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Moisture Sorption and Quality Characteristics of Instant Rice

Anna Mays
University of Arkansas, Fayetteville

Griffiths Atungulu
University of Arkansas

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University of Arkansas

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Table of Contents

Abstract

Market demand for instant rice--a processed form of rice that is cooked and dehydrated before it is sold--has risen tremendously and become a significant component of the rice industry. Compared to freshly cooked rice, the quality of instant rice (in terms of texture, color, aroma, etc.) is much lower. There exists little information regarding how instant rice's storage conditions affect its quality. Such information may be elucidated by studying sorption isotherms which describe the storage temperature, relative humidity, and instant rice moisture relationships.

The purpose of this study was to generate moisture sorption isotherms of instant rice for temperatures and relative humidity ranges encountered during instant rice handling and storage. In addition, the study explored changes in physicochemical characteristics of instant rice during prolonged storage of up to one year.

Rough rice samples conditioned to 12.5% moisture content (MC) wet basis were used to make 4 sample types: brown, white (0.4% surface lipid content), parboiled brown, and parboiled white. Samples were cooked and dried to 12% MC wet basis. The vapor sorption analyzer (VSA) was used to determine the moisture sorption isotherms (desorption and adsorption) of dried instant rice held at 25°C for six months, with relative humidity ranging from 0% to 100%.

To determine the impact of prolonged storage on shelf life, samples of the dried instant rice were securely stored at 20, 25, and 30°C for a total of 6 months. Stored samples were taken out and tested for quality changes (protein content, texture, and color) every 8 weeks.

Results show that the storage duration and temperature conditions used had minimal impacts on the rice quality parameters tested. However, there were significant changes in quality due to parboiling and between brown and white rice samples. Moisture sorption curves showed that parboiling had little effect on storage behavior of rice samples, but extended storage (6 months) did cause change. Moisture sorption adsorption and desorption curves were shifted up following storage, indicating that storage duration does impact storage behavior.

Ultimately, it is expected that the results from this study will provide foundational knowledge that is crucial for the rice industry to predict storability of instant rice, improve the quality of instant rice, and make the products more competitive.

Introduction

Background and Need

As American consumers become increasingly drawn towards fast, convenient food, the market for instant rice has risen tremendously and become a significant component of the rice industry. Instant rice is a convenience product that requires additional industrial processing. Its nature of convenience is achieved by pre-cooking and dehydrating the rice before it is sold. Additionally, the dehydration step of producing instant rice makes the product lighter and can extend its shelf life, cutting costs of transportation and distribution (Chen et al., 2014). However, the tradeoff for the convenience of instant rice is significantly decreased product quality as compared to freshly cooked rice (Huang et al., 2013).

Rice quality can be broken down and categorized by texture, aroma, appearance, nutritional benefits, and safety. Consumers are drawn to uniform shape and color, a soft-cooked texture, pleasant aroma, and high nutritional content (Custodio et al., 2019). Consumers reject rice that is firm and dry once cooked, has a rough texture, or contains small, broken kernels (Custodio et al., 2019). Outside of textural and aromatic quality, food safety is of utmost importance as it prevents foodborne illness in consumers and effectively maintains trust of the rice industry to distribute safe, high-quality products.

Moisture content and water activity are important to understand as they have significant impacts on rice quality and safety. Water activity (a_w) describes free, unbound water that is available for chemical reactions and microbial use. Therefore, understanding a_w of rice throughout processing is fundamental to maintaining food safety and quality. Rice samples with a high a_w provides a suitable environment for microorganisms or chemical reactions capable of damaging the quality and safety of rice (Champagne et al., 2004). The process flow used to create different types of rice products is important to understand when studying rice quality and safety. Processing has significant impacts on the flavor, texture, aroma, chemical components, and safety of rice.

Differences in Rice Processing for Rice Types			
Brown	**Milled (White)**	**Parboiled**	**Instant**
Brown rice is dehulled, separated, stored, cooked and eaten.	White rice is dehulled, milled, separated, stored, cooked and eaten.	Parboiled rice is soaked in warm water, steamed, dried, dehulled, milled*, separated, stored, cooked and eaten.	Instant rice** is dehulled, milled*, separated, cooked, dehydrated, stored, reconditioned and eaten.
* Rice is only milled if processed into white rice.			
** Instant rice can also be parboiled. Parboiling would occur first.			

Table 1. Describing differences in processing between the 4 types of rice used in this study.

There are multiple rice products that can be produced by altering the production process. For standard rice processing, rough rice is dried, dehulled, milled, separated, and stored. Milling only takes place for white rice processing, as it removes the brown bran layer that brown rice has after dehulling.

Parboiling is an additional step that can take place before rice is dehulled. Rough rice is soaked in warm water, steamed, and then dried before further processing ensues. From this point, white or brown rice can be produced from the parboiled rough rice. This rice is often stored before distribution to grocery stores. There are numerous benefits to parboiling rice, with some of the most notable being increased nutrient content and decreased kernel breakage during processing.

Instant rice is another processed rice product with a unique process flow. Instant rice is produced by cooking and dehydrating rice right at the production facility. This pre-cooking allows instant rice to cook much faster than non-instantized rice. This is because the starch within the rice kernel has been partially gelatinized during the industrial cooking process, then dried, which together allows the kernel to absorb water at a more rapid rate than before. Like other types of processed rice, instant rice is often stored for some time before it ends up in consumers' homes. Consumers buy instant rice in its dehydrated state and can then prepare instant rice within 5-10 minutes using boiling water (Phukasmas & Songsermpong, 2019). Instant rice is a remarkably convenient product, making it a very marketable and sought-after product in the United States.

As emphasized above, most rice is stored for some time before it ends up in consumers' homes. This is an important element of rice processing as storage can have profound impacts on the safety and quality of rice. Due to this, storage of post-processed rice is a common research topic in the rice industry. It is important that rice quality is preserved as it ages, and this is dependent on storage temperature, security of the storage container, water activity, and the type of rice being stored. It's worth noting that even instant rice, with its unique processing, undergoes storage before reaching consumers' homes. Understanding instant rice storage is essential for a comprehensive grasp of rice quality and safety in the supply chain.

A useful tool for predicting instant rice behavior during storage are moisture sorption isotherms. Moisture sorption isotherms explain the relationship between equilibrium moisture content (EMC) and equilibrium relative humidity (ERH) at a constant temperature (Kaymak-Ertekin & Sultanoglu, 2001). The sorption isotherm includes adsorption (moisture gaining) and desorption (moisture loss). Both adsorption and desorption help tell the story of how stored instant rice will behave at different temperatures.

Problem Statement

Much research has been conducted on the efficiency of varying drying and cooking techniques of instant rice, as well as the storage conditions and duration of non-instant rice (Chen et al., 2014, Phukasmas & Songsermpong, 2019, Prasert & Suwannaporn, 2014, Sasmitaloka et al., 2019, Zhou et al., 2007). However, little research has been conducted studying the impacts of storage on instant rice quality and safety. Moreover, there is limited research on how distinct types of instant rice (parboiled, non-parboiled, brown, white) behave differently during storage. To understand instant rice storage behavior at different temperatures and durations, moisture sorption isotherms and quality analysis are needed.

Purpose Statement

The purpose of this study was to generate a series of moisture sorption isotherms that can be used to predict instant rice storage behavior at different temperatures and duration conditions, as well as measure quality parameters dependent on the same storage conditions. Results from this study are necessary in the exploration and development of processing methods that will improve the quality of instant rice.

Research Questions

The following research questions guided this project:

1. To what degree does the storage duration of instant rice impact quality parameters?

2. To what degree does the temperature at which instant rice is stored impact quality parameters?

3. To what degree does the type of processed rice (parboiled, non-parboiled, brown, and white) impact quality parameters and moisture sorption?

Literature Review

Rice is one of the most prominent grains consumed in the world and remains a staple crop for more than half of the global population (USDA ERS - Rice Sector at a Glance, 2021). The global rice industry is responsible for producing and distributing tons of rice every year, with each passing year demanding more than the year before (USDA ERS - Rice Sector at a Glance, 2021). Convenience foods have become more popular in recent years as people have adopted modern values that encourage hustle and continuous productivity (Phukasmas & Songsermpong, 2019). The global push for convenience has increased the popularity of instant rice. Instant rice is a form of pre-processed rice that may be prepared in only a few minutes, just by adding water and heating. The convenience of instant rice comes at a cost, however. Instant rice quality is of agreeably less quality, both in flavor and texture, than rice cooked using conventional methods (Prasert & Suwannaporn, 2009). Rice quality is affected by many different components of the production process, but one of the most critical components is rice storage. The temperature and duration at which rice is stored before distribution greatly impacts the physical and cooking characteristics of rice, and resulting eating quality (Zhou et al., 2010). Much research has been conducted exploring storage effects on rice quality and cooking characteristics, but the effects of these processing components on instant rice quality specifically have yet to be explored.

Rice Processing and Desired Quality

Rice goes through several processing steps before it is ready to be consumed by the public. Rough rice, or rice still encased in the hull, is harvested and sent to drying facilities. In order to mitigate spoilage during storage, rough rice is generally dried to a moisture content of about 12.5% before any further processing (Hardke, 2013). Rice can also be parboiled to enhance rice quality and nutrition by soaking, steaming, and drying paddy rice (Luh & Mickus, 1991). After drying, rice kernels can be separated from the hull using dehulling equipment. At this point, rice processing can go in many different directions, depending on the desired end-product.

Immediately after being dehulled, rice kernels are covered in a starchy, fatty bran layer, and this product is called brown rice. This bran layer can be removed through milling, and the level of achieved whiteness depends on milling duration. Increasing milling duration decreases the bran layer on the rice. After being milled, rice is "separated," a process where broken kernels are isolated from "head rice" kernels. Head rice kernels are defined as being at least 75% of the full-sized milled rice kernel (Hardke, 2013). Parboiling reduces rice breakage, increasing head rice yield. During the parboiling process, the crystalline form of starch unique to paddy rice is disrupted as the starch swells and fuses during soaking and steaming (Luh & Mickus, 1991). This fusion of the starch significantly decreases rice breakage, resulting in significantly higher head rice yield than non-parboiled rice (Luh & Mickus, 1991). After processing, the head rice is ready to consume, or may undergo further processing as seen in instant rice production.

One of the most significant factors affecting rice quality is the degree of milling (DOM). The DOM affects the surface lipid content (SLC) of rice, which heavily impacts the cooking characteristics and nutrient content of the rice. Rice milled for longer periods of time has a lower SLC, and therefore different physical properties. The bran layer of rice contains fiber, lipids, minerals, vitamins, and protein, all of which are stripped away during the milling process (Ascheri et al., 2012). The removal of this layer decreases the nutritional content of the rice, as well as changes its cooking characteristics (Wang, Z et al., 2021). To increase nutrient content in rice, parboiling can be added to the traditional rice processing steps. Parboiling rice can enhance nutrient contents in rice up to 4 times that of non-parboiled, milled rice (Luh & Mickus, 1991). This is because nutrients migrate from the outer layers (husk and bran) of the rice grain to the endosperm. The outer layers of the rice grain contain most of the nutrients such as vitamins, minerals, and some proteins. Parboiling allows these nutrients to move into the endosperm, which is the starchy part of the grain that becomes the white rice after milling. This process helps in retaining some of the nutrients that would otherwise be lost during traditional milling, where the husk, bran, and germ are removed to produce white rice. Parboiled rice is often considered to be more nutritious than white rice because of this nutrient migration during the parboiling process (Luh & Mickus, 1991). Additionally, DOM affects cooking characteristics of rice. Milled rice absorbs more water and gelatinizes more quickly during cooking, as well as produces a softer kernel (Ahmad et al., 2017). Brown rice takes longer to cook due to the fibrous bran layer that increases gelatinization time and is harder in texture once cooked (Ahmad et al., 2017; Rather et al., 2016). The DOM is critical to the cooking behaviors of rice and resulting consumer preference and satisfaction.

Desired rice quality varies by region and culture. The quality parameters that guide the classification of rice quality are texture, size, chalkiness, color, aroma, and overall eating experience (Purhagen et al., 2018). Universally, most consumers prefer a rice product that is homogenous in color, and soft and aromatic once cooked (Custodio et al., 2019). Consumers in the United States prefer a long-grain variety that cooks dry, fluffy, and with kernels separating from one another (International Rice Research Institute, 1979). In recent years, brown rice has become more popular as people become more conscious of the health benefits of consuming brown rice over white rice (Mir et al., 2020). Still, white rice is generally preferred as it takes less time to cook and has a softer, cooked texture (Fukagawa & Ziska, 2019).

Degradation of Rice Quality in Storage

After being processed, rice is often stored before distribution. Storage duration can have significant impacts on rice quality, as the grain undergoes internal physical degradation and is more susceptible to spoilage over time (Atungulu et al., 2019). Post-processing shelf life is dependent on the SLC of the rice. The high fat and protein levels in the bran layer of brown rice make it more susceptible to spoilage and decrease its shelf life (Atungulu et al., 2019). Lipids deteriorate quickly and produce free fatty acids during storage, which affect the eating quality of rice (Tamaki et al., 1989). Brown rice has a higher SLC and therefore shorter shelf life than milled rice due to more free fatty acid formation. Insect pests are also more drawn to brown rice due to its higher nutritional content, and microbial growth is also possible depending on temperature and humidity in storage (Atungulu et al., 2019). Because the bran layer is removed from milled rice, it has a significantly longer shelf life.

