of the research work.

Chapter 2: This chapter consists of the literature review of the work that has helped in a better understanding of the concept of the topic.

Chapter 3: This chapter discusses the materials used and methods implemented for accomplishing the objectives.

Chapter 4: This chapter illustrates the results obtained from following the methodologies of the 4 objectives and discusses the probable reasons for those results.

Chapter 5: This chapter gives a summary of the complete work and concludes the thesis.

1.6 Summary of Chapter I

The introductory view of our proposed idea and brief literature relating to *Komal Chaul* and its unique characteristics suggested a need for a standard parboiling process. Earlier researchers had carried out different standardizations to get better quality products. This study, however, focused on the method of parameter analysis during processing that shall help monitor the quality. In this chapter, the work also proposes a study on storage and the effect on *Komal Chaul* quality. In order to carry out the titled work the thesis proposes four objectives: the development of a kinetic model for the process of parboiling brown *Chokuwa* rice followed by the development of an ML model using spectral data for the determination of processing parameters; the third objective is a study of changes of physicochemical properties of *Komal Chaul* followed by the development of ML model based on NIR for determining the ageing period of *Komal Chaul*.

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