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Abstract

Rice is utilized as an adjunct grain by the beer manufacturing industry. Before utilization, the rice has to be dried to a desired moisture content. The drying process employed may have an impact on the rice's physicochemical properties which influence the rice's performance in the brewing process. This study focused on investigating the impact of microwave drying on rice's physicochemical properties and utilization in the brewing process. Rough rice samples at an initial moisture content of 19.7% wet basis were exposed to microwave dryer set to deliver 525 kJ/kg of energy in a single drying pass. The effects of the single-pass continuous drying on the dried rice amylose content, protein content, and specific gravity (°Plato, fermentable sugar content) of the wort were determined. The results were compared with samples dried using natural air at 25°C and 56% relative humidity (RH), and two-pass heated-air drying at 45°C and 60°C with RH set at 20%. There was a statistical difference in measured rice amylose and protein contents ($p= 0.042$) of microwave dried samples compared to the natural air-dried samples. However, these attributes were significantly different from those of samples dried at a higher temperature of 60°C and RH of 20%. There was a significant difference ($p=0.0197$) in the initial gravity content of all-malt samples and the rice adjunct samples as expected, but there was no significant difference between the rice adjunct samples. Overall, the studied drying methods could create variation in the rice's physicochemical properties, but no measurable differences were observed among the wort's initial gravity contents. This study analyzed the effect of microwave drying on rice processing and subsequent use in the brewing process and determined that it was most comparable to natural air drying, but results in a greater head rice yield resulting in a larger profit for rice farmers and processors.

Keywords:

Amylose content, Brewing process, Microwave drying, Rice drying, Specific gravity

Introduction

Background and Need

Rice is a commonly consumed cereal grain across the world that has many industrial uses in the food industry. Rice is a versatile grain that has grown in popularity in recent years due to its physicochemical composition of primarily being starch with low amounts of protein and lipid (fat) content. These macronutrient properties along with being gluten-free have helped its growth in popularity. While rice has many uses in the food sector, it also has many uses in the beverage sector, specifically in the brewing industry.

Rice has been a commonly used adjunct in the brewing industry for well over 300 years since its birth in Germany. Adjunct brewing is a style of brewing designed to supplement the overall fermentable sugar content of the wort by incorporating cereal grains into the grain bill rather than using all-malt. Using an adjunct is done as a cost-effective way of producing better beer since cereal grains are significantly cheaper than malted grains. The desirability of rice to be used as an adjunct in the brewing process is primarily attributed to its physicochemical composition of high starch and low protein and lipid content. The starch content of rice consists of two polymers of amylopectin and amylose, typically in a 75:25 ratio range (Fox et al., 2019). For the rice starch to be used in the brewing process, the rice grains must first be gelatinized in water at high temperatures. After the gelatinization of the rice which pulls the starch out of the grain, enzymes from the malted barley can hydrolyze the starches into maltose and glucose during the main mash. The sugars produced by the enzymatic hydrolysis of the long-chain starches can be utilized by the yeast during fermentation.

For rice to be used in the brewing process or food sector it must be subjugated to a post-harvest drying process to ensure safe storage. There are currently two commonly used commercial drying techniques to lower the moisture content of the rice from 18-22% (w.b.) to 13% (w.b.). These methods are natural air drying and high-temperature hot air drying, which both affect the structural composition of the rice in different ways and result in varying head rice yields (HRY**).** While these methods of drying rice have been established for years, current research has evaluated new methods of post-harvest rice drying. One of the methods that showed potential of high head rice yield and can be cost-efficient is microwave drying (Smith & Atungulu, 2020).

Problem Statement

The majority of past rice research has been primarily focused on the drying techniques, the ability to improve the HRY, and its effect on the quality characteristics of rice. Due to the expansive growth of the craft beer sector, a new market has emerged for the use of head rice. This market has the potential to have a significant impact on the rice economy as it has had on several state economies such as New York State. There, the impact of the craft beer market has already translated into a 3.5-billion-dollar impact for New York State and similar impacts can be seen across the country (Simpson, 2017). The rice economy could potentially benefit from the expansive market of craft beer as smaller craft breweries look to use rice as an adjunct in brewing. As there are currently two common commercial rice drying techniques, little research has looked into the impact of drying techniques on the utilization of rice in the brewing process.

Purpose of the Study

The purpose of this study is to understand the effects of different drying treatments of rice on its physicochemical quality important for the brewing process.

The following objectives guided this study:

- To determine the effect of different drying techniques on the protein and amylose content of rice.
- To determine the impact of rice dried in different ways on the specific gravity (fermentable sugar) content on the wort before fermentation
- To determine how different drying techniques, affect the ability of the yeast to use the rice during fermentation in terms of attenuation.

Literature Review

This chapter introduces a review of literature and research into the rice drying process, brewing industry, and rice usage in the brewing process. Items selected to review address current research and literature evaluating each topic. The first review evaluated research into current commercial drying methods as well a new alternative drying method. The second area of review evaluated the brewing industry in its economic impacts and current practices. The third and final area of review evaluated current research of rice in brewing and the process of how rice is utilized.

Rice Drying Methods

Drying is an important aspect of the rice industry due to its effect on the profit and quality of rice, especially the amylose content, which can affect its taste, value, and cooking characteristics (Shi et al., 2021) Rice drying is an important topic in the farming community due to its large implication on profits for farmers in terms of head rice yield. Currently, in the rice farming industry, hot air and natural air drying are used and are chosen at the discretion of the farmer or of the grain bins owners. While these two methods are used in the industry, research is conducted to evaluate other options that might offer greater HRY. One option that has emerged as a viable option is microwave drying where lab-based simulations resulted in an increase of HRY from 58% to >65%, which translates into a $145 million annual increase in rice value (Smith & Atungulu, 2020). Microwave drying has increased HRY and can also do it in a cost-efficient manner when performed in a specific energy range of 450-600 $kJ\ kg^{-1}$ (Olatunde et al., 2017).