Additionally, rice becomes discolored the longer it is stored, due to both enzymatic and non-enzymatic reactions that take place in the kernel as it ages (Atungulu et al., 2019). It takes approximately three months of storage for rice to become less sticky, harder, and discolored once cooked (Atungulu et al., 2019). Essentially, rice quality decreases as storage time increases. It is suspected that the increased hardness in aged rice can be attributed to the increase in insoluble materials that develop as rice ages (Zhou et al., 2007). The physical changes in the rice kernel as it ages affect its cooking properties and therefore eating quality. It was found that aged rice took a longer time to fully cook and exhibited a harder, more solid texture once cooked. Essentially, aged rice has less desired cooking characteristics than fresher rice (Zhou et al., 2007).

Moisture Sorption Isotherm of Rice

The temperature and relative humidity at which instant rice is stored is critical to the quality and safety of the product. The moisture sorption isotherm curve describes the relationship between moisture content within the rice kernel and the relative humidity of the location it is being stored in at a specific temperature (Hayati et al., 2021). Water activity (a_w) can be defined as the ratio between vapor pressure within food and the vapor pressure of distilled water under identical conditions (Dept. Of Health, Education, and Welfare Public Health Service Food and Drug Administration, 2014). The a_w of rice is an important factor in rice quality as many deterioration reactions and the survival of harmful microorganisms are dependent on the a_w of the rice kernel (Toğrul & Arslan, 2006). At higher temperatures and relative humidity levels, rice kernels are more susceptible to microbial spoilage and accelerated kernel degradation. Kernel degradation can be defined as increased free fatty acid formation and production of volatile compounds like aldehydes, ketones, and furans (Biao et al., 2019). High temperature and high humidity in storage accelerates the process of lipid degradation and therefore negatively impacts rice quality (Biao et al., 2019).

Microbial spoilage is also dependent on storage temperature and relative humidity. Storage at high temperature and relative humidity provides more suitable growing conditions for microorganisms like fungi that can produce dangerous mycotoxins that threaten food safety (Choi et al., 2015). In a study using *Aspergillus flavus* and *Fusarium graminearum*, microorganisms that produce mycotoxins in grains, it was found that lower temperature and relative humidity in rice storage were effective in suppressing microbial growth (Choi et al., 2015). Increasing the a_w value of rice decreases its shelf life as the rice is more susceptible to microbial spoilage (Abdullah et al., 2000). Higher temperature and relative humidity conditions in grain storage are responsible for increased a_w values, and therefore threaten food quality and safety due to microbial growth.

Instant Rice Processing, Storage, and Desired Quality

Improving the quality of instant rice is an important issue in the rice industry. Consumers desire an instant rice product that will resemble the flavor, texture, and aroma of rice cooked using standard methods. Although much research has been conducted on improving the quality of instant rice, its quality remains inferior to freshly cooked rice due to the process by which it is made.

Instant rice has additional processing steps that allow it to cook quickly. The quick-cooking nature of instant rice is achieved by cooking rice at the processing facility, and then dehydrating it. The precooked, dehydrated rice is packaged and sold to consumers where it can be rehydrated and ready to eat by simply adding hot water. The dehydration step is largely responsible for the reduced quality of the product. To achieve a porous kernel structure that can be rehydrated and prepared quickly, the dehydration step in instant rice processing removes moisture from the surface of the kernel faster than the center (Prasert & Suwannaporn, 2009). This causes "puffing" of the grain and results in a larger grain with a hollow structure that allows for rehydration (Prasert & Suwannaporn, 2009). In doing so, instant rice loses quality in texture and flavor.

After being cooked and dehydrated, instant rice is often stored before distribution, much like standard rice. Storage of rice has fundamental effects on its quality and safety, depending on storage duration and moisture isotherm. While different cooking and dehydration methods, quality additives, post-drying freezing, and other aspects of processing have been tested for effect on instant rice quality, the effects of storage duration and isotherm on instant rice quality has not yet been explored (Chen et al., 2014; Huang et al., 2013; Phukasmas, 2019; Sasmitaloka et al., 2019). Because storage duration and isotherm have such substantial effects on standard rice quality, it would be beneficial to the rice industry to investigate how storage duration and isotherm affect instant rice quality.

Methodology

Much research has been conducted exploring the effects of storage duration and temperature on uncooked rice quality. Extended storage duration and high storage temperature have adverse effects on uncooked rice quality, often negatively affecting rice flavor and texture. Instant rice has significantly inferior quality to uncooked rice. In this project, the effects of storage duration and temperature on instant rice quality will be assessed, to improve the quality of instant rice.

Research Design

This experimental study followed a full factor factorial design. The independent variables tested in this experiment are storage temperature and duration, with each temperature condition being tested within each storage duration condition. A full factor factorial design research method allows for paired conditions that give an exhaustive set of results for each possible variable pairing scenario (Zhou et al., 2007). After storage, every sample underwent the same quality tests, and the effects of storage duration and isotherm were measured.

The rice used in this project is a long-grain cultivar, RT7321. It was obtained from Pocahontas, Arkansas after harvest in Fall 2022. Approximately 10 kg of rice was used for this study.

Parboiling

After harvest, 5 kg of rough rice was parboiled. To do this, rice was wrapped in cheesecloth and soaked in a water bath at 70°C for two hours. Then, the rice was moved to a Tuttnauer autoclave where it was steamed at 113°C for 15 minutes. Parboiled rice was then dried to a moisture content of 12% using an equilibrium moisture chamber (EMC) and moisture content levels were determined using an AM 5200 grain moisture tester. The 5 kg of non-parboiled rice was dried to a moisture content of 12% using the EMC.

Milling and Separation

Both the parboiled and non-parboiled rice was halved into two samples to allow for two different SLC conditions: brown and milled rice. The milled rice sample was milled to a SLC of 0.4%. Brown and milled rice samples were then separated and weighed for head rice yield.

Quality Analysis

Subsequent experimental tests were conducted for each sample condition (parboiled, non-parboiled, white, brown) Rice was tested for different components of quality using appropriate instrumentation. Before cooking, head rice was tested for chalked kernels, protein content, texture, and color. Chalked kernels were analyzed using Winseedle™ Pro 2005a Regent Instruments Inc. (Leethanapanich et al., 2016). Then, 5 g of each rice sample was ground into flour using a mill (cyclone sample mill, Udy Corp., Ft. Collins, Colorado). Protein content (PC) analysis was conducted at the University of Arkansas Poultry Science General Laboratory. There, PC was determined by the Dumas method 992.23 of AOAC (2000) using the Nitrogen conversion factor of 5.95 (N*5.95). The results were reported on a dry basis. Rice color was analyzed using the Hunter colorimeter (Hunterlab Colorflex Spectrophotometer). For color testing, 10 g of rice was used for three tests per sample. New rice was drawn from the sample bag for each test. Texture was analyzed using a texture analyzer instrument (Plus-upgrade; Stable Microsystems) on cooked rice samples. To cook samples, 5 g of rice was cooked at 400°C and 160 rpm in 100 mL of deionized water using a 100 mL Pyrex beaker. To obtain cooking duration time for each rice type, the Rhangino glass plate white center method (1966) was used. Rice is fully cooked when there are no white kernel pieces left and the crystalline structure of rice has been completely disrupted. According to cooking trials conducted using the Rhangino method, milled parboiled rice was cooked for 23 minutes, milled non-parboiled rice was cooked for 25 minutes, parboiled brown rice was cooked for 35 minutes, and non-parboiled brown rice was cooked for 45 minutes.

Instantization:

Cooking duration times obtained from the first round of texture analyses were used for instantization. For this process, two 2000 mL Pyrex beakers and one 4000 mL Pyrex beaker were used to cook all the rice at a 1:10 ratio of rice to water. There was no experimental reason for the different sized beakers, those were just the accessible materials. In the 2000 mL beakers, 180 g of rice was placed in 1800 mL of deionized water. In the 4000 mL beaker, 360 g of rice was placed in 3600 mL of deionized water. The hot plate was set at 400°C and 160 rpm. Cooked rice was then dried to a final moisture content of 12% using a convection oven (Axis AX-CL10M by MVP Group Corporation, Italy). Cooked rice was dried in a circular tray using the convection oven for 15 minutes at 120°C. This rice was evenly spread in a mesh-bottomed tray and left in ambient temperatures overnight. The tray was then moved to an EMC chamber to gently dry rice down to 12%. The moisture content of these samples was determined using an oven and calculated using the MC (%) formula (Okeyo et al., 2024). After drying, rice samples underwent the same quality tests previously outlined, excluding the chalked kernel analysis.

Storage

Instant rice samples were then divided into 50 g bags and assigned a storage duration time and temperature condition. The three temperatures tested were 20, 25, and 30°C. There were three bags in each incubator for each storage duration assignment. Each sample was taken out of the incubator based on that assignment. The assigned duration times in this project are 2, 4, and 6 months. Each sample was tested for quality (25 g), isotherm (10 g), and microbial analysis (15 g) upon removal. The same quality tests previously outlined were performed, excluding chalkiness analysis. For the texture analysis, instant rice samples were cooked using the same beaker on a hot plate method (400°C, 160 rpm). The 100 mL Pyrex beaker was filled with 100 mL of deionized water and 5 g of each rice sample. White rice samples were cooked for 10 minutes, and brown rice samples were cooked for 13 minutes. Samples were then removed from the beaker and allowed to cool for 5 minutes before texture analysis.

Isotherm Determination

Isotherm was determined using Aqualab's Vapor Sorption Analyzer (VSA) (Decagon Devices, Inc., Pullman, WA). Only 0- and 6-month samples at 25°C and 30°C were used for post-instantization VSA analysis. These samples were chosen to understand the extremities of storage duration and temperature on instant rice quality. Both moisture adsorption and desorption isotherms were gathered using the DDI approach. Methodology for VSA tests was adopted from Luthra et al. (2020). The VSA is connected to a computer, where data is stored. To use the VSA, these steps were followed: (1) desiccant and water level in the VSA were checked (desiccant should be blue in color); (2) moisture analysis toolkit (VSA's software) was used to select parameters for the test, i.e. method: DDI, ERH range: 10 to 95%, temperature: 25, or 30°C, resolution: 1% (data were recorded at every 1% change in relative humidity, recommended setting), airflow rate: 100 mL/min (air was supplied to the sample at the rate of 100 mL/min, recommended setting); (3) sample was placed in the sample cup (approximately 2 g, recommended weight) as shown in Figure 1-B; (4) test was started and the data was downloaded in a spreadsheet file once the test was completed (duration of the test was around 2-3 days).

Microbial Analysis:

Drying the instantized rice took longer than anticipated, around 14 days. Because of this, microbial analysis on the instant rice was conducted to observe any fungal or microbial growth that could have occurred before storage. To do this, microbial enumeration was completed using standard procedures to determine the total microbial load on samples. These procedures were adopted from Ranalli et al. (2002) and Smith et al (2018) and slightly modified. In a 1 L volumetric flask, 34 g of KH_2PO_4 was dissolved in 500 mL of water to make phosphate-buffered dilution water. Then, 1 M of NaOH solution was used to adjust the pH to 7.2. In the volumetric flask, distilled water was added to prepare 1 L of stock solution. The stock solution was autoclaved at 121°C for approximately 20 minutes to ensure sterility before use. Then, a 10 g sample of the instant rice was weighed and placed into a sterile stomacher bag. Following this, 90 mL of sterile phosphate-buffered dilution water was added to the stomacher bag and masticated. A lab masticator (Silver Panoramic, iUL, S.A., Barcelona, Spain) set at 240 s and 0.7 strokes/s was used to dislodge the microorganism by ensuring that the rough rice samples were pulverized into powder for microbial analysis when mixed with dilution water. Serial dilutions were carried out by mixing 1 mL of the original mixture in the stomacher bag (first dilution 10-1) with 9 mL of sterilized phosphate-buffered dilution water in a test tube (second dilution 10-2) and so on until the sixth dilution (10–6) was made (Okeyo et al., 2017).

Fungal plate count:

Fungi and bacteria counts were counted using 3M Petrifilm fungal Count Plates and 3M Petrifilm Aerobic Count Plates (3M Microbiology Products, Minneapolis, MN). Plates were placed in the biosafety cabinet. The top film of the plate was gently lifted and a P1000 micropipette (Finnpippete F2, Thermo Fisher Scientific, Inc, Vantaa, Finland), placed perpendicularly to the plates, was used to transfer 1 mL of the sample solutions onto the center of the 3M Petrifilm plates. The top film was then carefully lowered. The center of a plastic spreader was then placed on the plates to align with the centers of the plates. The plastic spreader was gently pressed so that there was even distribution of the inoculum on the Petrifilm plate. Gel was allowed to solidify for 1 min. Inoculated Petrifilm plates were stored with clear sides up and stacked no more than 20 units high. They were then placed in an incubator (Thelco Model 4, Precision Scientific Instrument, Inc., Buffalo, NY) at 25°C for 120 hrs, before counting. After the incubation periods, colony forming units (CFU) on each plate were counted. Fungal colonies on the plates appeared blue, black, yellow, or green, while bacteria colonies on the plates appeared red with a regular shape (Okeyo et al., 2017).

