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Impacts of Size Fractionation and Processing on Functional Characteristics of Broken Rice Kernels

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Impacts of Size Fractionation and Processing on Functional Characteristics of Broken Rice Kernels

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by

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Abstract

Rice flour generated from broken rice (brokens) has inconsistencies in functional properties. This may be due to differences in size and composition of brokens used for the flour. It is postulated that size classification of brokens can improve flour functionality. This study sought to investigate the effect of size fractionation of brokens on the functional or pasting properties of resulting rice flour. Broken rice was generated from six cultivars of freshly harvested rough rice that were dried at 25°C in the laboratory. The brokens were classified into large, medium and small, using US sieve size 10, 12 and 20 respectively. Comingling of the brokens based on size was done. Pasting properties of broken rice flour were analyzed. Results indicate that, larger brokens had better pasting properties than smaller brokens. Size and cultivar of brokens had significant impacts on protein content, peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity and peak time of brokens. Rice aging influences pasting property. The moisture content (MC) of rice before parboiling affects the pasting property of the parboiled broken rice flour, thus rice parboiled at 12.5% MC (aged rice) had higher peak viscosity and final viscosity than rice parboiled at 18% MC (fresh rice). Size fractionation of brokens is essential in understanding the functionality of brokens to produce premium and high-quality products.

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I. INTRODUCTION

At present, there is a rise in the demand of brokens for various uses ranging from flour manufacturing, beer brewing, starch and pet food production. In part, the demand is attributed to market trends leaning to favor gluten-free products, of which rice has become a major player. In the United States, most of the rice flour is produced from brokens; some companies have also started to use flour from brokens to extrude rice-like pellets. Typically, the brokens used as feedstock in these processes consist of different degrees of breakage, thus differences in sizes and in most cases, are from a comingled rice lot comprising of several cultivars. This results in inconsistencies in the characteristics of brokens used as feedstock during processing and affects the quality of processed products. However, despite the increasing demand for brokens, there is not enough study to clarify how characteristics of brokens, such as size, mass fraction/proportion, rice cultivar and prior treatments such as drying temperature affect the functionality of the flour produced from the brokens.

This study was an assessment of the pasting characteristics of size fractionated industrial parboiled and non-parboiled broken rice. The specific objectives were to investigate the effect of size characterization of brokens on pasting properties of parboiled and regular broken rice, to determine the implications of comingling brokens of different sizes on pasting properties, and to study the effect of MC before parboiling on the pasting property of parboiled brokens. The research then gives an insight of the factors that influence the inconsistencies in the functionalities of the brokens and helps their prediction and channeling the right types of brokens to the right end use.

II. ASSESSMENT OF PASTING CHARACTERISTICS OF SIZE FRACTIONATED INDUSTRIAL PARBOILED AND NON-PARBOILED BROKEN RICE

A. ABSTRACT

Background and objectives: Rice flour generated from broken rice (brokens) has inconsistencies in functional properties. This may be due to differences in size and composition of brokens used for the flour. It is postulated that size classification of brokens can improve flour functionality. Parboiled brokens generated at 12.5% (aged rice) and 18% (fresh rice) moisture content (MC, wet basis) and non-parboiled (regular) brokens were obtained from commercial milling streams. Broken rice was also generated from six cultivars (2 long-grain pureline, 2 long-grain hybrids, and 2 medium-grain) of freshly harvested rough rice that were dried at 25˚C in the laboratory. The brokens were classified into large, medium and small, using US sieve size 10, 12 and 20 respectively. Comingling of the brokens based on size was done. Pasting property of the broken rice flour was determined using the Rapid Visco Analyzer.

Findings: The results indicate that the MC of rice before parboiling affects the pasting property of the parboiled broken rice flour, thus rice parboiled at 12.5% MC (aged rice) had higher peak viscosity and final viscosity than rice parboiled at 18% MC (fresh rice). Larger brokens had better pasting properties than smaller brokens. Smaller brokens had higher protein content than large brokens. Whole kernels had higher peak and final viscosities than brokens across all cultivars. These differences may be due to variations in starch distributions across the rice kernel. Comingling of large and small brokens produced flour that has pasting property like either the medium or small brokens.

Conclusions: Size classification of brokens is important in maintaining consistency in the pasting properties of the broken rice flour and resulting products.

Significance and novelty: Size fractionation of brokens provides the opportunity to better understand the functionality of brokens, to direct them to the right end-use processes and to maximize the potential of this by-product in producing premium and high-quality products.

Keywords: Brokens, comingling, functional properties, pasting property, parboiled rice, regular rice.

B. INTRODUCTION

Broken rice (brokens) are rice fragments that are less than 75% of the length of whole kernels (USDA 2009). Brokens are one of the most important by-products of the rice milling process (Mhalaskar et al. 2017). They are a result of many factors such as degree of milling, rapid moisture absorption of rice in the field, rapid drying, chalkiness, immature kernels and other environmental factors such as relative humidity (RH) and temperature changes as well as insect infestation (Siebenmorgen et al. 1998). Brokens are less profitable because they cost 40-30% less than the price of whole kernels (USDA, 2018). They are characteristically inexpensive (Mhalaskar et al. 2017), undesirable, inevitable in the milling process and affect rice end-use functionalities. Globally, medium and large mills generate about 10% to 15% brokens during milling (Muthayya et al. 2014). Local mills that use old machinery and technologies produce about 23% to 25% brokens (Muthayya et al. 2014). Broken rice production is affected by factors such as cultivar, mill type, degree of milling, cultural practices, rice growing conditions, environmental factors, and handling especially pre-milling practices. The US largest rice producing state, Arkansas produces about 5,350,198 MT of paddy rice annually (USDA 2017). An estimated annual broken rice production based on a head rice yield of 60% which generates about 10% brokens yields approximately 535,019.8 MT of brokens in Arkansas. From a national or global perspective, there is a huge supply of broken rice which can be exploited to benefit the rice industry.