While microwave drying has proven to be an effective means of raising the HRY, it is still a new method and has not been integrated commercially. Natural air drying is a longer drying process because air temperature is manipulated closer to the natural environment of 25°C to avoid damaging the rough rice quality. This uses the principle of drying using relative humidity rather than manipulating the temperature of the drying air in that specific region of processing. Hot air drying has a high evaporative capacity which can lead to damage in the rice's endosperm causing fissures. The fissures formed in turn lead to broken heads in the milling process (Aquerreta, 2007). Hot air drying of rough rice at a temperature of 60°C a viable option while maintaining its quality in terms of HRY and resulting in favorable amylose content (Janaun et al., 2016).

Brewing Industry

The brewing industry has become economically impactful to a state's economy, so much so that New York State economy has had to implement legislation to keep the $3.5 billion impact within the state (Simpson, 2017). While this impact is attributed to the influence of craft breweries, commercial breweries have always had a significant bearing on the economy and more specifically the rice economy. This impact comes from commercial breweries being one of the largest buyers of rice in the United States, through the purchase of broken rice, a byproduct of rice drying and milling processes. With the introduction of new drying techniques that can potentially increase head rice yield (HRY) and its physicochemical properties, breweries are faced with the issue of learning how it affects them.

Rice is considered an adjunct in the brewing industry and is implemented into the brewing process through adjunct brewing. Adjunct brewing is a form of brewing that uses un-malted grains as a means of increasing the fermentable sugar of the wort (sweet/sugar water) (Yorke & Ford, 2021). In many cases, beer is categorized based on which adjunct is its primary component. Examples of beer such as Budweiser and Michelob Ultra (Anheuser-Busch, St. Louis, MO) are rice-based while Busch (Anheuser-Busch, St. Louis, MO) and Miller (Molson Coors, Milwaukee, WI) use corn-based adjuncts. While many consider the adjunct as the primary ingredient, it is a common misconception because in most cases an adjunct only constitutes 20-30% of the beer's grain bill. The grain bill of the beer is the recipe that shows what ingredients are incorporated during the mashing process to produce the wort used by yeast. Adjunct brewing was first introduced to the brewing industry by German brewers and resulted in having a profound influence on why adjunct lager beer became America's beer (Casey, 2020). Adjunct brewing, while common in many of the major breweries, is also present in smaller craft breweries. Craft breweries often use high gravity brewing production as a means of producing beer with a high alcohol by volume content (Kincl et al., 2021). This method uses adjuncts in the grain bill due to its ability to have little impact on the overall flavor and appearance of the beer. This is because when an all-malt grain bill is used to produce a high gravity beer, a study noted that it changes a beer's flavor profile with the production of acetate esters causing fruity and solvent-like odors (Kinčl et al., 2021). These “off-flavors” are strictly unwanted in the production of any type of beer and industry such as the beer industry. Good beer is expected and is the standard and adjuncts help in producing this in a cost-efficient manner.

Brewing with rice as an adjunct

Rice is a unique grain in which 90% of its endosperm is made up of starch, a long branch carbohydrate. Brewers can use this unique grain as a means of increasing the fermentable sugar content in the wort which is then used to pitch yeast to start fermentation. This is first done by subjugating the rice separate from the malted barley to a rice cooker that gelatinizes the rice at a high temperature to avoid denaturing the enzymes present in the malted barley (Yu et al., 2018). This is typically done with all un-malted grains such as corn and rice to extract the amylose and other sugars present in the grain. Once the rice or corn is allowed to gelatinize for the desired time, the solution is brought down to the strike temperature and added into the all-malt mash so the enzymes present can work on the extra sugars extracted from the grains (Casey, 2020). The sugars extracted are long starch molecules known as amylose or amylopectin, which are to be hydrolyzed by the enzymes present in the mash.

Amylose is a long straight chain carbohydrate formed by alpha 1-6 linkages of the glucose molecules and amylopectin is amylose chains connected by a branching alpha 1-4 linkage. These starch molecules can be broken down by the enzymes present in the malted barley into smaller molecules such as maltotriose (three glucose molecules linked together), maltose (two glucose molecules linked together), and glucose. To form these sugars, the amylose and amylopectin must be broken down by alpha and beta-amylase throughout the mash. To facilitate this hydrolysis of starch by the alpha and beta amylases, the mash must be performed within the saccharification range of 64°C to 72°C (Green, 2018). This range is considered the optimal range for the amylase to perform its action. Yu et al. (2018) saw in their study that amylose and amylopectin contribute most to the total fermentable content of the wort in maltose and maltotriose production through enzymatic hydrolysis. This contribution to the wort is significant when looking at continuous fermentation maltose is the one sugar that is utilized by yeast during fermentation at all times (Smogrovicova et al., 2001). The creation of a wort that is ideal for the yeast to ferment is an essential aspect of brewing and is the goal of the mash. So that during subsequent fermentation the fermentable sugar content can be converted into ethanol and carbon dioxide. A combination of mash temperature and enzymatic action are two key factors that influence the amount of maltose produced during mashing and if yeast can utilize the sugar (Fox et al., 2019).

The utilization of rice is dependent on both its physicochemical structure and how it is incorporated into the mash. The physicochemical structure can be affected by post-harvest handling of the rice specifically the drying method to which it is subjected. There has been little research into how microwave drying impact amylose and other quality characteristics. These characteristics such as total protein and amylose content, post milling can impact how the rice can be gelatinized, and its impact on the nutrient content of the wort.

Methods

In this study, four different drying methods were evaluated to determine the effects of each on the physicochemical properties of rice that directly affect the rice brewing process.

Experimental Design

The experiments were performed in two sets as mentioned in Table 1. The first set is the drying experiments and the second is the brewing experiments. The first set experimental design aimed to mimic the drying procedures for high moisture rice of commercial systems, which uses multi-pass drying and tempering (Shafiekhani, 2020). Four drying treatments, with drying treatment and replication as independent variables while amylose and protein content as dependent variables were tested.