Aerobic plate count:

Aerobic bacteria counts were counted using 3M Petrifilm Aerobic Count Plates (3M Microbiology Products, Minneapolis, MN.). The plates were placed in the biosafety cabinet. The top film of the plate was gently lifted and a P1000 micropipette (Finnpippete F2, Thermo Fisher Scientific, Inc, Vantaa, Finland), placed perpendicularly to the plates, was used to transfer 1 mL of the sample solutions onto the center of the 3M Petrifilm plates. The top film was carefully lowered. The center of a plastic spreader was placed on the plates to align with the centers of the plates. The plastic spreader was gently pressed so that there was even distribution of the inoculum on the Petrifilm plate. Gel was allowed to solidify for 1 min. Inoculated Petrifilm plates were stored with clear sides up and stacked no more than 20 units high. They were then placed in an incubator (Thelco Model 4, Precision Scientific Instrument, Inc., Buffalo, NY) at 35°C for 48 hrs, before counting. After the incubation periods, colony forming units (CFU) on each plate were counted. Aerobic bacteria colonies on the plates appeared red with a regular shape. The colony-forming unit per gram of rice (CFU/g) for each sample was obtained using equation (Okeyo et al., 2017).

$T_{cfu} = P_{cfu} / (D_r)$

where

T_{cfu} = total colony forming units per gram of rice (CFU/g),

P_{cfu} = colony forming units counted on the plate per gram of rough rice, and

D_r = dilution rate 10^{-1} to 10^{-6} durations.

Data Analysis

Data were analyzed for mean and standard deviations using Microsoft Excel and JMP Pro 17. Based on the mean and standard deviation, levels of different factors tested was compared for differences in the response variables.

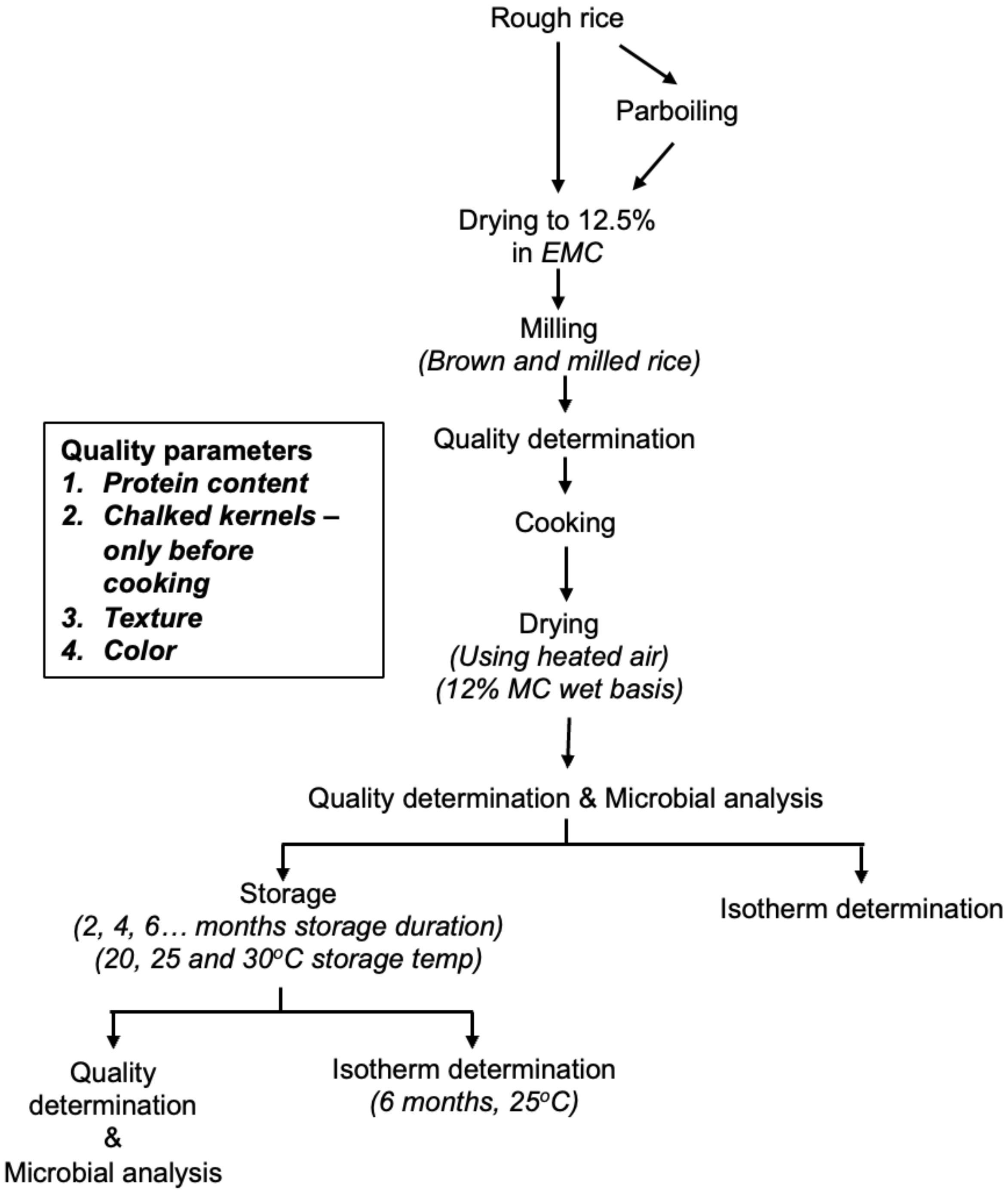

Fig. 1. Project flow chart

Results and Discussion

Quality Evaluation

Protein Content Analysis

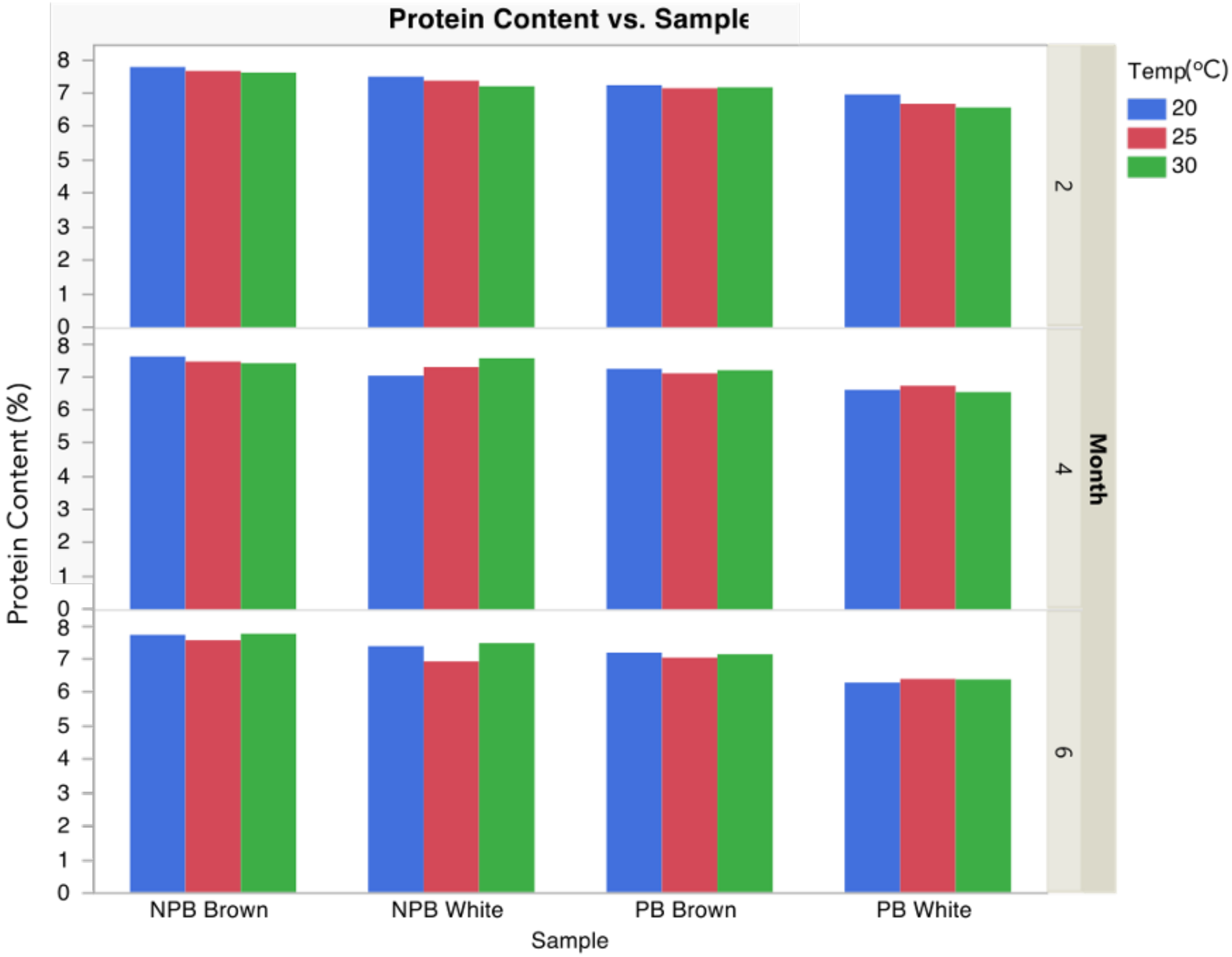

Fig. 1. Protein Content levels at each storage duration and temperature condition. These values are based from one replication and one data point.

As seen in Fig. 1, storage duration and temperature did not influence sample protein content. Protein content in rice is susceptible to change if stored at high temperatures. Higher temperatures drive enzymatic activity, which can break down rice proteins (Wang, T et al., 2021). In previous studies, temperatures above 30°C catalyzed enzymatic activity that lowered sample protein content (Wang, T et al., 2021, Zhao et al., 2021). Because rice samples in this study were stored at 30°C maximum, it is possible that enzymatic activity that would affect protein content was inhibited. A temperature above 30°C would sustain enzymatic activity, but 30°C would not.

Color Analysis

$$\Delta E = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}$$

Equation 1.

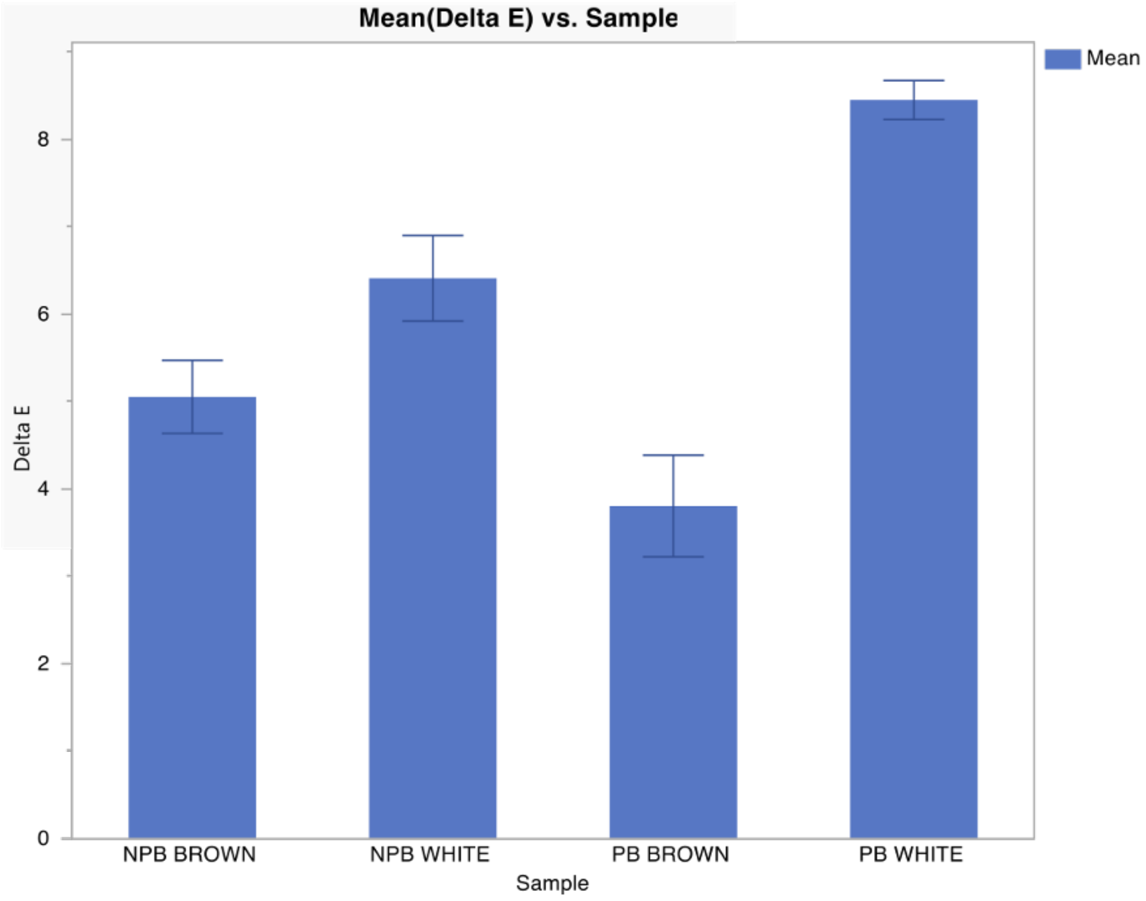

Fig. 2. A measure of the difference in color between uncooked instant and uncooked non-instant rice based on Equation 1.