Parboiling is another rice processing method. It is a hydrothermal process which involves soaking, steaming and drying of rice kernels before milling (Elbert et al. 2001). During this process, the rough rice is soaked in excess water to a final MC of 25-35% (Bhattacharya 1985). The rice is then steamed at 100-130 °C and dried to approximately 12% MC. The parboiling process gelatinizes starch, causing the starch to expand and fill the fractures in the rice kernel, resulting in a harder kernel which resists breakage during milling (Derycke et al. 2005; Elbert et al. 2001). Under ideal conditions, brokens are not expected to be produced from parboiling streams. However, industrial reports have shown some level of brokens production in parboiling plants. Even though the main reasons for this is not known, paddy rice properties, soaking duration, steam duration and intensity, are some parameters that are likely to affect brokens production in parboiling streams. Parboiled brokens have higher economic value than the regular (non-parboiled) brokens because parboiled rice has been reported to have higher nutritional content (Thiamine, nicotinic acid, phosphate) than regular rice (Juliano 1985; Pedersen et al. 1989; Amato et al. 2002). Parboiled brokens also have a different usage because they differ in functionality from the regular brokens. Brokens from parboiling streams can be obtained from two processing scenarios. The first is parboiled brokens from high moisture fresh rice that was obtained from the farm and immediately parboiled. The other processing scenario is parboiled brokens that were obtained from rice that has been dried to about 12.5% MC and stored for some months before parboiling. It is therefore hypothesized that brokens from fresh rice before parboiling and aged rice before parboiling are likely to have different pasting properties since aging in regular rice have been shown to produce some changes in the peak and final viscosities of rice (Guo et al. 2015).

The current use of brokens in the industry is diverse. For instance, brokens are used in the beauty and cosmetic industries for skin brightening creams. In textile industries, starch obtained from brokens are used for stiffening cloth. They are also applicable in the manufacture of pet foods, a wide variety of foods, biodegradable or edible films (Dias et al. 2010) and edible cutlery. Extrusion is the most popular method of processing brokens in the food industry. The brokens are ground into flour and extruded into many products such as extruded rice pellets, pastas, breakfast cereals, etc. Rice flour production is a growing market and the demand keeps increasing because rice serves as a natural gluten free crop that is being used as a replacement in the diets of patients battling with celiac disease. Celiac disease is an auto-immune disease whereby the patient's system reacts to gluten (a protein present in wheat, barley and rye) causing intestinal damage (Green and Cellier 2007).

An interesting aspect of the rice kernel is that it is not uniform in its composition and properties across the length of the kernel **(**Mukhopadhyay and Siebenmorgen 2017**)**. Because of this, brokens are likely to have different physical and functional properties based on the position of the rice kernel the brokens occurred, and the size of the brokens. Therefore, when brokens are obtained from milling streams for rice flour, the functionality of the flour will depend on how the different sizes of brokens are combined. In the United States, brokens are used for rice flour and these brokens consist of different degrees of breakage (differ in sizes). Because of the comingling practices of many milling streams, the resulting brokens are also a mixture of several cultivars (Moldenhaur et al. 2004). The characteristics of brokens affect the quality of processed products.

In studying the pasting properties of rice, it is relevant to know the protein content of the kernels because generally, protein content affects starch morphology. A study of the impact of proteins on the pasting and cooking properties of rice showed a significant decrease in the peak, breakdown and consistency viscosity values of waxy rice flour treated with a protease. Additionally, increased RVA pasting temperatures, decreased viscosities along all the points of the viscosity curves were observed in non-waxy rice flour that was pre-incubated with a protease (Xie et al. 2008).

Because there is inadequate information on broken rice functionality, the objectives of this study were: (1) to investigate the effect of size characterization of brokens on pasting properties of parboiled and regular broken rice, (2) to determine the implications of comingling brokens of different sizes on pasting properties, and (3) to study the effect of MC before parboiling on the pasting property of parboiled brokens.

C. MATERIALS AND METHODS

Sample Procurement (Industrial Samples)

Parboiled and non-parboiled brokens from commercial mills were procured from Rivianna Foods, Carlisle Arkansas and Riceland, Stuttgart Arkansas respectively. The original rough rice from which the brokens were obtained was also procured. Following procurement, all samples were stored at 4°C in the cold room.