The second set of experiments used the head rice obtained in the first set of experiments. The dried rice was analyzed for initial gravity, final gravity, alcohol content, and attenuation. All experiments were performed in a complete randomized design.

Table 1. Experimental design for drying and brewing experiments.

Experiment Set	Factor	Levels	Total
Drying	Drying Treatment	25°C, 45°C, 60°C, MW	12
	Replications	1, 2, 3	
Brewing	Brewing Adjunct	Dried rice (25°C, 45°C, 60°C, MW) & All Malt	10
	Replications	1, 2	

This study was designed to evaluate how different drying processes can affect the physicochemical characteristics of rice commonly used in the brewing process. To limit the threats to internal validity each sample was subjected to processing in the same equipment for each respective test. Each sample was weighed and separated based on which test is being performed and no carry-over of the rice from one test to another occurred. External validity can be threatened by the differences in temperature exposure of rice when removed from storage, milling, and processing. Steps were taken to decrease these threats to validity. When looking at the impact of the environmental changes to the rice whether it was rough or milled, each sample was stored in airtight packages and allowed to equilibrate to room temperature before processing.

Sample Collection and Storage

Newly harvested, long-grain RT 7521 FP rice gathered from Hazen, Arkansas with an initial moisture content of 19.7% (wet basis) was used for this study. The samples were cleaned using dockage equipment (XT4, Carter-Day, Minneapolis, MN, U.S.A). The equipment is a standard laboratory scale, used to separate the rough rice from other debris that can be collected when rice is harvested. Rice was then stored in a laboratory cold room at 4°C until the sample was removed at the beginning of the experiments. When the rice was removed, it was allowed to equilibrate in an airtight bag, the initial moisture content was taken using a single kernel moisture content meter (CTR-800A, Shizuoka Seiki Co, Japan), a representive average of rough rice kernels was taken from each drying expirments. All moisture contents were reported on a wet basis.

Drying Treatments

The rice was then be subjugated to four separate drying treatments one EMC (25°C) chamber (natural air) with conditions of 25°C and 56% RH (relative humidity), two-pass hot air treatment one at 45°C and 20% RH, two-pass hot air treatment at 60°C and 20% RH, and continuous microwave treatment at a power of 5 kW and resulting specific energy of 535 kJ/kg. Each method was performed with 2 kg triplicates, where each test was run consecutively. For the EMC chamber, rice was placed then allowed to dry to the desired MC of 12.5% (w. b.). Hot air treatments were performed in a controlled environment chamber (ESPEC, Hudsonville, MI.). Rice was subjugated to two-pass drying with four hours of tempering at the same temperature of the hot air used to dry the sample. Microwave drying occurred in a continuous single-pass drying, where continuous refers to the belt being run that exposes the rice to the specific energy for a set duration. The 2 kg sample was spread on the belt of the microwave at a thickness of 0.03 m and exposed for a drying duration of 210 seconds. After the drying pass, the rice was placed in glass tempering jars and tempered for four hours at 60°C. After the final tempering pass for both the microwave and high temperature hot air-drying treatments, samples were transferred to the EMC chamber to condition to the final MC of 12.5% (wb).

Rice Dehulling and Milling

After the rough rice is conditioned down to 12.5% MC in the EMC chamber, a 150g sample of the rice was removed to be dehulled and milled. The rough rice was dehulled using a laboratory sheller (THU 35B, Satake Engineering Co., Tokyo Japan) with a clearance of 0.48 mm between the rollers. The dehulled brown rice was then milled (McGill No. 2. RAPSCO, Brookshire, TX) for a set duration for each drying technique. The duration was determined by creating a standard curve for the surface lipid content (SLC), to ensure all samples are milled to the standard of 0.4% SLC. Milled rice was separated into head rice and broken heads using a sizing device (Model 61, Grain Machinery Manufacturing Corp., Miami, FL).

Total Protein and Nitrogen Content Analysis

Nitrogen and total protein content were determined through the combustion method derived from the Dumas method. A software-controlled Fissions NA2000 Nitrogen/Protein Analyzer (Manchester, U.K.) according to the manufacturer's instructions was used. Rice flour was ground and passed through a No. 20 sieve. The rice flour was subjugated to combustion at high temperature to convert the nitrogen atoms into diatomic nitrogen which is measured by gas chromatography using a thermal conductivity detector. The nitrogen was then converted to equivalent protein by an appropriate numerical factor.

Amylose Content Analysis

Amylose content was determined by the simplified iodine assay method (Juliano, 1971). Approximately 100 mg of rice flour were transferred into a 50 mL test tube where 1 ml of 95% ethanol and 9 mL of 1 N NaOH were added. The sample was then heated for 20 minutes in a boiling water bath. After cooling, the content was transferred into a 100 mL volumetric flask and the volume made up to 100 mL. A 5 mL aliquot was pipetted from the 100 mL solution into a disposable test tube, and 0.1 mL of 1 N acetic acid and 0.25 mL of iodine solution were added. The mixture was stirred and allowed to incubate for 30 minutes, and the absorbance was read at 620 nm. The amylose content of the sample was determined about a standard curve and expressed on a percentage basis.

Brewing Process and Fermentation

Rice was subjugated to an infusion mash for each drying treatment, the infusion mash consisted of a 15% rice and 85% 2-row malt for a 50 g grain bill. The rice flour at a weight of 7.5 g was gelatinized with 2.5 g malt with 100 mL of boiling distilled water. The rice malt solution was allowed to soak with boiling tap water for 30 min to let the rice starch fully gelatinize. The solution was held at 65°C before being transferred into the main mash. The main mash was brought up to 65°C at a volume of 150 mL, once the striking temperature was reached 40 g malt, and rice solution (10 g/100 ml) was added. Extra 50 ml of water was added to bring the final volume of 300 ml. Once the final volume was reached, magnetic stirrers were added to stir the grain additions and held at a constant rate of 260 RPMs to agitate the grains throughout the mash. The mash profile was 65°C for 45 minutes, then a ramp of 72°C for 10 minutes, and held for a final rest at 72°C for 10 minutes. After the final rest was completed, the wort was cooled to 20°C then filtered to remove the spent grains. Filtered wort was transferred to a fermentation vessel, 0.25 g lager yeast (L28, Urkel, Imperial Yeast, Philadelphia, PA) pitched and allowed to ferment over 4 weeks. Original gravity (OG) was taken before yeast pitch was taken using a refractometer (ATAGO, Bellevue, WA). The final gravity (FG) through the use of a refractometer (ATAGO, Bellevue, WA) was taken upon completion of the four-week fermentation period.