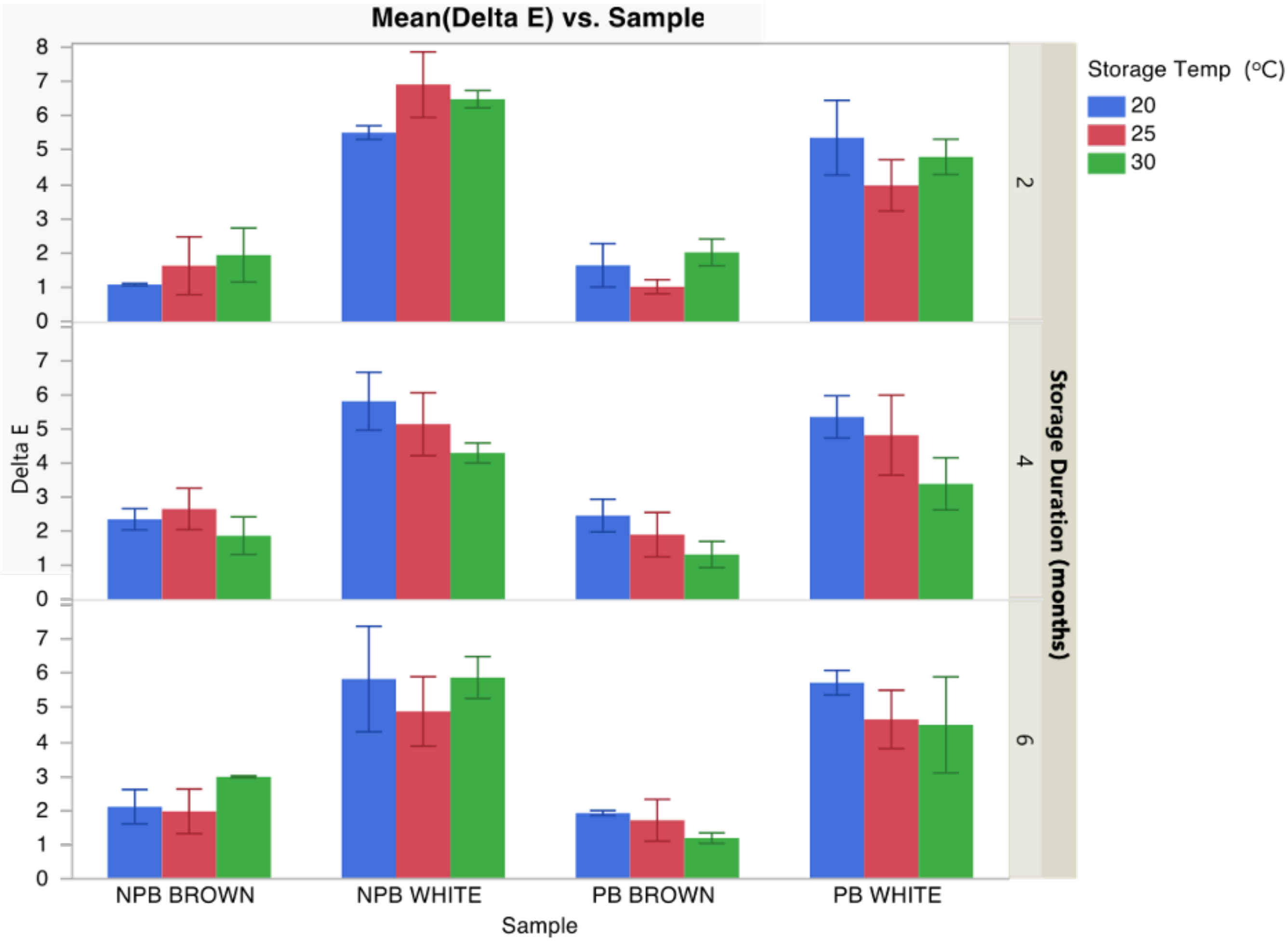

Fig. 3. A measure of the differences in color of instant rice samples at each storage duration and temperature condition.

Sample color was measured before instantization, and at 0-, 2-, 4-, and 6-month storage conditions after instantization. To calculate color change, Equation 1 was used. Uncooked non-instantized samples were compared to 0-month storage instantized rice to measure color change from the instantization process. All four sample types (NPB Brown, NPB White, PB Brown, and PB White) had significant change in color post-instantization. However, white rice samples had higher change in color than brown rice samples. The same trend was true for stored instantized rice. Equation 1 was also used to measure color change of instantized samples at 0-, 2-, 4-, and 6-month storage conditions. There was no significant difference in color between storage duration and storage temperature conditions. However, white rice still exhibited more color change than brown rice. White rice had higher Delta E (ΔE) values than brown rice in both comparisons. It's possible that white rice had a higher ΔE because white rice becomes more yellowed as it ages, which is a visibly different color than white. When brown rice discolors, it is more difficult to see as brown rice becomes a different shade of brown, rather than a completely different color as seen in white rice.

Texture Analysis

Hardness (g)

Duration (months)	*Temperature* (°C)	*PB Brown*	*PB White*	*NPB Brown*	*NPB White*
0	*25*	10661.53	9040.78	8070.48	5469.42
2	*20*	13406.74	9764.74	10840.17	4512.03
	25	12906.72	9488.75	12206.20	4684.68
	30	14582.83	1040.09	6517.95	4505.77
4	*20*	12183.39	8509.56	9080.42	5189.08
	25	10686.67	9733.71	10039.85	3578.95
	30	12518.89	10324.80	12286.56	4572.65
6	*20*	12723.06	8006.28	9279.24	5914.12
	25	12234.46	7862.57	8344.81	3615.38
	30	10071.41	6848.80	9914.57	3354.50

Table 2. Hardness values for each type of rice held at each temperature and each storage duration.

As seen in Table 2, brown rice was harder in texture than white rice. Brown rice has higher amounts of fiber than white rice due to the milling process, thus a stronger barrier for moisture to get through and be absorbed by the grain (Ravichanthiran et al., 2018). Parboiling increased hardness values in both brown and white rice. The parboiling process causes starch within the rice to gelatinize and then harden, making parboiled rice harder than rice that has not undergone that process. Storage duration and temperature did not impact rice hardness.

Adhesiveness (g/sec)

Duration (months)	*Temperature* (°C)	*PB Brown*	*PB White*	*NPB Brown*	*NPB White*
0	*25*	-7.71	21.50	-9.45	-25.18
2	*20*	-1.82	-3.32	-1.88	-2.41
	25	-1.73	-3.04	-1.55	-1.04
	30	-2.07	-2.38	-2.63	-8.52
4	*20*	-2.40	-4.22	-2.35	-3.35
	25	-3.67	-3.23	-2.57	-1.89
	30	-3.12	-3.92	-1.91	-1.92
6	*20*	-3.39	-3.92	-3.87	-7.33
	25	-4.52	-4.06	-2.67	-2.43
	30	-2.81	-3.46	-3.22	-5.02

Table 3. Adhesiveness values for each type of rice held at each temperature and each storage duration.

As seen in Table 3, white rice was more adhesive than brown rice. Adhesiveness in this context describes the stickiness between kernels, or how much they stick together. White rice undergoes milling, which removes surface layers of the kernel and allows more moisture penetration, thereby making white rice stickier than brown rice. The inner, starchy core is more exposed in white rice than brown rice (Ravichanthiran et al., 2018). Parboiling increased adhesiveness in both brown and white rice samples. Storage duration and temperature did not impact rice adhesiveness.

Chewiness (N)

Duration (months)	*Temperature* (°C)	*PB Brown*	*PB White*	*NPB Brown*	*NPB White*
0	*25*	3923.28	3000.36	2953.93	1423.13
2	*20*	16024.06	4713.24	13992.91	1991.50
	25	5992.82	11129.39	5669.97	2277.63

	30	8813.96	453.28	3121.90	1713.24
4	*20*	5537.24	3415.16	11242.49	1754.16
	25	4612.41	3980.48	3991.65	1179.26
	30	5811.23	4108.83	17221.42	1717.01
6	*20*	5990.76	2447.54	3714.06	2045.31
	25	5036.64	3029.43	2711.61	1146.93
	30	3945.18	2468.27	3715.39	789.88

Table 4. Chewiness values for each type of rice held at each temperature and each storage duration.

As seen in Table 4, brown rice had a chewier texture than white rice. This is likely due to the higher amounts of fiber in the bran of brown rice, which slows and limits kernel absorption of water (Ravichanthiran et al., 2018). Parboiled rice had higher chewiness values than non-parboiled rice. This is likely because of the parboiling process, as the gelatinized starch creates a harder texture and is therefore more chewy. Storage duration and temperature did not impact rice chewiness.

Springiness (%)

Duration (months)	*Temperature* (°C)	*PB Brown*	*PB White*	*NPB Brown*	*NPB White*
0	*25*	0.75	0.65	0.77	0.62
2	*20*	1.86	0.64	1.75	0.74
	25	0.69	1.82	0.63	0.77
	30	0.80	0.72	0.60	0.61
4	*20*	0.53	0.61	0.61	0.60
	25	0.65	0.62	0.61	0.60

	30	0.68	0.58	1.94	0.71
6	*20*	0.71	0.47	0.69	0.64
	25	0.61	0.58	0.62	0.59
	30	0.57	0.58	0.62	0.48

Table 5. Springiness values for each type of rice held at each temperature and each storage duration.

As seen in Table 5, the type of rice did not have any effect on springiness. Between parboiled and non-parboiled, as well as brown and white rice, there was no clear difference in springiness. Furthermore, storage duration and temperature also had little impact on sample springiness.

Resilience (b/a)

Duration (months)	*Temperature* (°C)	*PB Brown*	*PB White*	*NPB Brown*	*NPB White*
0	*25*	0.40	0.42	0.38	0.31
2	*20*	0.62	0.59	0.60	0.44
	25	0.65	0.59	0.55	0.39
	30	0.68	0.56	0.64	0.34
4	*20*	0.64	0.63	0.58	0.43
	25	0.65	0.61	0.64	0.38
	30	0.63	0.62	0.60	0.35
6	*20*	0.64	0.59	0.48	0.41
	25	0.64	0.61	0.48	0.41
	30	0.69	0.53	0.55	0.33

Table 6. Resilience values for each type of rice held at each temperature and each storage duration.

As seen in Table 6, rice type exhibited no discernible influence on grain resilience. Whether parboiled or non-parboiled, as well as brown or white rice, no distinct disparity in grain resilience was observed. Similarly, storage duration and temperature showed minimal effects on the resilience of the samples.

Cohesiveness ((d+e)/(a+b))

Duration (months)	*Temperature* (°C)	*PB Brown*	*PB White*	*NPB Brown*	*NPB White*
0	*25*	0.49	0.51	0.47	0.41
2	*20*	0.65	0.64	0.63	0.56
	25	0.67	0.64	0.60	0.60
	30	0.75	0.60	0.65	0.50
4	*20*	0.68	0.66	0.62	0.53
	25	0.67	0.66	0.64	0.52
	30	0.67	0.67	0.63	0.51
6	*20*	0.67	0.63	0.58	0.53
	25	0.67	0.66	0.52	0.54
	30	0.68	0.62	0.59	0.46

Table 7. Cohesiveness values for each type of rice held at each temperature and each storage duration.

As seen in Table 7, cohesiveness of grains showed no significant correlation with the type of rice. Across parboiled and non-parboiled samples, as well as between brown and white rice, no discernible differences in cohesiveness were observed. Moreover, neither storage duration nor temperature appeared to exert a notable influence on the cohesiveness of the samples.

Gumminess (N)

Duration (months)	*Temperature* (°C)	*PB Brown*	*PB White*	*NPB Brown*	*NPB White*
0	*25*	5226.59	4578.87	3821.10	2261.19
2	*20*	8732.56	6159.16	6848.66	2575.06
	25	8622.95	6061.61	7520.09	2772.18

	30	10810.98	615.86	4291.17	2311.38
4	*20*	8315.87	5590.97	5632.49	2758.26
	25	7123.80	6450.89	6456.64	1886.12
	30	8434.49	6899.09	7733.96	2385.21
6	*20*	8486.92	5042.50	5343.69	3134.46
	25	8183.60	5157.11	4349.78	1933.17
	30	6883.68	4225.66	5908.74	1573.99

Table 8. Gumminess values for each type of rice held at each temperature and each storage duration.

As seen in Table 8, the gumminess of the grains exhibited no discernible pattern associated with the type of rice. Whether comparing parboiled to non-parboiled or brown to white rice, no clear distinction in gumminess emerged. Furthermore, the impact of storage duration and temperature on the gumminess of the samples appeared negligible.