Sample Preparation

Whole Kernels

A sample weighing 8 kg of the rough rice (parboiled and non-parboiled) from which brokens were generated in the industry was removed from cold storage (4˚C) and equilibrated to room temperature (25˚C) for 24 h. The sample was dried to 12.5% MC (wet basis) in a climate-controlled chamber (25˚C, 55% RH) regulated by a standalone air conditioner (5580A, Parameter Generation and Control, Black Mountain, N.C.). In these conditions the one pass drying lasted 2 days. Sub-samples weighing 150 g were then milled using a laboratory mill (McGill Number 2, Rapsco, Brookshire, TX, USA) for 50 s (i.e. surface lipid content standardized at 0.4%). The whole kernels were separated from the brokens using a grain separating device (Grain Machinery Manufacturing Miami, FL, USA).

Brokens

The brokens were fractionated into large, medium and small sizes using a sieve shaker (RX-29, RO-TAP, Mentor, OH, U.S.A), for 15 min with US SIEVE No. 10 (2.00 mm), 12 (1.68 mm) and 20 (0.84 mm) to separate the brokens respectively. The whole kernels, large, medium and small brokens were milled into flour using UDY cyclone sample mill (UDY Corp., Ft. Collins, CO) fitted with a 0.50-mm screen. Pasting property and protein contents were determined. A flowchart of the method is shown in figure 1.

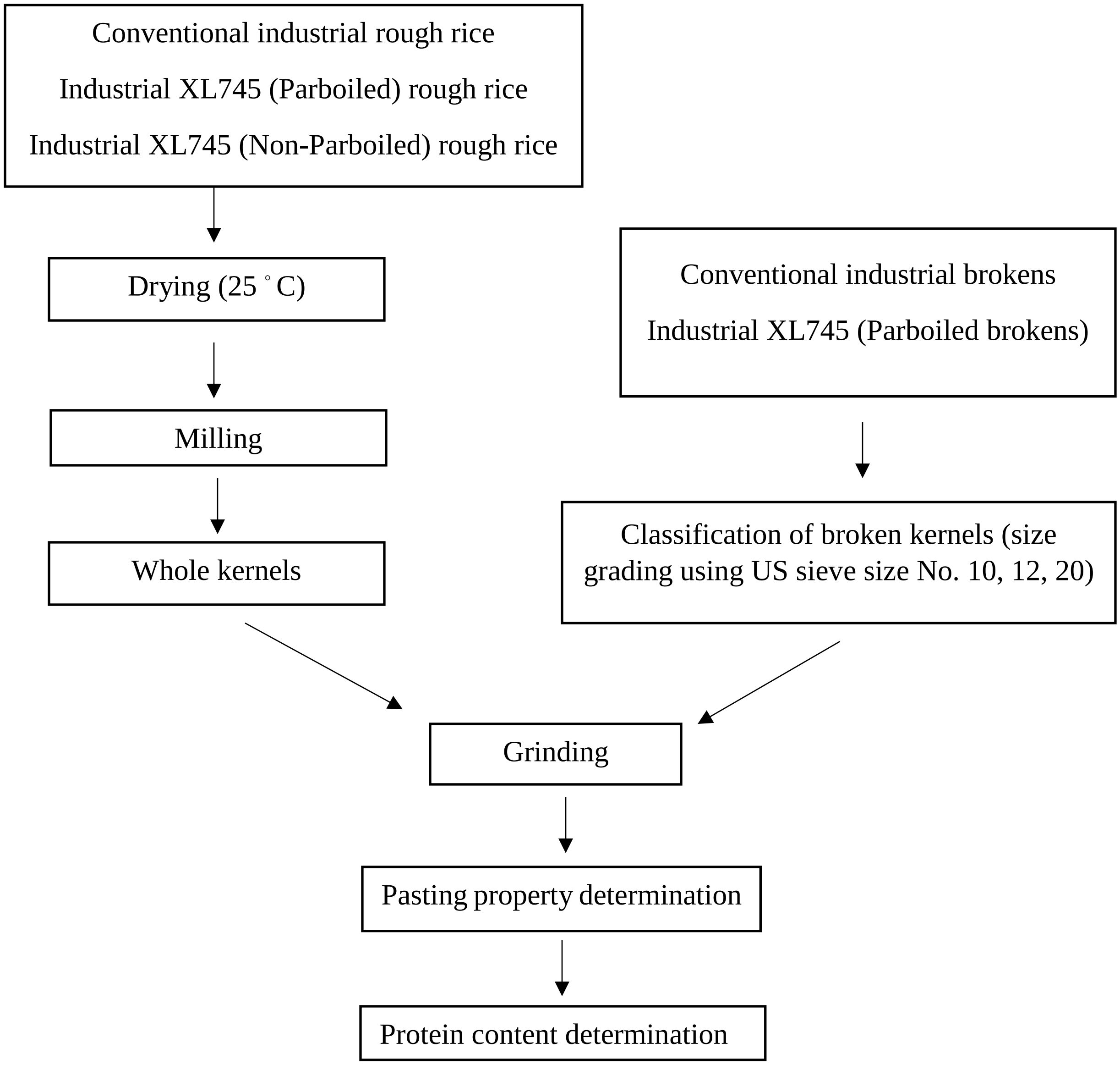

Figure 1. A flowchart of the method

Laboratory Samples

Industrial samples are prone to several variations. Therefore, after analyzing parboiled and non-parboiled broken kernels from commercial rice plants, we generated brokens naturally (no treatment was applied to induce breakage) from 6 cultivars (2 long-grain pure line, 2 long-grain hybrids, and 2 medium-grain). The six freshly harvested rice cultivars (Roy J, Diamond, XL745, XL753, Titan and Jupiter) were procured from the University of Arkansas Division of Agriculture Rice Research Experiment stations and commercial farms in North Eastern Arkansas. These samples were dried, milled, and brokens separated from whole kernels. The brokens were classified. The brokens and whole kernels were ground into flour and pasting properties determined in the same manner as the industrial samples.