Data Analysis

Data were analyzed for analysis of variance (ANOVA) using JMP Pro 16 a statistical software (JMP Pro 16, SAS Institute, Cary, NC) with complete randomization. ANOVA was done to see any effect of drying treatment and replications on rice physicochemical properties (protein and amylose content) and rice brewing quality (initial & final gravity, alcohol content, and attenuation). Tukey's HSD method was used to compare the levels of each factor. The level of significance was fixed at 95%.

Results

Effects of Rice Drying in Physicochemical Properties

The total protein analysis and amylose analysis showed statistical significance across drying treatments (p=0.0421) and (p=0.0425) respectively seen in Table 2.

Table 2. Analysis of variance results with drying treatment and replication as factors and protein and amylose content as response variables.

Factor	Levels	Protein Content *p*-value	Amylose Content *p*-value

Drying Treatment	25°C 45°C 60°C MW	0.0421*	0.0425*
Replication	1 2 3	0.4219	0.6967

*Statistical significance at α=0.05

There was a significant difference in the amylose content of the rice between the 25°C chamber treatment and the 60°C hot air treatment as seen in Figure 1. A significant difference between the protein content of the 60°C hot air-dried rice and the MW dried rice as seen in Figure 2. MW dried rice showed similar protein and amylose content as gently dried rice. The results indicate that the MW dried rice has similar physicochemical properties to gently dried rice.

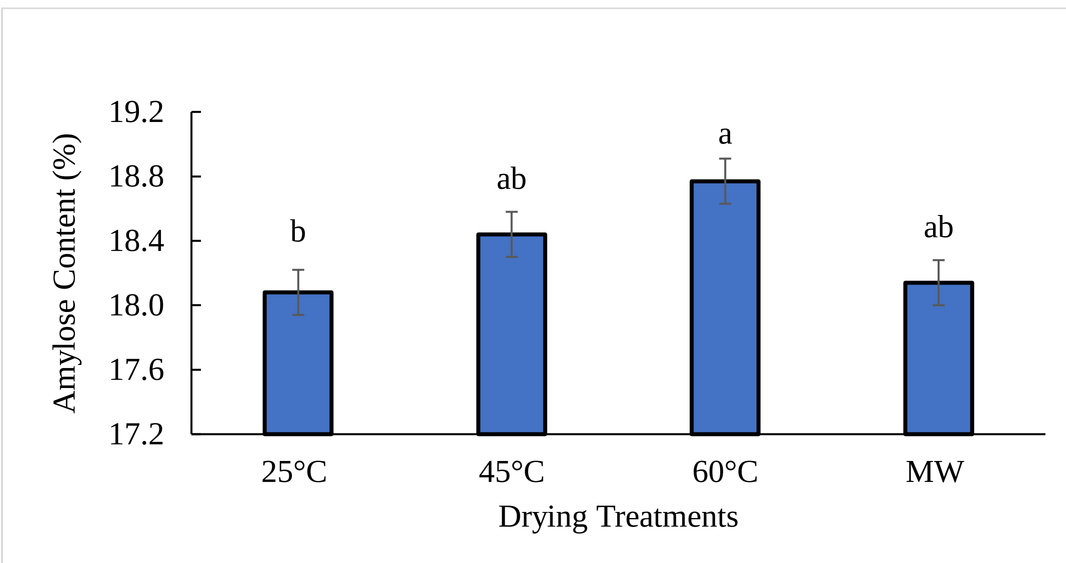

Figure 1. Comparison of the mean amylose content and standard deviations of dried rice using different drying treatments. Letters a and b signify the statistical difference between different drying treatments.

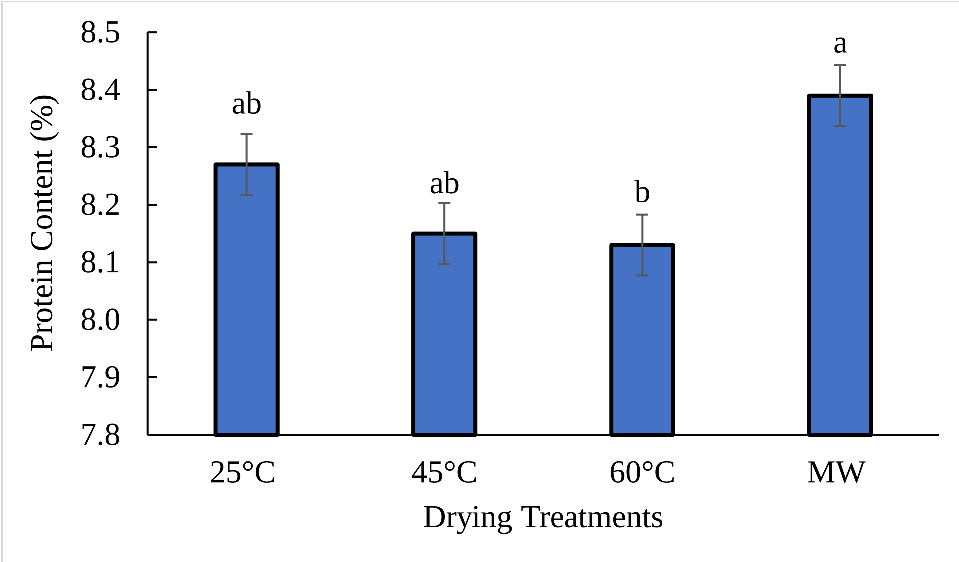

Figure 2. Comparison of the mean protein content and standard deviations of dried rice using different drying treatments. Letters a and b signify the statistical difference between different drying treatments.