Chalkiness

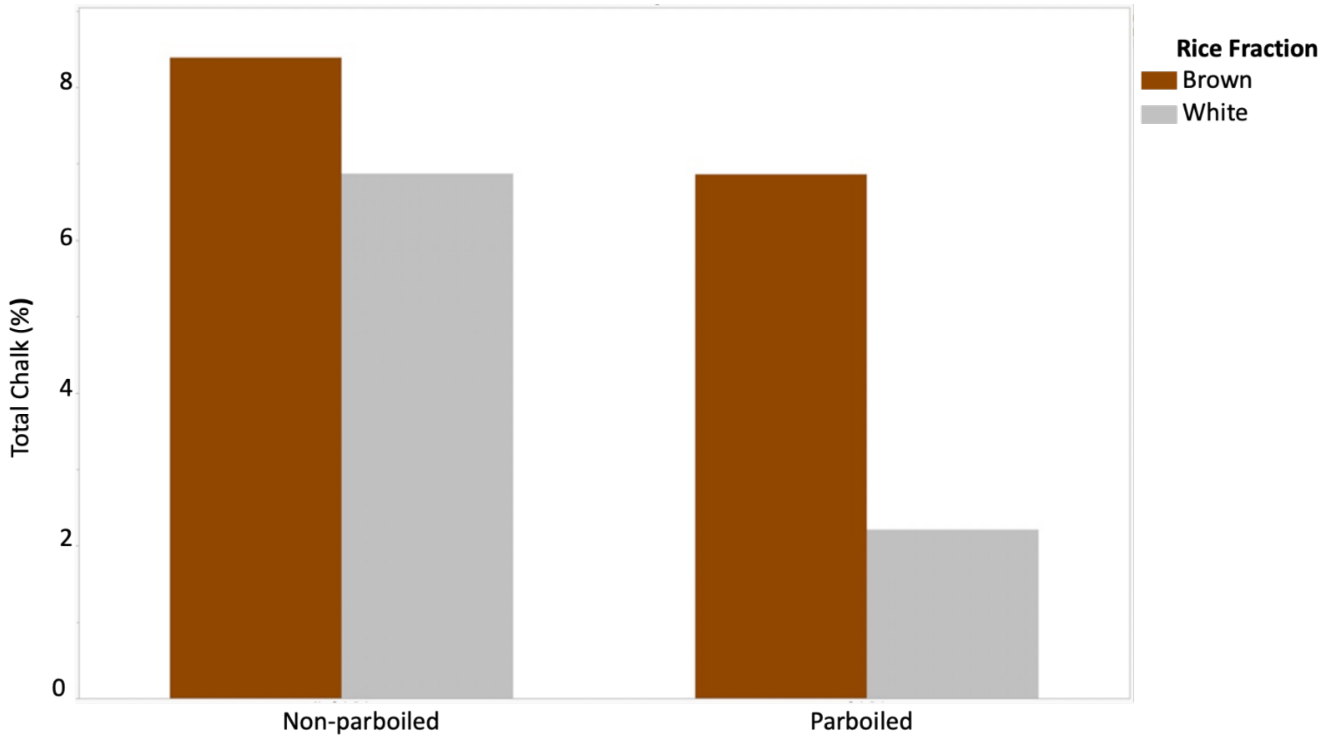

Fig. 4. Chalkiness values of pre-instantized rice

As seen in Figure 4, chalkiness values were higher in brown rice than white rice. Chalkiness describes white, opaque areas within a rice kernel (Fan et al., 2022).White rice is less chalky than brown rice due to the milling process that often removes the dispersed air bubbles caused by immature starch in the kernel that contribute to chalkiness. Parboiling decreased chalkiness in both white and brown rice. This is likely due to the parboiling process, as the pre-soaking and steaming clarify the rice kernel and remove air bubbles trapped in the kernel. Only control samples were measured for chalkiness.

Microbial Analysis – Total Bacteria

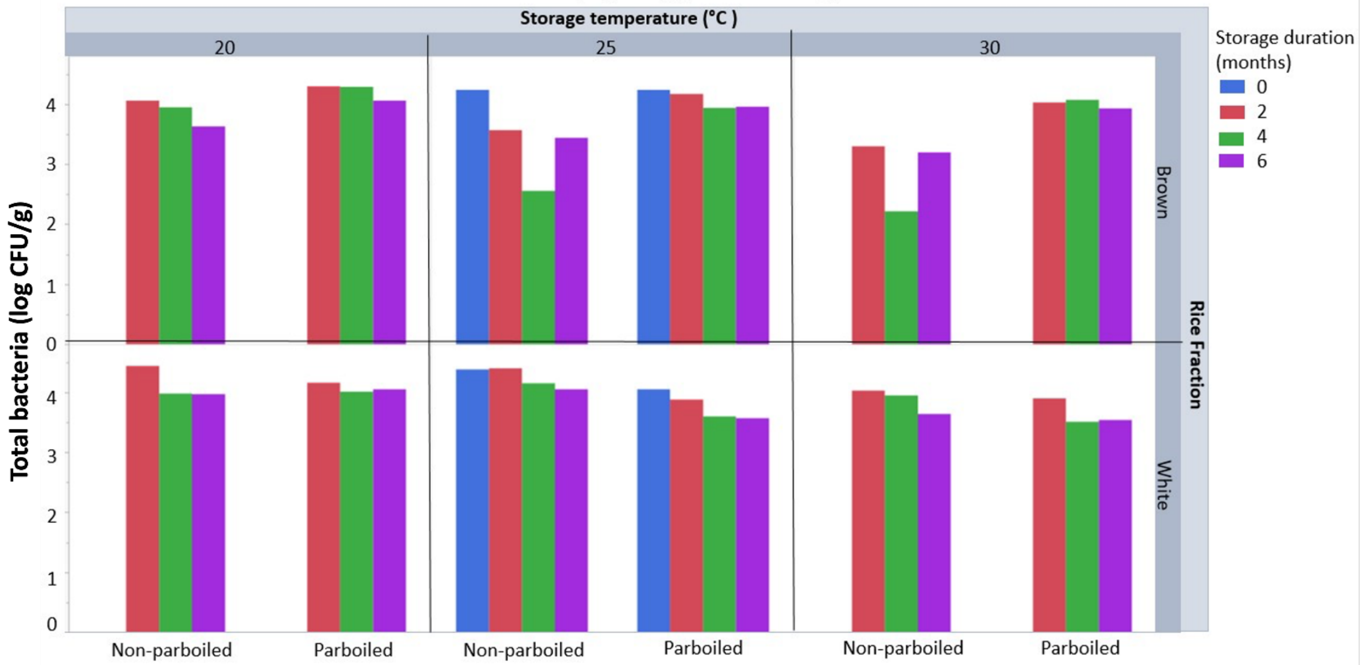

Figure 5. Total bacteria count of 0-month instant rice samples

As seen in Figure 5, regardless of storage duration, storage temperature, type of rice (white or brown), or whether it was parboiled or non-parboiled, none of these parameters exhibited any effect on microbial growth.

Microbial Analysis – Fungi

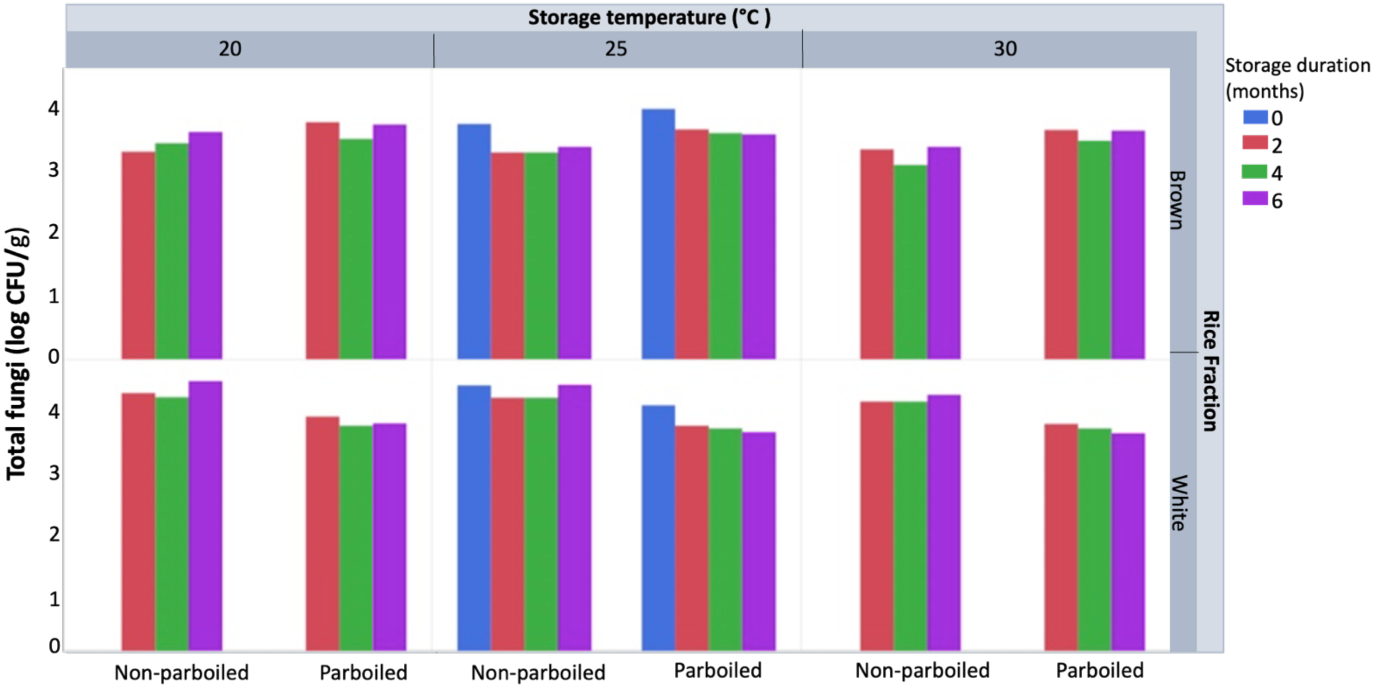

Figure 6. Fungal microbial analysis of 0-month instant rice samples.

As seen in Figure X, varying storage durations, temperature settings, rice types (white or brown), and processing methods (parboiled or non-parboiled), none of these factors were found to influence fungal growth.

Moisture Sorption Curves

Non-parboiled Brown

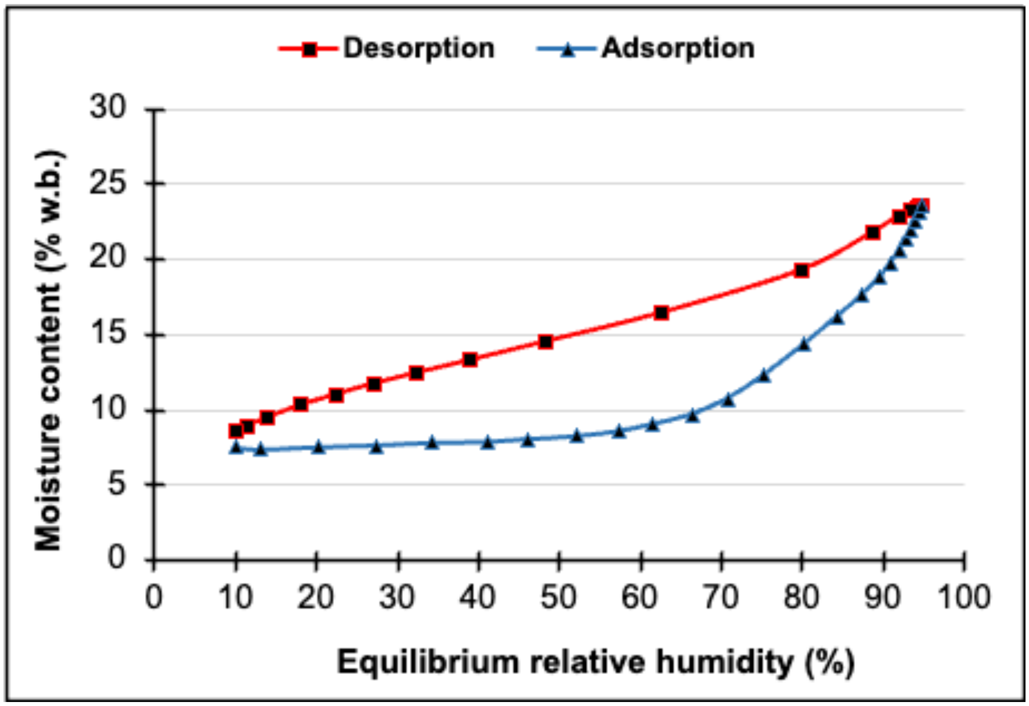

Figure 7. 0-month non-parboiled brown rice moisture sorption curve at 25°C.

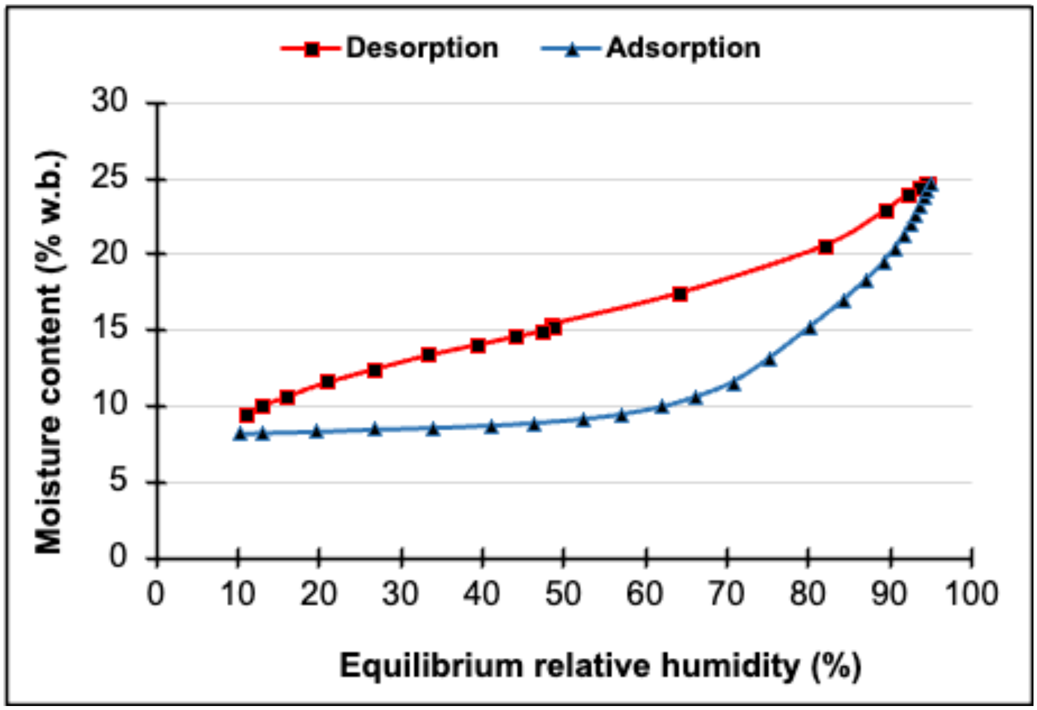

Figure 8. 6-month non-parboiled brown rice moisture sorption curve at 25°C.