Pasting Property Determination

Paste viscosity of the rice flour was determined according to the AACC international approved method 61-02.01. The viscosities were determined on the paste of 3 g rice flour and 25 mL of distilled water with a viscometer (RVA-Super 4, Newport Scientific, Warriewood, NSW, Australia). Flour paste was held at 50˚C for 1.5 min, heated to 95˚C at 12.2˚C /min, held at this temperature for 2 min and then cooled to 50˚C at 12.2˚C /min and held at 50˚C for 1.5 min. The peak viscosity, final viscosity, setback, trough, breakdown viscosity, pasting temperature and peak time were recorded in centipoises (cP).

Protein Content Determination

The Kjeldahl method of protein content determination used includes protein digestion, nitrogen distillation and titration. About 0.50 g of rice flour was placed in a digestion tube. Kjeldahl catalyst tablet (1/2 tablet) was added, followed by 5 mL concentrated sulfuric acid. The digestion tubes were heated for 1.5 h. and cooled to room temperature. The digested samples were quantitatively transferred into a 25-mL volumetric flask and topped up to the 25.0 mL mark with deionized water. The final solution was transferred into 30-mL test tube to be used for nitrogen distillation. The digested sample solution (5.0 mL) was then placed into the distillation chamber

(Labconco Rapid Still Distillation System). A 100 mL beaker containing receiver/boric acid solution (15 mL) was placed at the condenser outlet of the distillation chamber, with the boric acid solution having direct contact with the condenser outlet. Exactly 10 mL 40% alkali solution (NaOH) was added to the sample in the distillation chamber. The distillation process was kept for 5 min after which the beaker was removed from the tip of the condenser outlet and the condensed liquid was drained into the receiver solution for 1 min. The distilled sample was titrated against 0.025 N HCl and the protein content was calculated as N x 5.95.

Statistical Analysis

Pasting properties and protein content of whole kernels and brokens were determined in replicate. Analysis of variance, Tukey's test and Two factor interactions were performed using statistical software (JMP version 13.1.0, SAS Institute, Cary N.C.) to determine significant difference among whole kernels, large, medium and small brokens. Level of significance was set at 5% for mean comparison.

D. RESULTS AND DISCUSSION

Protein Content of Size Fractionated Brokens

The results for this study cover an assessment of the pasting properties of whole kernels and brokens from parboiled (industrial XL745) and non-parboiled streams (conventional industrial rice) streams. The protein contents of conventional industrial rice and aged parboiled rice (industrial XL745) are shown in tables 1 and 2 respectively. Higher protein content was recorded in smaller brokens than larger brokens and whole kernels. In the parboiled stream, parboiled kernels (whole and brokens) have significantly higher protein content than non-parboiled whole kernels (the original rice from which parboiling was done).

Table 1. Protein content of conventional industrial rice (non-parboiling stream)

Sample name	Protein content (%)
Whole kernels	6.42
Large brokens	6.17
Medium brokens	6.66*
Small brokens	6.73*

* Significant at 5% level.

Table 2. Protein content of aged parboiled rice (industrial XL745)

Sample name	Protein content (%)
Non-Parboiled whole kernels	6.55
Parboiled whole kernels	7.0*
Parboiled large brokens	6.78*
Parboiled medium brokens	6.92*
Parboiled small brokens	7.48**

Different symbols are significantly different. Same symbols are not significantly different.

Differences in the protein content of the different sizes of brokens can be attributed to the fact that the rice kernel is non-uniform in its compositions across the kernel (Hamaker 1994; Mukhopadhyay and Siebenmorgen 2017). The tips and the middle portions of the rice kernels are of different compositions. Therefore, the chemical properties of brokens are informed by the degree of size fractionation. Another possible explanation is that higher protein contents have been reported in thinner kernels (Chen et al. 1998; Grigg and Siebenmorgen 2013) which are susceptible in forming various degrees of brokens during milling. Thinner kernels of rice are likely incompletely filled with starch during rice development. The higher protein contents of the smaller brokens is likely to affect their cooking properties because previous studies (Derycke et al. 2005; Hamaker and Griffin 1990 ; Hamaker and Griffin 1993; Martin and Fitzgerald 2002) have shown a decrease in viscosity profiles when rice flour was treated with proteases. Parboiled brokens have distinctive higher protein contents than the non-parboiled. During parboiling, nutrients such as proteins, B-vitamins (thiamine and nicotinic acid) and phosphates migrate from the rice bran to the core of the rice endosperm. The parboiled kernels can retain more nutrients than the non-parboiled kernels, giving parboiled rice some advantage over non-parboiled rice. Parboiled rice has other advantages such as increased head rice yield which is beneficial to the rice grower.