These results, show the impact of the drying treatments on the rice's structural components in terms of protein content and amylose starch content. These differences likely arose from the required milling duration to achieve the 0.4% SLC of the rice. The rice subjugated to the hot air treatments required a longer milling duration to achieve the 0.4% SLC compared to the 25°C and MW treatments as seen in Table 3.

Table 3. Milling Duration required to achieve 0.4% SLC for respective drying treatments.

Drying Treatment	Milling Duration (s)
25°C	16.3
45°C	16.9
60°C	18.8
MW	14.0

This longer duration is inferred to have removed a greater portion of the protein content in the bran which resulted in a higher amylose content to be observed as part of the inverse protein amylose relationship.

All rice used in the experiment was analyzed at 0.4% SLC, a degree of milling also known as the extent of the bran removal from the brown rice (Hardke, 2013). The SLC was measured using the rapid method of near-infrared (NIR) spectroscopy. In the study, individual SLC curves were calculated for each treatment. Figure 3 – 6 show the surface lipid content milling cure and required milling duration with a polynomial curve trendline to the third order.

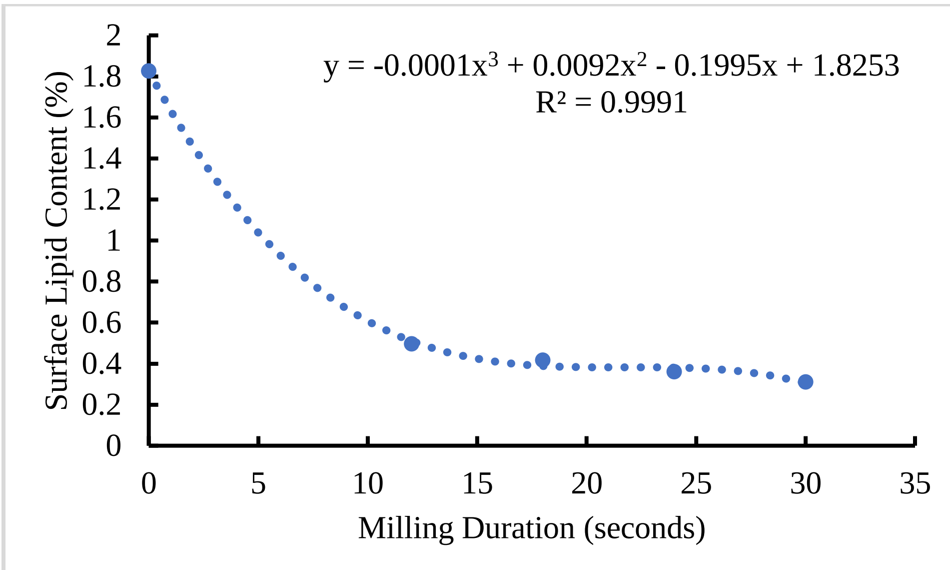

Figure 3: Surface lipid content calculation of rice dried 25°C ambient air. Trendline generated using a polynomial line to the third order.

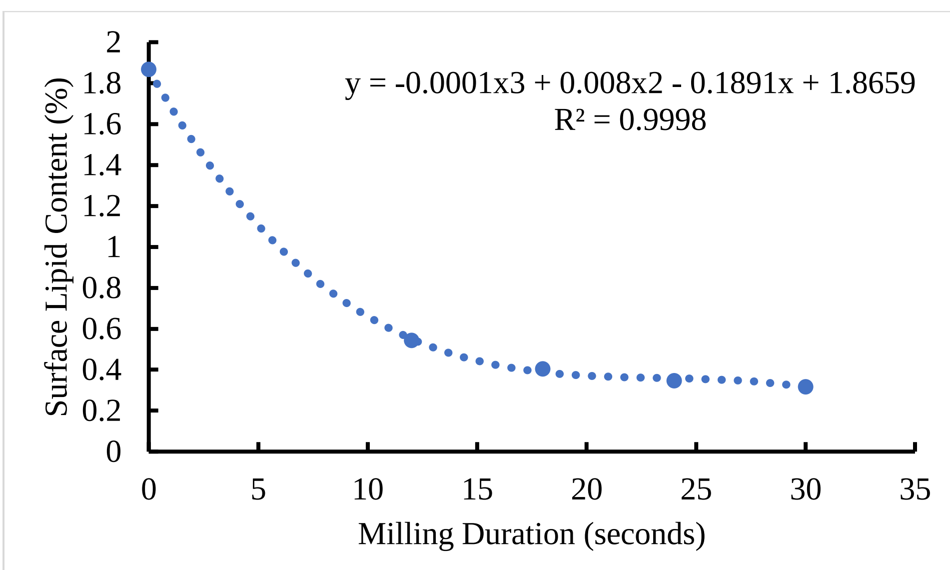

Figure 4: Surface lipid content calclulation of rice dried at 45°C hot air. Trendline generated using a polynomial line to the third order.