Non-parboiled White

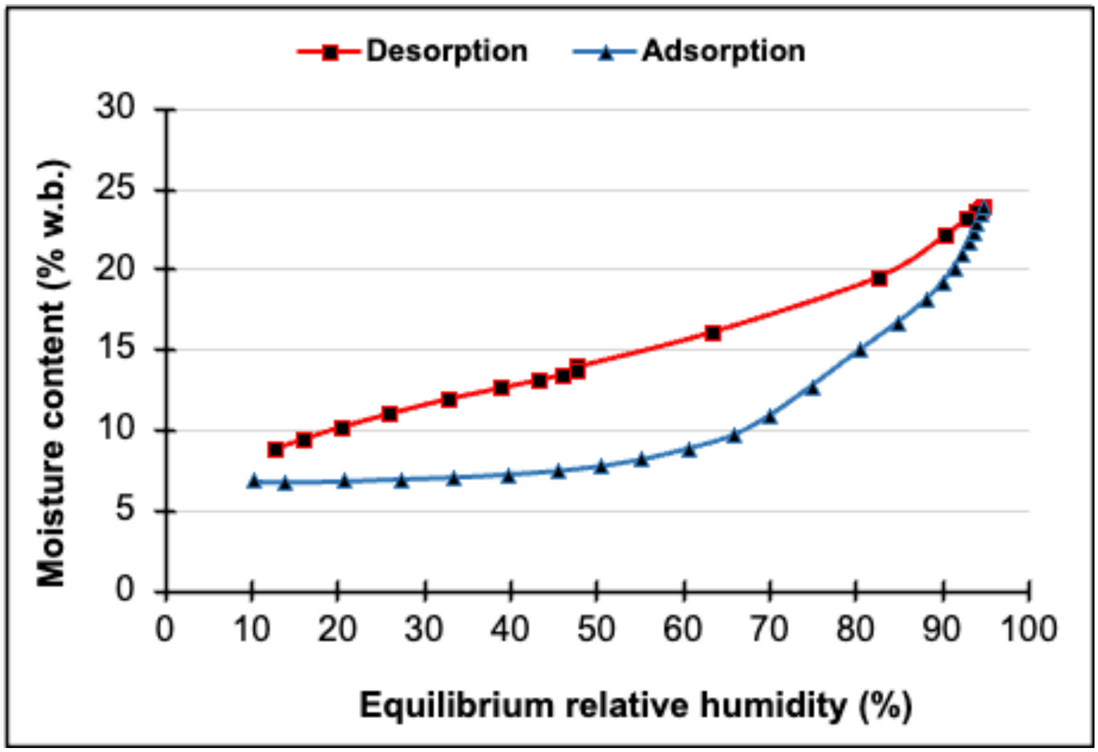

Figure 8. 0-month non-parboiled white rice moisture sorption curve at 25°C

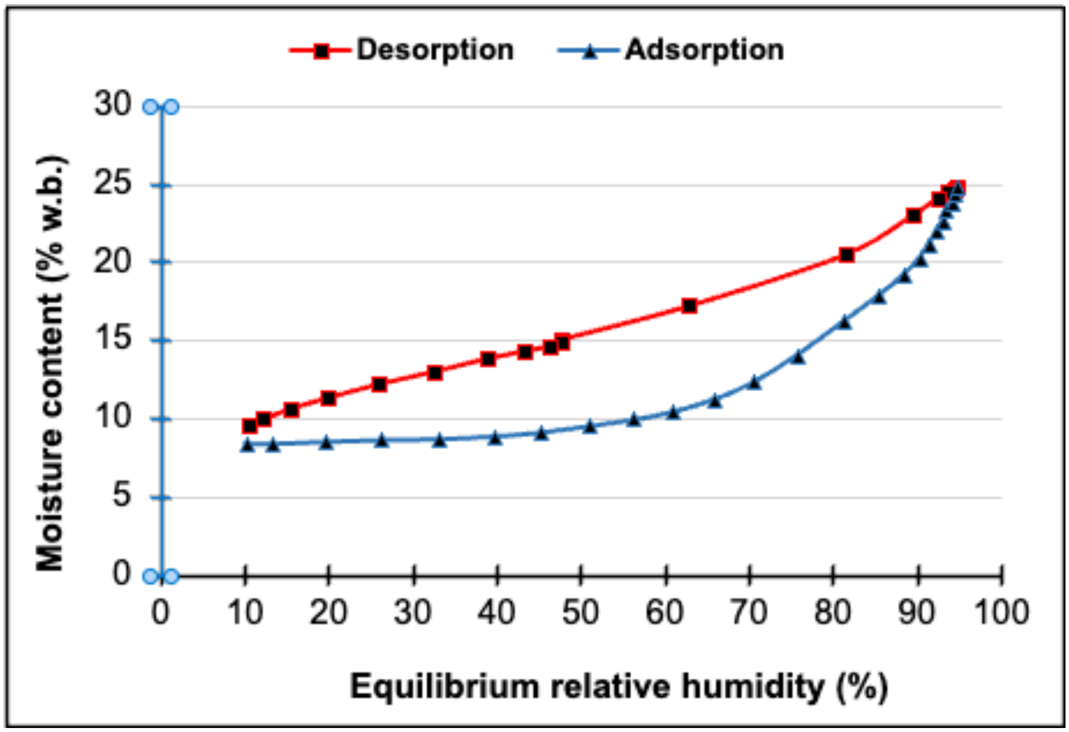

Figure 9. 6-month non-parboiled white rice moisture sorption curve at 25°C.

Parboiled Brown

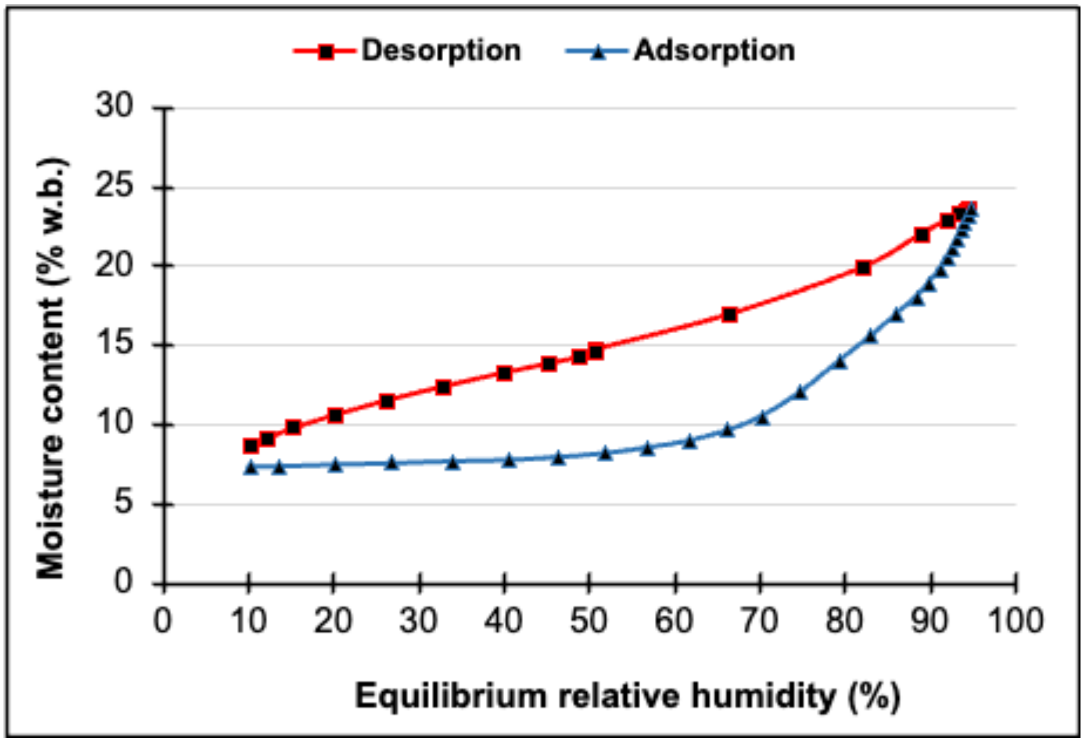

Figure 10. 0-month parboiled brown rice moisture sorption curve at 25°C.

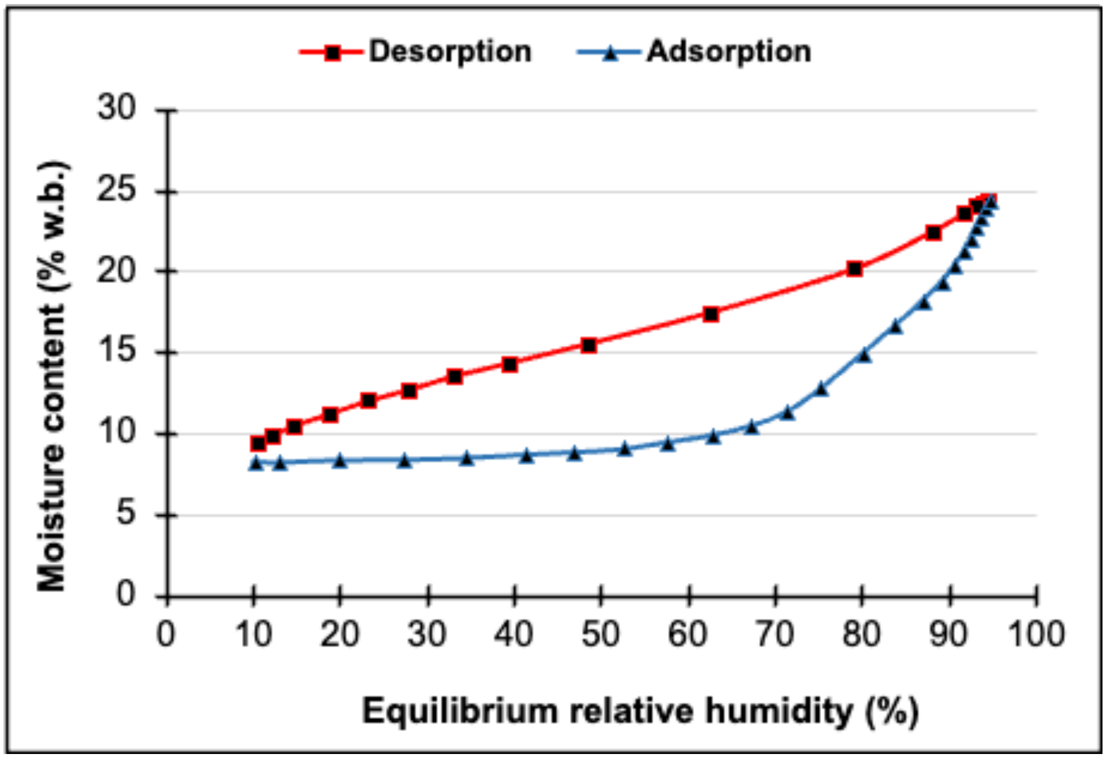

Figure 11. 6-month parboiled brown rice moisture sorption curve at 25^{o}C.

Parboiled White

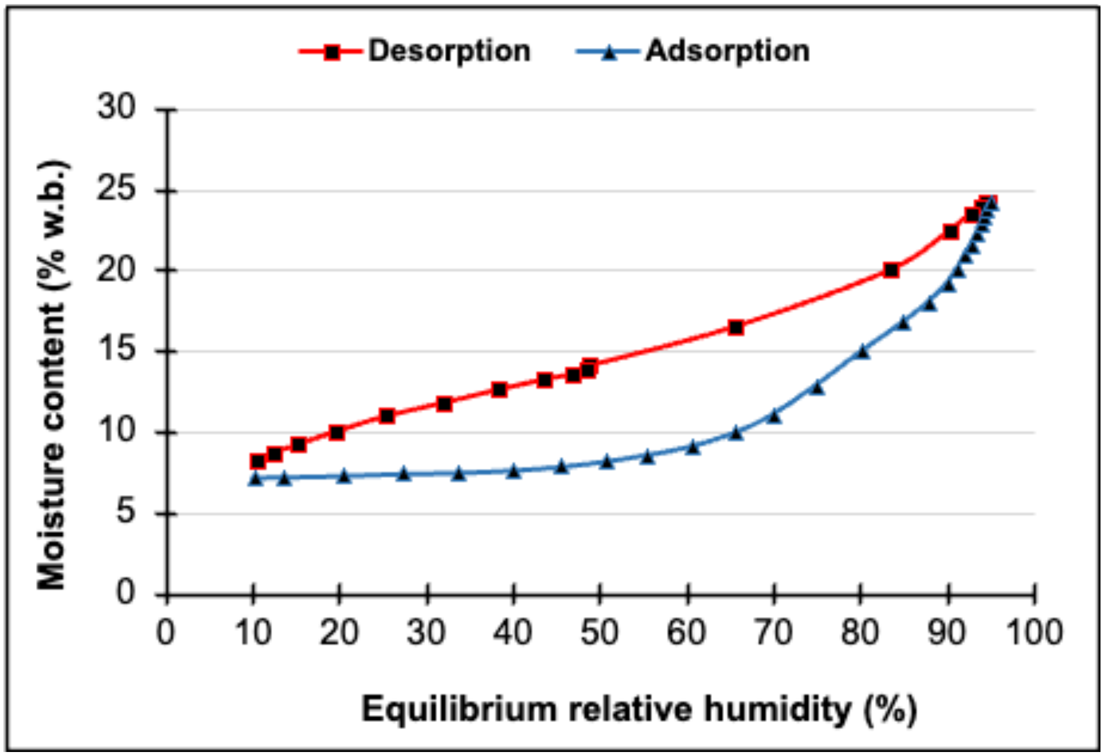

Figure 12. 0-month parboiled white rice moisture sorption curve at 25^{o}C.