Pasting Properties of Conventional Industrial Rice

The peak and final viscosities of conventional industrial rice are shown in Figures 2 and 3 respectively. Smaller brokens have significantly lower peak and final viscosities than larger brokens and whole kernels. Comingling of large and small brokens in the ratio of 1:1 have peak and final viscosities like that of the small brokens. Smaller brokens have a higher setback viscosity than whole kernels and large brokens (figure 4). The peak and final viscosities decrease significantly with decreasing size of brokens while the setback viscosity decreases with increasing size of the brokens. The brokens have a significantly higher pasting temperature than the whole kernels (table 3; figure 5).

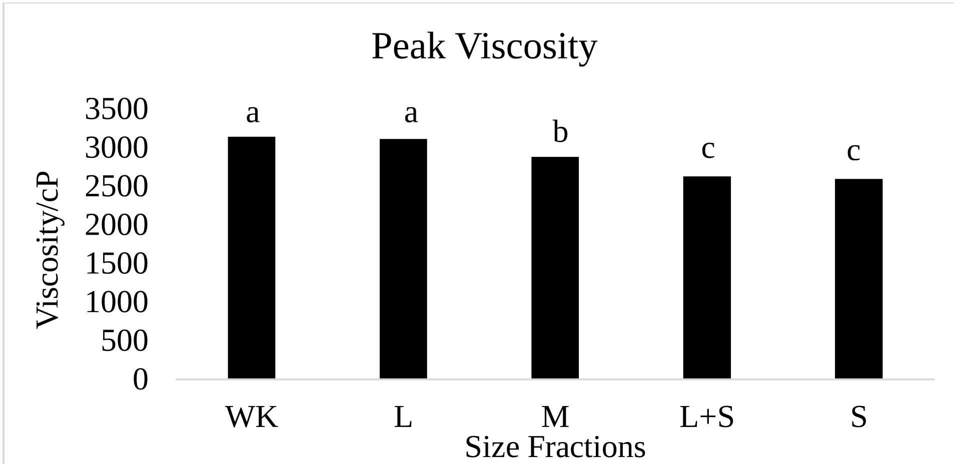

Figure 2. Peak viscosity of size fractionated conventional industrial rice (non-parboiling stream). WK-whole kernels, L- large brokens, M-medium brokens, L+S- a 1:1 mixture of large and small brokens, S-small brokens.

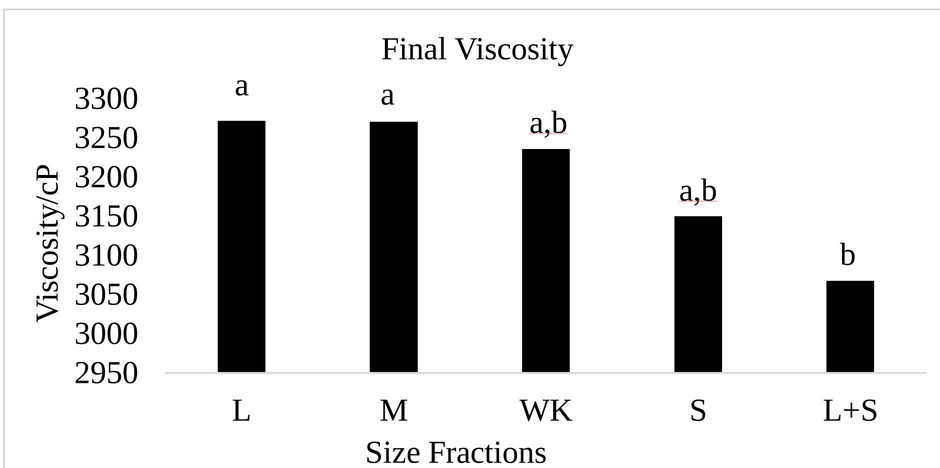

Figure 3. Final viscosity of size fractionated conventional industrial rice (non-parboiling stream). WK-whole kernels, L- large brokens, M-medium brokens, L+S- a 1:1 mixture of large and small brokens, S-small brokens.

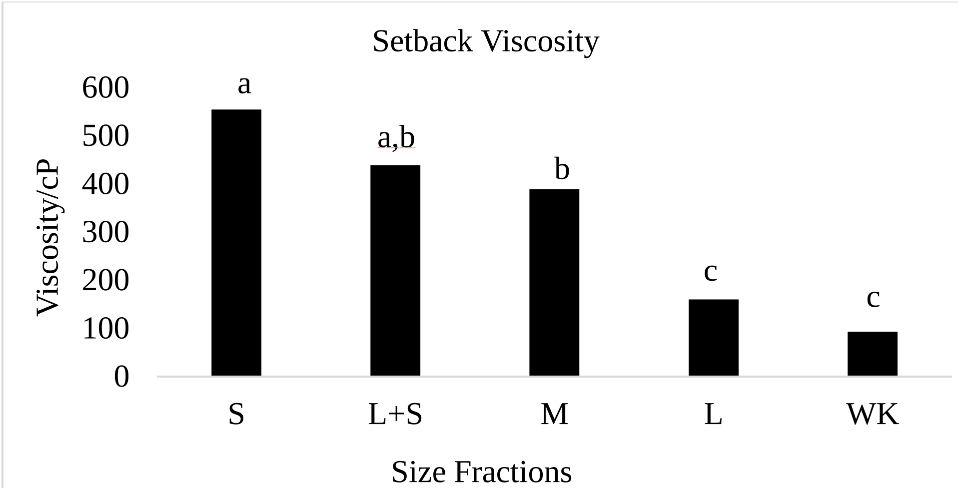

Figure 4. Setback viscosity of size fractionated conventional industrial rice (non-parboiling stream). WK-whole kernels, L- large brokens, M-medium brokens, L+S- a 1:1 mixture of large and small brokens, S-small brokens.