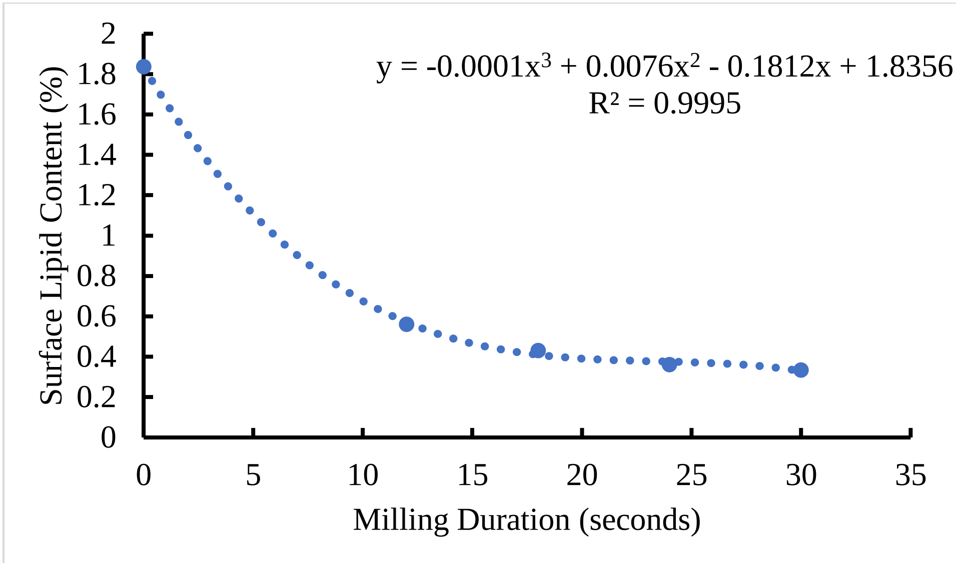

Figure 5: Surface lipid content calclulation of rice dried at 60°C hot air. Trendline generated using a polynomial line to the third order.

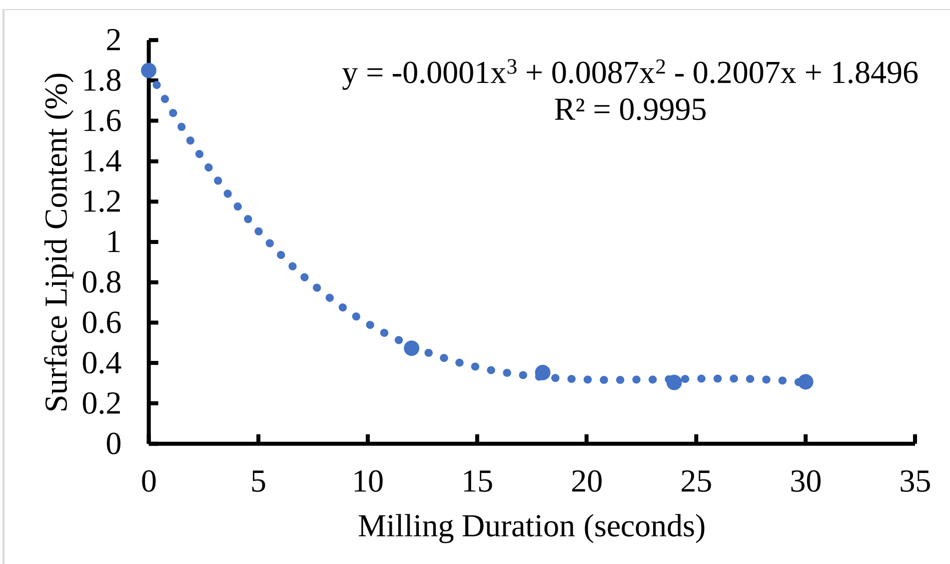

Figure 6: Surface lipid content calclulation of rice dried using continuous one-pass microwave drying at 525 kJ kg^{-1} hot air. Trendline generated using a polynomial line to the third order.

It was observed that the milling duration to achieve the same SLC, increased across the hot air-drying treatments compared to the 25°C and MW treatments. More milling duration means more energy and cost, thus, the hot-air drying, milling process can be costlier than other processes.

SLC is a measurement of the amount of lipids present on the surface of a rice kernel. Based on the results in Table 3 and Figures 1 and 2. There is lower protein content and higher amylose content for the drying treatments requiring a longer milling duration seen in 45°C C and 60°C treatment. This would indicate that a longer milling duration will remove a larger proportion of the protein present in the bran. The results gathered follow the trend of the inverse relationship between protein and amylose as less protein would lead to higher amylose present in the rice kernel (Bao et al., 2020)

Effects of Dried Rice Adjunct Sample on Brewing Process

In the brewing process initial gravity, final gravity, alcohol content, and attenuation were analyzed. All-malt sample, based on initial gravity and alcohol by volume results, was statistically different from the other four samples having dried rice as an adjunct. These four samples involved using rice at 15% of the grain bill from each respective drying treatment. All-malt sample used an all-malt grain bill as a control to measure how the yeast performed. The initial gravity across all treatments showed statistical significance (p=0.0197) as seen in Table 4.

Table 4. Comparative analysis of rice's impact in the brewing process.

Factor	**Levels**	**Initial Gravity *p*-value**	**Final Gravity *p*-value**	**Alcohol Content *p*-value**	**Attenuation *p*-value**
Brewing Adjunct	25°C 45°C 60°C MW All Malt	0.0197*	0.3431	0.1790	0.4156

Replication	1 2	0.7436	0.2998	0.9149	0.4142

*Statistical Significance at α=0.05

The all-malt treatment initial gravity was significantly different from all adjunct rice utilized brewing which was to be expected and can be observed in Figure 7.