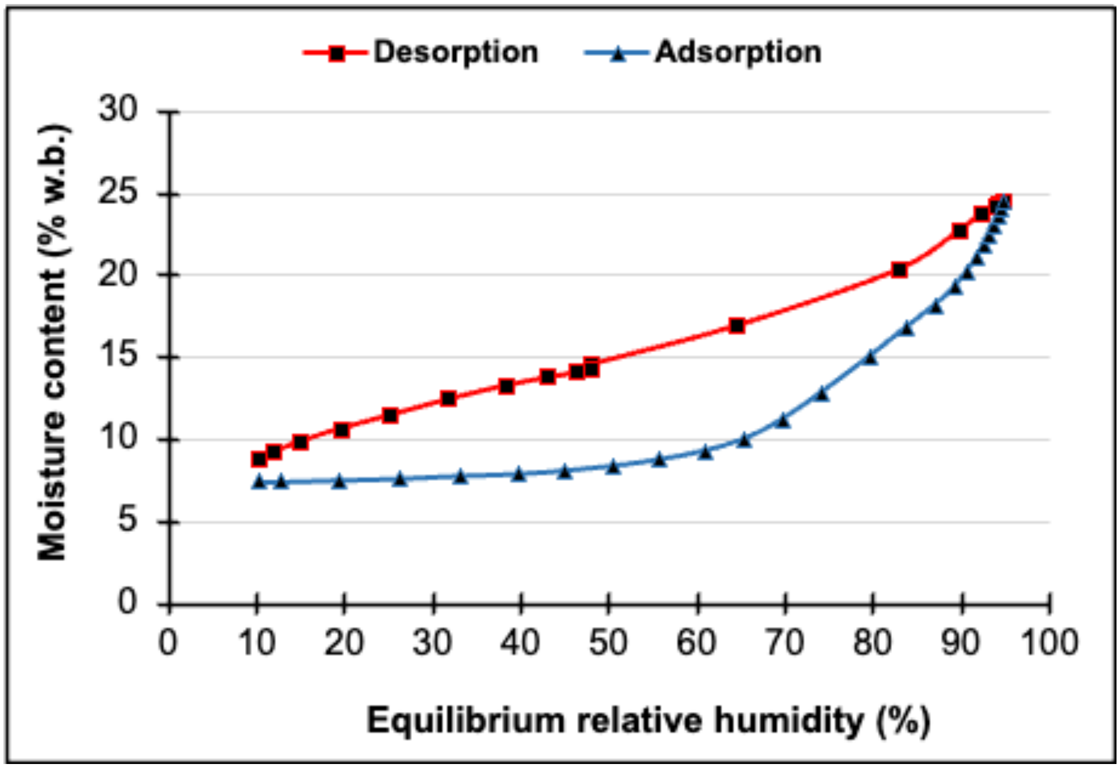

Figure 13. 6-month parboiled white rice moisture sorption curve at 25^{o}C.

Moisture sorption curves were developed for 0- and 6-month samples held at 25^{o}C. This curve illustrates the relationship between the moisture content of rice samples and the surrounding relative humidity (RH) during the process of adsorption (moisture uptake) and desorption (moisture release). All sample curves contain a hysteresis loop, which describes the response of the sample’s moisture content to changes in relative humidity. As the relative humidity increases, the material absorbs moisture until it reaches equilibrium at a certain moisture content. Conversely, when the relative humidity decreases, the material releases moisture until it reaches equilibrium again.

While most of the curves look very similar, there are some noticiable differences. All curves had plateauing adsorption curves until around the 60-70 RH marks, at which point moisture content rapidly increased. The moisture content of white rice samples, both parboiled and non-parboiled, increased the most around 70 RH, while brown rice samples increased more around 60 RH. Brown rice also has a slightly wider curve than white rice samples, meaning the difference between adsorption and desorption was greater for brown rice samples. Furthermore, parboiled rice samples had a slightly larger difference between adsorption and desorption than non-parboiled samples. Storage duration did not have a noticeable effect on moisture sorption of any of the rice samples.

These moisture sorption curves are very useful for predicting shelf life and storage behavior. By using these tools, producers can establish optimal storage conditions, maintain quality, and minimize food waste, ultimately ensuring consumer satisfaction.

Consolidated Curves

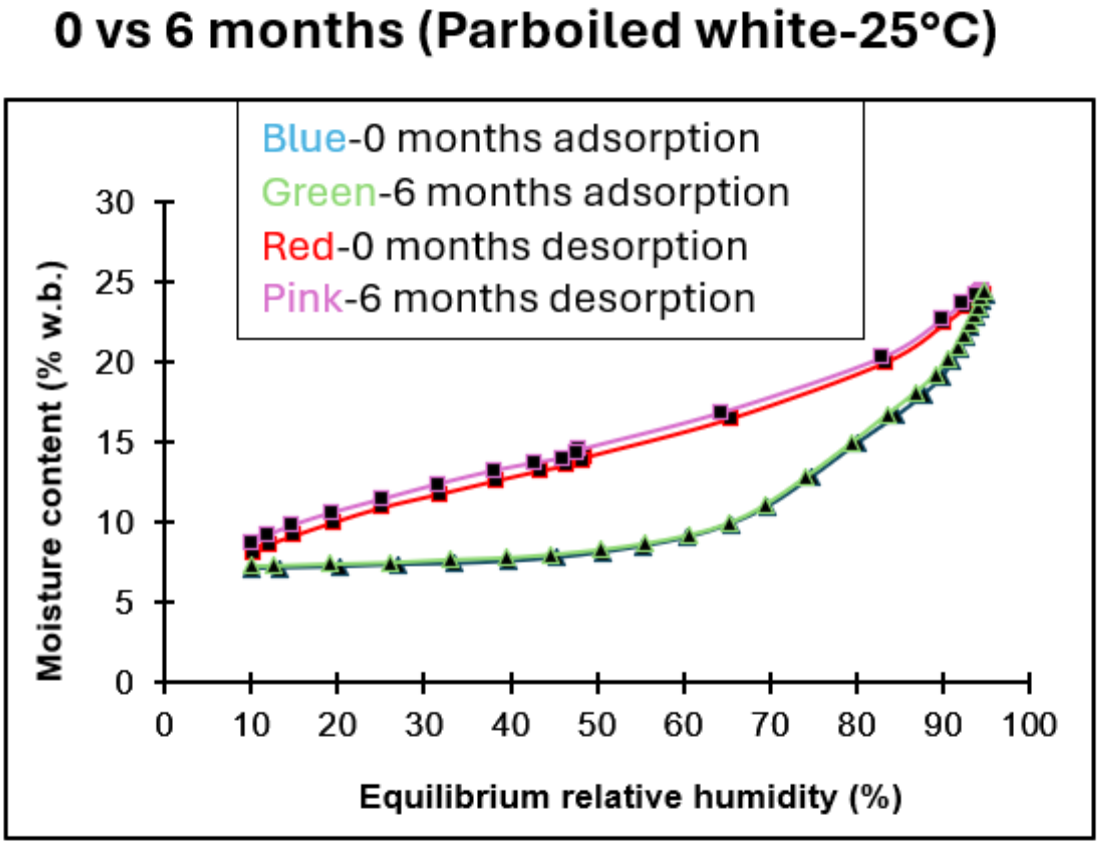

Figure 14. Curve showing effect of storage on parboiled white rice moisture sorption.

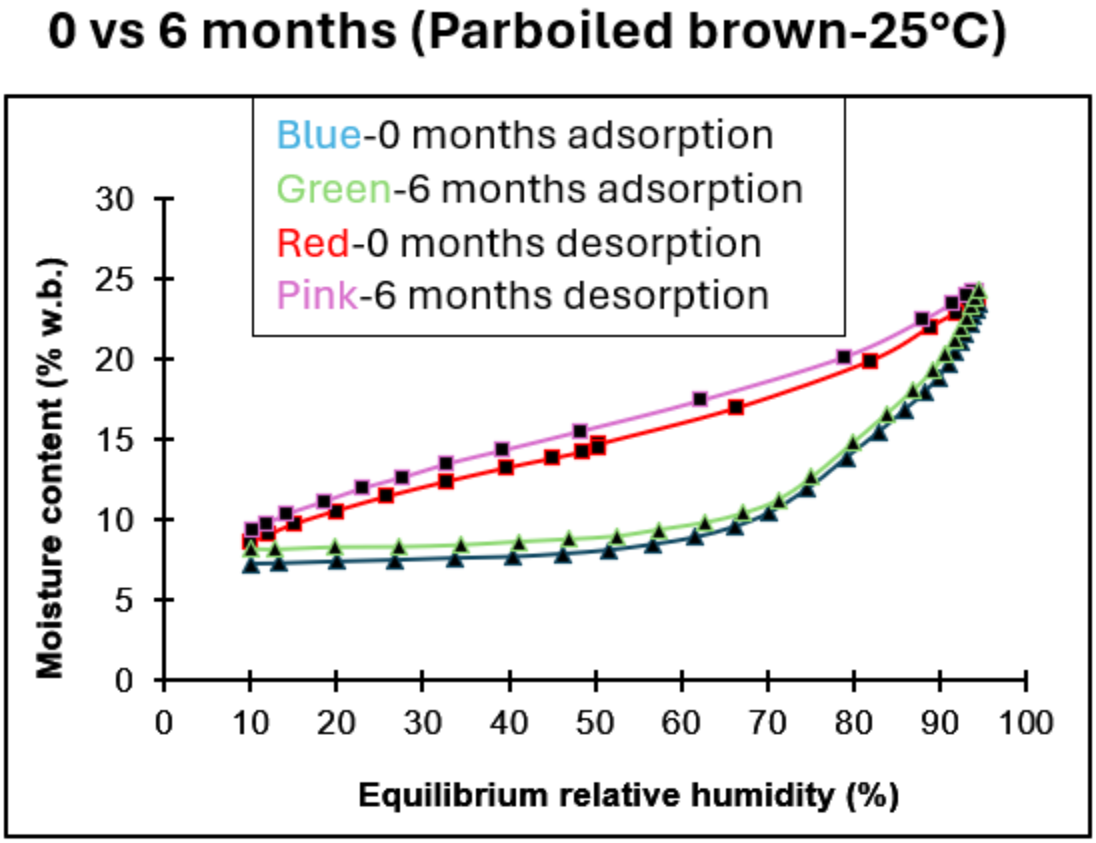

Figure 15. Curve showing effect of storage on parboiled brown rice moisture sorption.

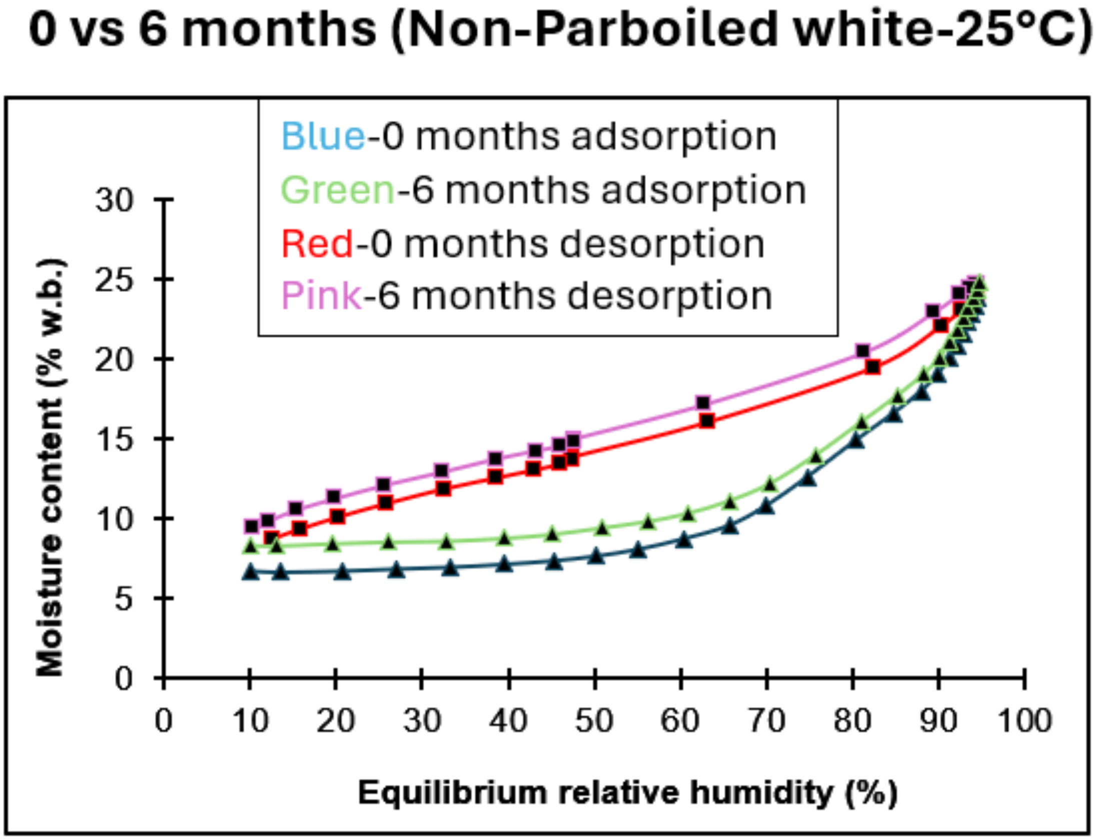

Figure 16. Curve showing effect of storage on non-parboiled white rice moisture sorption.