Table 3. P-values and R-square values of the pasting properties of all six laboratory cultivars

Pasting Property	P-values			R-square
	Cultivar	Size	Size*Cultivar	
Peak viscosity	0.00000	0.00000	0.00000	0.993389
Final viscosity	0.00000	0.00000	0.00000	0.993965
Breakdown	0.00000	0.00000	0.00000	0.985947
Setback	0.00000	0.00000	0.00000	0.999584
Pasting temperature	0.00000	0.05194	0.02921	0.952344
Peak time	0.00000	0.00200	0.00000	0.969481
Trough	0.00000	0.00000	0.00000	0.985563

P <0.05 = significant. P > 0.05 = not significant.

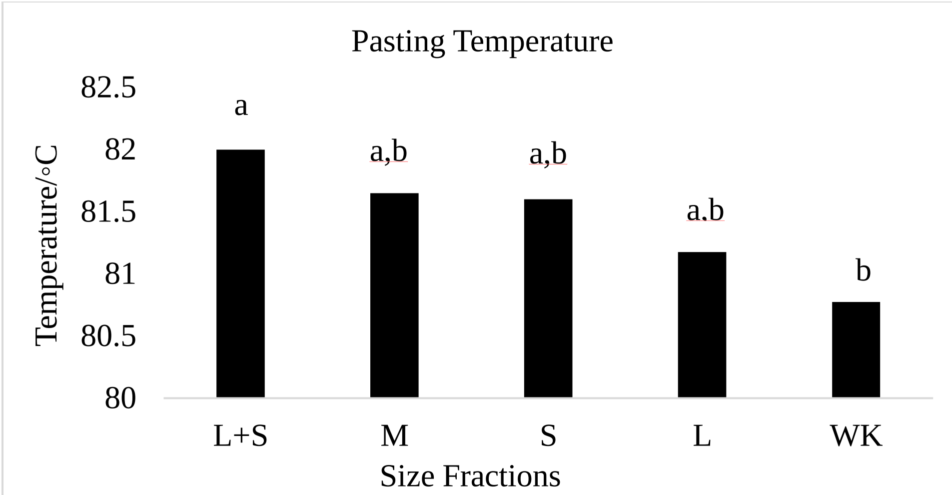

Figure 5. Pasting temperature of size fractionated conventional industrial rice (non-parboiling stream). WK-whole kernels, L- large brokens, M-medium brokens, L+S- a 1:1 mixture of large and small brokens, S-small brokens.

The results above are consistent with the findings of Mukhopadhyay and Siebenmorgen (2017), Wang et al. (2002) and Proctor and Goodman (1985), where brokens were shown to have a lower peak viscosity (PV) and final viscosity (FV) than whole kernels. Mukhopadhyay and Siebenmorgen (2017) in their work on physical and functional characteristics of broken rice kernels caused by moisture adsorption fissuring, did a similar size fractionation of the brokens. However, the brokens used for their study were generated in the laboratory and they were obtained by subjecting the rice to rapid moisture absorption to induce fissures in the kernels. Their reason for the observed low PV and FV in the brokens is that, the positions at which kernels fissure and subsequently break to form brokens dictate the physical characteristics and chemical composition of the brokens. Consequently, this affects the relative amount of starch, protein and lipids in the brokens due to the changes in the surface area/interior ratio. Because of the non-uniform physical and chemical properties of the rice kernel across the length of the kernel, there is therefore inherent differences within brokens which is manifested in the RVA profiles.

Wang et al. (2002) did not perform a size fractionation of brokens. In their work on properties and structures of flour and starches, the brokens used were obtained by subjecting whole kernels to high temperature drying (60°C) followed by low temperature cooling (5°C). Proctor and Goodman (1985) had provided a reason that the low PV and FV observed in brokens may be due to differences in the relative amounts of amylose and amylopectin in head rice and brokens. They also proposed that a protein-phytin complex may be more prominent in broken kernels than head rice. Wang et al. (2002) focused on testing the hypothesis of Proctor and Goodman (1985). Although Wang et al. (2002) did not observe a difference in the relative amounts of amylose and amylopectin in head rice and brokens, it is still possible that there could be a difference when size fractionation is done. This possibility is evident in the observed differences in the setback viscosity (SBV) of the size fractionated brokens in this current study.

It is interesting to note that based on the reviewed literature, brokens have still maintained the trend of having lower PV and FV than whole kernels regardless of the method of brokens formation. It is therefore plausible to attribute the reason for these trends to the inherent properties of the kernel and the non-uniform nature of the chemical composition of the kernel across its length.