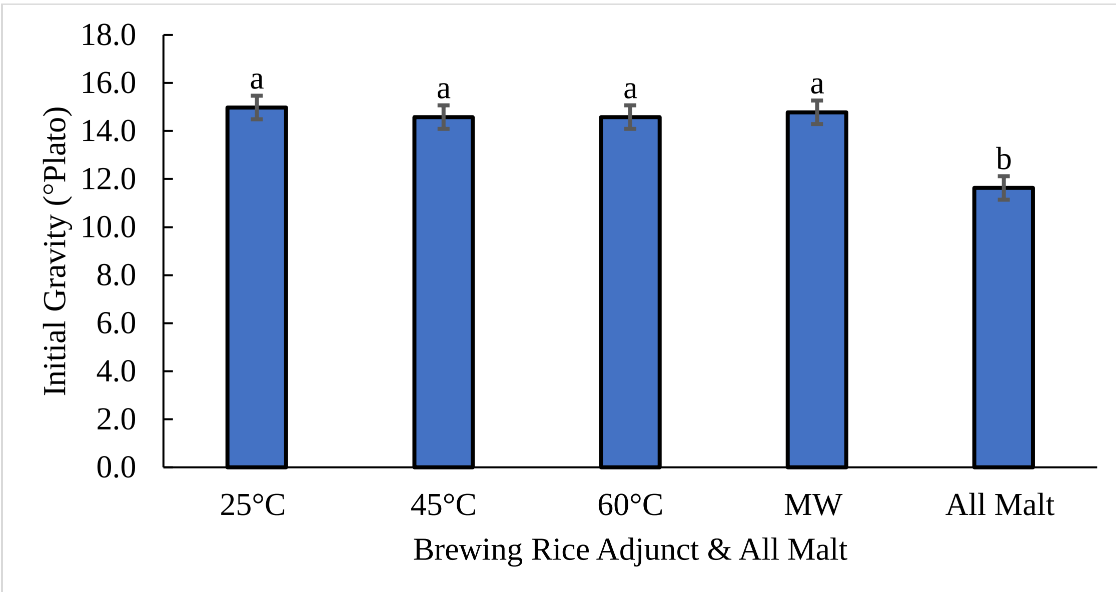

Figure 7. Resulting initial gravity of wort prior to fermentation.

The final gravity was not significantly different across all adjuncts and all-malt samples as seen in Figure 8. The attenuation of all brewing treatments was also similar across all treatments seen in Figure 9. Meaning that the yeast performed similarly across all treatments and fermented till there was a limiting factor present or no more fermentable sugars available. The alcohol content did show significant differences across treatments, with all-malt treatment having the lowest as seen in Figure 10.

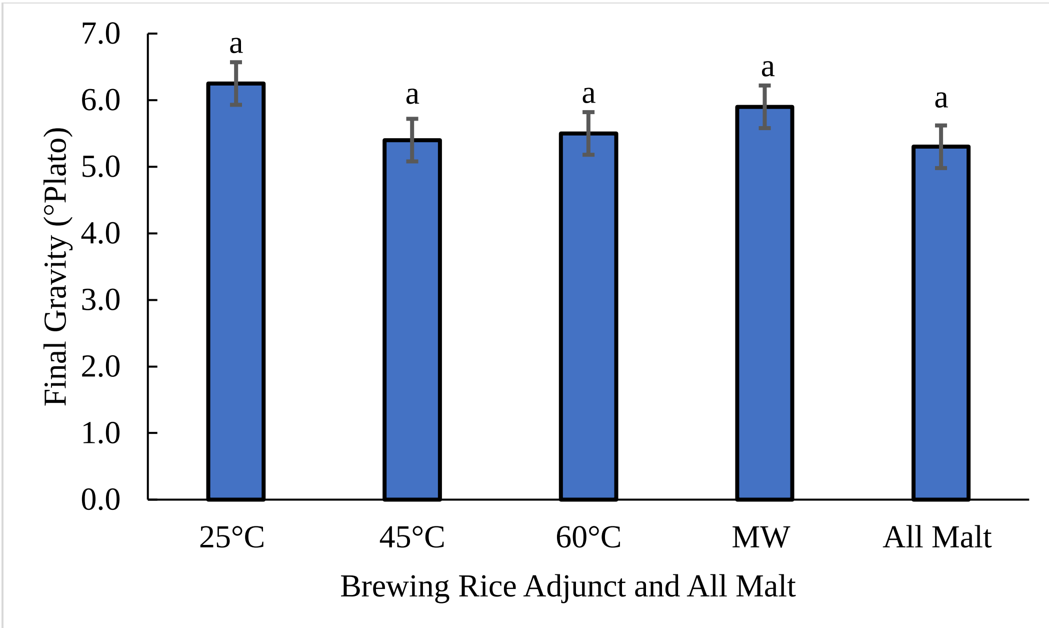

Figure 8. Final gravity of wort post 4 week fermentation period.

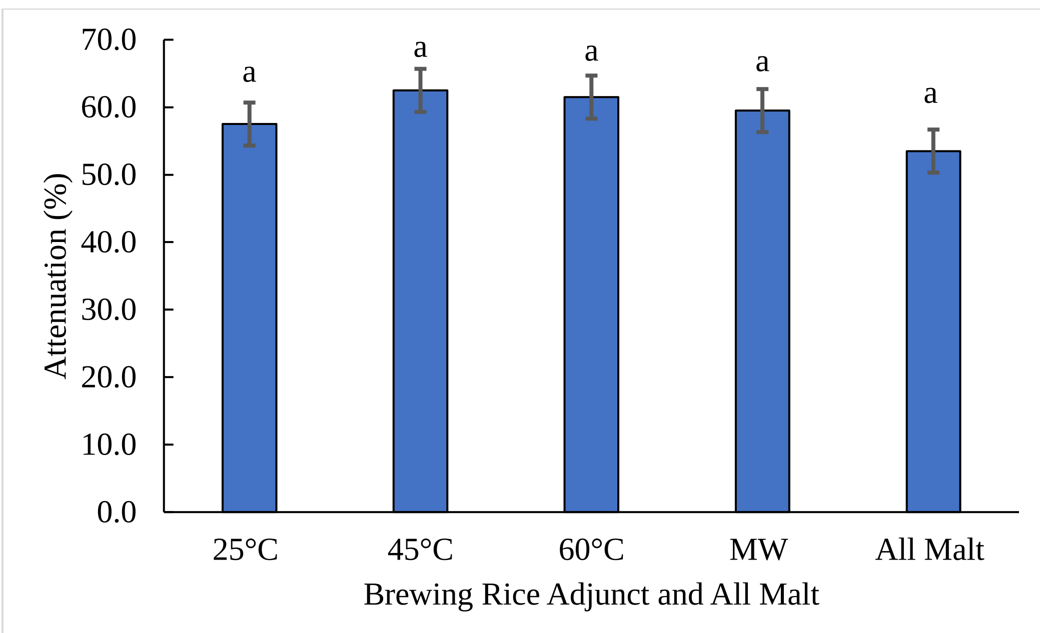

Figure 9. Apparent attenuation of wort by lager yeast.