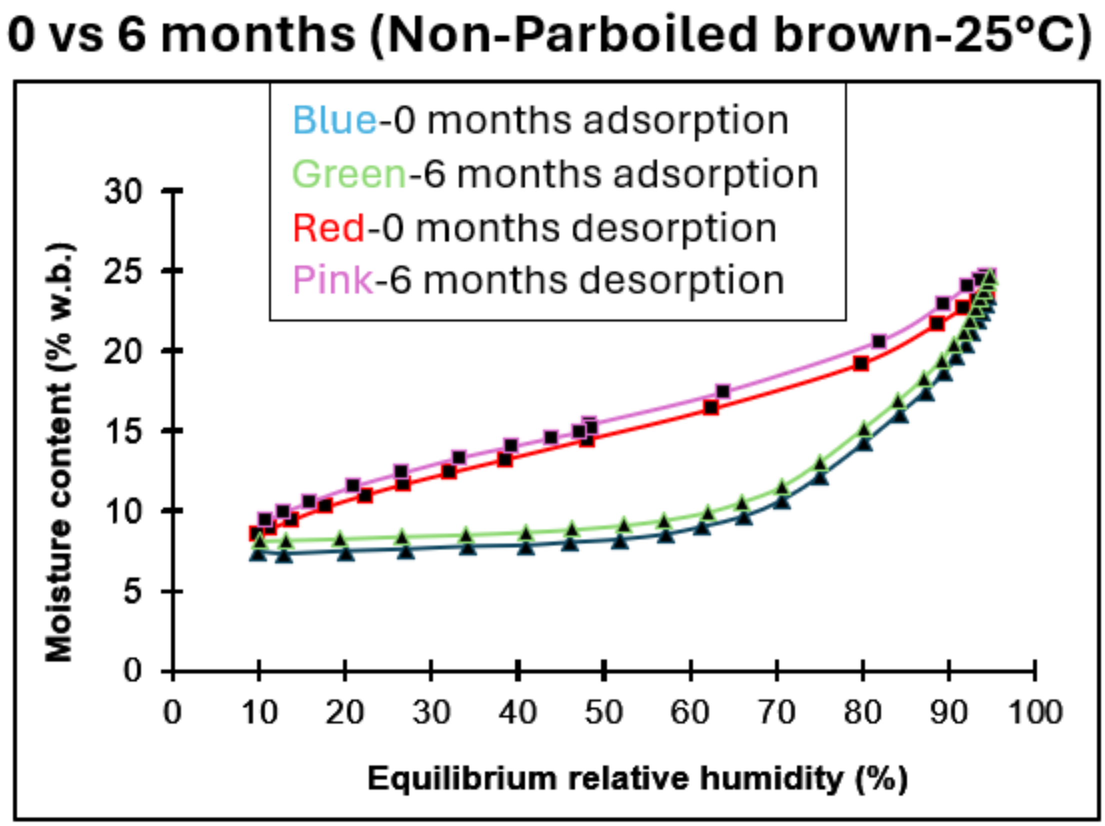

Figure 17. Curve showing effect of storage on non-parboiled brown rice moisture sorption.

The moisture sorption curves above illustrate the effect of six-month storage on the moisture sorption of all rice sample types. Isolated sample curves were consolidated into one figure to show if or how storage shifted the moisture sorption curve. It can be seen in all the figures that six months of storage shifted the moisture sorption curves up. This means that rice stored for six months had a higher capacity for absorbing water than rice stored for 0 months. This phenomenon was true for all rice types.

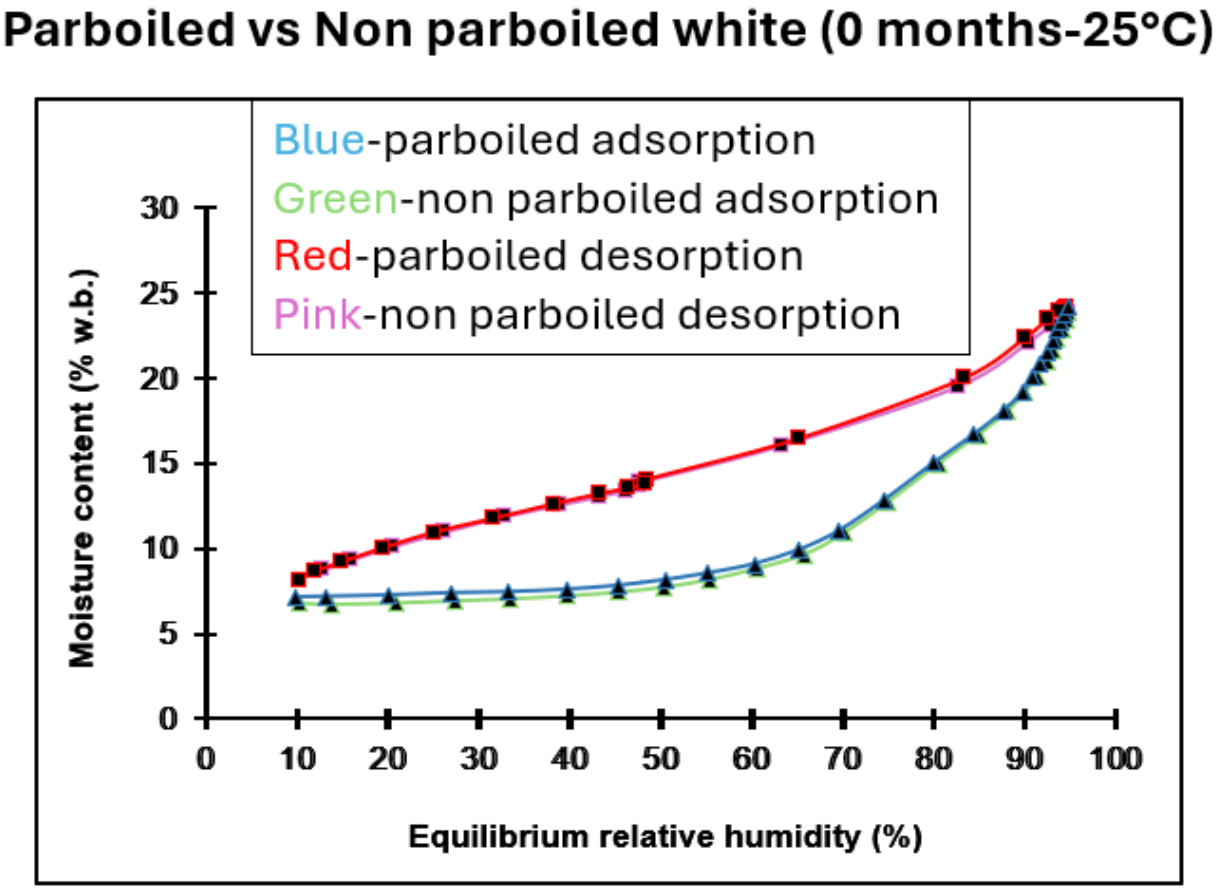

Figure 18. Curve showing effect of parboiling on white rice moisture sorption.

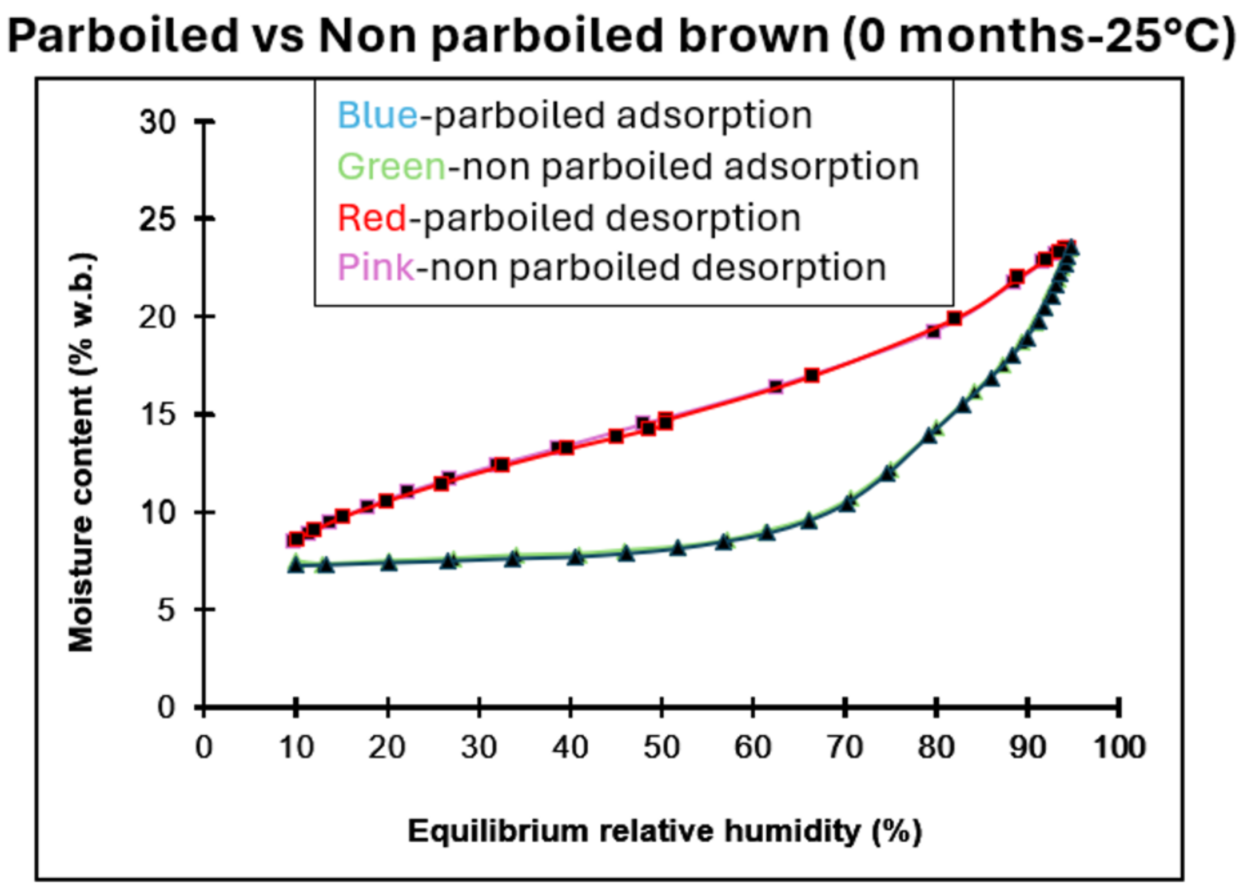

Figure 19. Curve showing effect of parboiling on brown rice moisture sorption.

The curves above illustrate how parboiling affected moisture sorption of brown and white rice samples. Parboiling had no significant impact on moisture sorption of brown or white rice. Curves between parboiled and non-parboiled samples overlapped almost exactly.

Conclusions

In this project, the effect of storage duration and temperature, as well as pre-instantization rice treatment, on instantized rice quality and moisture sorption was measured. The quality parameters tested were texture, color, and protein content. Before instantization, chalkiness was measured. Due to an extensive drying time in ambient conditions, microbial analysis of instant rice was also measured.

Protein content of samples didn’t change much with storage duration and temperature either. Brown rice had slightly higher protein content than white rice, and parboiled rice had slightly lower protein content than non-parboiled rice.

As expected, treatment of rice also created differences in sample color. Color change after instantization occurred for all samples but was more visually obvious in white rice samples. Storage duration and temperature had little effect on sample color.

Treatment of rice pre-instantization created noticeable differences in textural qualities of the samples. Parboiled rice had higher hardness values than non-parboiled samples. There were differences between brown and white rice samples too, as brown rice was harder and chewier when cooked than white rice. White rice had higher adhesiveness values than brown rice as well. Storage duration and temperature did not have noticeable impact on rice texture.

Chalkiness was measured before instantization. Chalkiness values were higher for brown rice than white rice and parboiled rice had lower chalkiness values than non-parboiled rice. Microbial analysis was conducted with all instant rice samples to measure if any microbial growth occurred before storage. This was done because drying instant rice samples took 14 days in ambient temperature, which raised microbial growth concerns. Storage duration and temperature had minimal effect on fungi and bacteria growth. Rice treatment also did not have much impact on microbial growth.

The moisture sorption curves for all rice types were similar but did have some slight differences. There was a greater difference between brown rice adsorption and desorption than white rice adsorption and desorption. There was also a greater difference between adsorption and desorption of parboiled samples than non-parboiled samples. Additionally, white rice had slower adsorption than brown rice. Only 0- and 6- month samples held at 25°C were used for development of moisture sorption curves, but there was no clear difference between 0- and 6-month curves of each rice type.

Assessing the influence of storage duration and temperature on the quality and storage behavior of instant rice is crucial for both the rice industry and consumers. It ensures manufacturers can maintain consistent quality and taste, meeting consumer expectations. Including both brown and white rice, as well as parboiled and non-parboiled samples, allows for a comprehensive analysis of different varieties and processing methods. While no significant effects of storage duration and temperature were observed on instant rice quality and storing behavior, differences were noted between parboiled and non-parboiled samples. This suggests that the relatively short storage period (6 months) and moderate temperature variations (20 ^{o}C, 25 ^{o}C, and 30 ^{o}C) may not have been sufficient for detecting broader impacts. Further investigation with longer storage durations and a wider range of temperature conditions may provide clearer insights, aiding industry decisions and consumer satisfaction.

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Appendix A (leave blank)