Pasting Properties of Industrial Parboiled Rice

The results in this section cover the pasting properties of aged rice before parboiling and non-aged rice (fresh rice) before parboiling. Aged rice refers to rice that has been dried and stored for more than 3 months before parboiling. Fresh rice refers to high moisture rice (18% MC) that was parboiled immediately after harvesting. The peak viscosity of aged and fresh rice (non-aged) from parboiling stream is shown in figure 6. There is no significant difference between the PV of aged non-parboiled whole kernel (aged rice before parboiling) and fresh non-parboiled whole

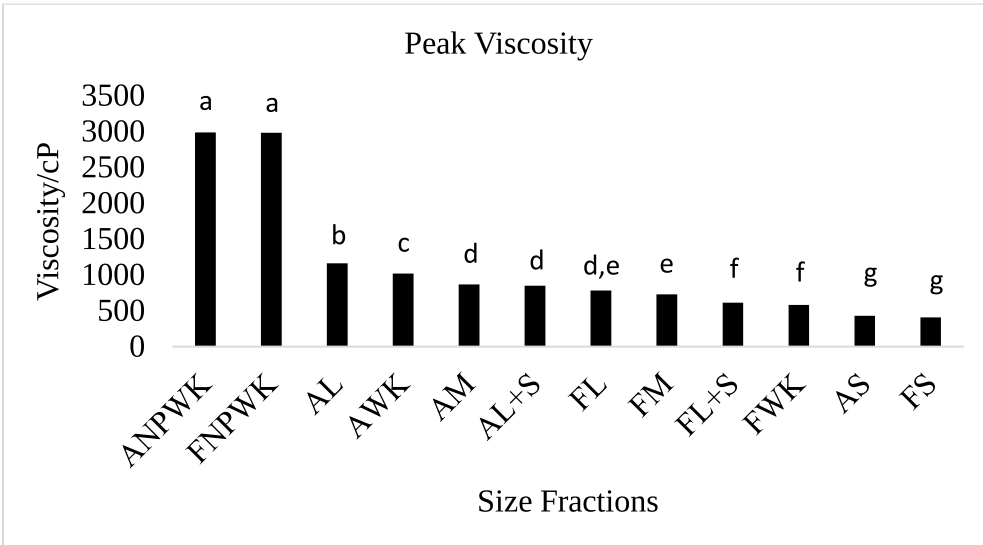

Figure 6. Peak viscosity of aged and fresh rice (non-aged) from parboiling stream. ANPWK- aged non-parboiled whole kernel (aged rice before parboiling), FNPWK- fresh non-parboiled whole kernel (fresh rice before parboiling), AL- parboiled aged large brokens, AWK- parboiled aged whole kernels, AM- parboiled aged medium brokens, AL+S- a 1:1 mixture of parboiled aged large and small brokens, AS- parboiled aged small brokens, FL- parboiled fresh large brokens, FM- parboiled fresh medium brokens, FL+S- a 1:1 mixture of parboiled fresh large and small brokens, FWK- parboiled fresh whole kernels, FS- parboiled fresh small brokens. Values followed by the same letter are not significantly different ($P > 0.05$).

kernel (fresh rice before parboiling). The aged brokens have a significantly higher PV than the fresh brokens. Although there was no significant difference between the PV of the aged non-parboiled whole kernel and fresh non-parboiled whole kernel, there is significant difference between the parboiled aged whole kernels and parboiled fresh whole kernels. A similar trend is seen in the FV, trough viscosity (TV) and SBV, however, there is a significant difference between the aged non-parboiled whole kernel and fresh non-parboiled whole kernel. On average, the aged rice has better/higher pasting properties than the non-aged rice (figure 7). There is no significant difference in the breakdown viscosities (BV) and peak times (PT) of all the parboiled rice.

Significant differences exist between the non-parboiled and parboiled samples. Parboiled kernels have higher pasting temperatures than non-parboiled kernels. There is a consistent decrease in pasting properties with decreasing size of brokens in the parboiled brokens. Parboiled rice has higher pasting temperature than non-parboiled rice because of the impact of parboiling which hardens the starch granules.