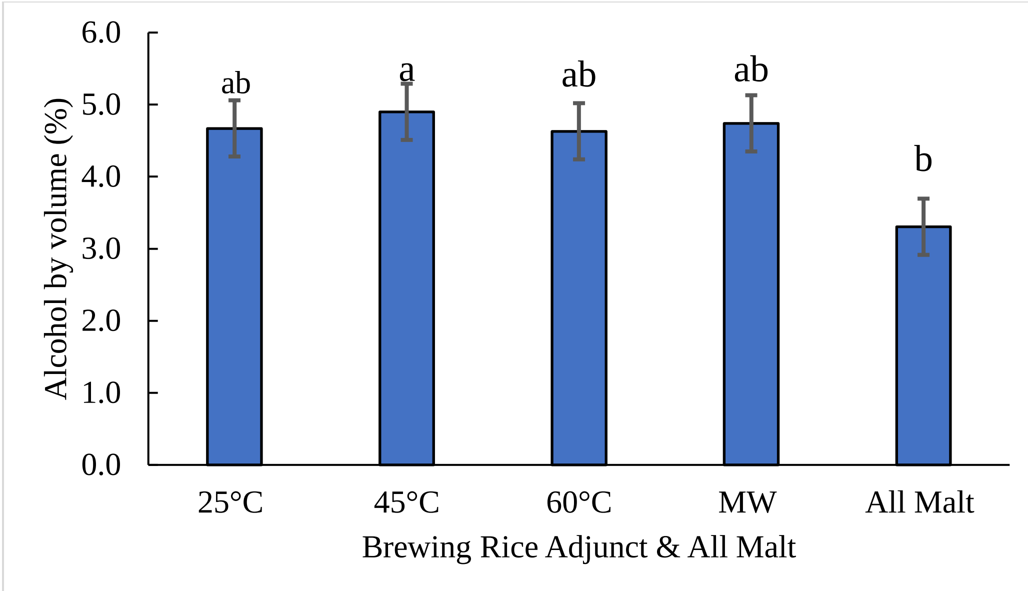

Figure 10. Resulting alcohol by volume content post-fermentation.

The brewing process looked into how a rice's structural components could affect its physicochemical characteristics and its utilization in the brewing process. Before rice can be utilized in the brewing process it must be subjugated to a rice cooker in which it is gelatinized, the process in which the starch granules swell, and the leaching of amylose and amylopectin occurs (Sun et al., 2005). Even though all brewing treatments with rice as an adjunct was subjugated to the same gelatinization process, rice protein and amylose content varied with the treatments. The protein and amylose can directly affect a rice's ability to be gelatinized as the protein content of the rice is negatively correlated with the peak viscosity of starch gelatinization while positively correlated with the gelatinization temperature (Wang et al., 2020). Meaning that the higher the protein content the harder the starch granules have at taking in the water and leaching the starch present into the wort. With each treatment receiving the same rice gelatinization process we observe how the protein amylose relationship affects the subsequent initial gravity after addition to the main mash. The amylolytic action by the alpha and beta amylases present cleave the available starch content present in the mash into fermentable sugars.

The amount of fermentable sugars present was then measured by a refractometer that showed the relative density of the solution correlating to the amount of sugar present.

The resulting attenuation of the yeast was slightly lower for the 25°C and MW drying treatments than that of the hot air treatments. Meaning that the yeast was better suited to consume the sugars present in the hot air treatments compared to the 25°C and MW. This could be caused by the fact that the hot air treatments had a lower protein content when compared to the 25°C and MW rice. In turn could have affected from the greater concentration of protein acting as a barrier to the for the starch leaching and swelling ability of the starch (Lin et al., 2022). The amount of starch that was able to be leached and then cleaved by the amylases into favorable sugars such as maltriose, maltose, and glucose. This can be correlated with that all treatments involving rice were considered high gravity worts with a gravity in the range of 13-18°Plato. There was no significant difference across attenuation meaning no wort had less of a limiting factor present in the wort than others. Limiting factors are considered nutrients available to the wort such as nitrogen or oxygen. With the attenuation being similar across all treatments, oxygen is considered to be the limiting factor on yeast performance as the wort was not aerated due to the chance of microbial contamination. This was because of the brewing process being performed at a lab scale. So, in the terms of attenuation, there were more available simple sugars that the yeast could easily consume in the hot air treatment compared to the MW and 25°C treatments.

Conclusions

Rice production has risen over the past years and with it, research into a way of providing more efficient drying methods has also increased. One industry that will be significantly impacted by new drying methods will be the brewing industry, more specifically the craft brewing industry that utilizes full head rice. Not many studies have evaluated the effects of rice drying treatment on brewing process. This study aimed to understand the use of different drying treatment effects on rice physicochemical properties and brewing performance. Rough rice samples with an initial moisture content of 19.7% wet basis were dried in a microwave drier with a 525 kJ/kg energy output in a single drying run. The effects of single-pass continuous drying on dried rice amylose content, protein content, and wort specific gravity were investigated. The results were compared to samples dried in natural air at 25°C with 56 percent relative humidity (RH), as well as two-pass heated-air drying at 45°C and 60°C with 20 percent RH. Microwave dried and gently dried samples showed similar results for all the properties. These properties, on the other hand, were considerably different for MW samples from those of samples dried at a higher temperature of 60°C and a lower RH of 20%. The initial gravity content of all-malt samples and rice adjunct samples differed significantly ($p = 0.0197$), as expected, although there was no significant difference between the rice adjunct samples. Overall, the drying procedures investigated caused variations in the rice's physicochemical attributes, but no substantial variances in the wort's initial gravity contents. Microwave drying was shown to be most comparable to natural air drying in terms of rice processing and subsequent use in the brewing process in this study.

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