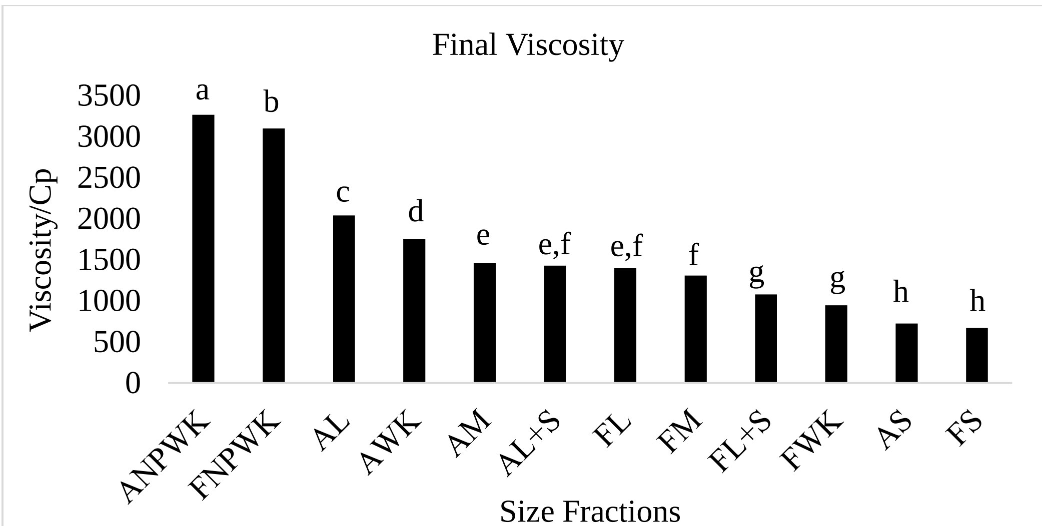

Figure 7. Final viscosity of aged and fresh rice (non-aged) from parboiling stream. ANPWK- aged non-parboiled whole kernel (aged rice before parboiling), FNPWK- fresh non-parboiled whole kernel (fresh rice before parboiling), AL- parboiled aged large brokens, AWK- parboiled aged whole kernels, AM- parboiled aged medium brokens, AL+S- a 1:1 mixture of parboiled aged large and small brokens, AS- parboiled aged small brokens, FL- parboiled fresh large brokens, FM- parboiled fresh medium brokens, FL+S- a 1:1 mixture of parboiled fresh large and small brokens, FWK- parboiled fresh whole kernels, FS- parboiled fresh small brokens. Values followed by the same letter are not significantly different ($P > 0.05$).

Aging is an intricate phenomenon that starts at pre-harvest and lasts until consumption. The process is incompletely understood (Saikrishna et al. 2018). Rice undergoes several changes in physicochemical properties during storage which can be identified after three months of storage (Sodhi et al. 2003). The reason why aged rice before parboiling has better pasting properties than the non-aged rice can be explained in various ways since there are many concepts of the causes of rice aging and the factors responsible for the aging (figures 8 and 9). Aged rice has lower water uptake than non-aged rice (Arai, Aoyama, &Watanabe, 1993; Sodhi et al. 2003). Decreased water absorption could be due to rearrangement of starch granules and the combination of starch and other substances in rice bran (Inprasit and Noomhorn 2001). In this study, though there is no significant difference in PV between the aged non-parboiled and fresh non-parboiled whole kernel, there is a significant difference between them after parboiling (figure 10). The difference in water uptake capacity of aged and fresh is likely to impact the degree of parboiling, whereby, aged rice is not able to absorb water as quickly as fresh rice during the parboiling process. This can affect the gelatinization of starch of the aged rice, leaving more starch granules ungelatinized unlike in the fresh rice where water uptake is rapid, and more starch granules are gelatinized. Ultimately, the aged parboiled whole kernels will have more ungelatinized starch granules compared to the fresh parboiled whole kernels. To further buttress this point, a study by Indudhara Swamy et al. (1978) showed a decrease in the amount of amylose from a 45-mesh flour that was soluble in boiling water during rice storage. The water insolubility and slow cooking rate of aged rice can be inferred from their study. Additionally, the viscosity of rice pasting is known to increase dramatically over short to intermediate-term storage (months) and decrease during longer term storage (years) (Sowbhagya and Bhattacharya 2001). Proteins have been identified as the components of rice that influence rice aging. Albumin and globulin are key proteins that cause rice aging changes in pasting properties (Guo et al. 2015).

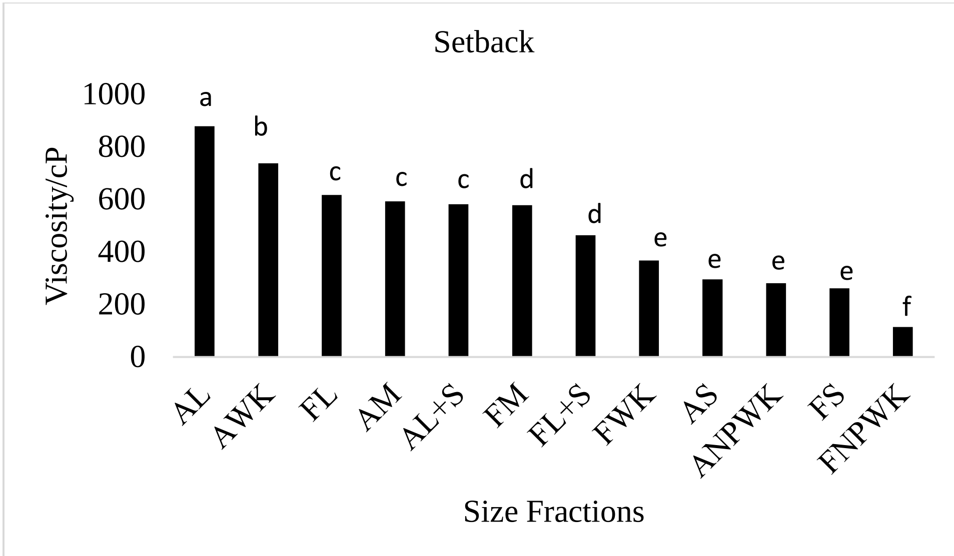

Figure 8. Setback viscosity of aged and fresh rice (non-aged) from parboiling stream. ANPWK- aged non-parboiled whole kernel (aged rice before parboiling), FNPWK- fresh non-parboiled whole kernel (fresh rice before parboiling), AL- parboiled aged large brokens, AWK- parboiled aged whole kernels, AM- parboiled aged medium brokens, AL+S- a 1:1 mixture of parboiled aged large and small brokens, AS- parboiled aged small brokens, FL- parboiled fresh large brokens, FM- parboiled fresh medium brokens, FL+S- a 1:1 mixture of parboiled fresh large and small brokens, FWK- parboiled fresh whole kernels, FS- parboiled fresh small brokens. Values followed by the same letter are not significantly different ($P > 0.05$).

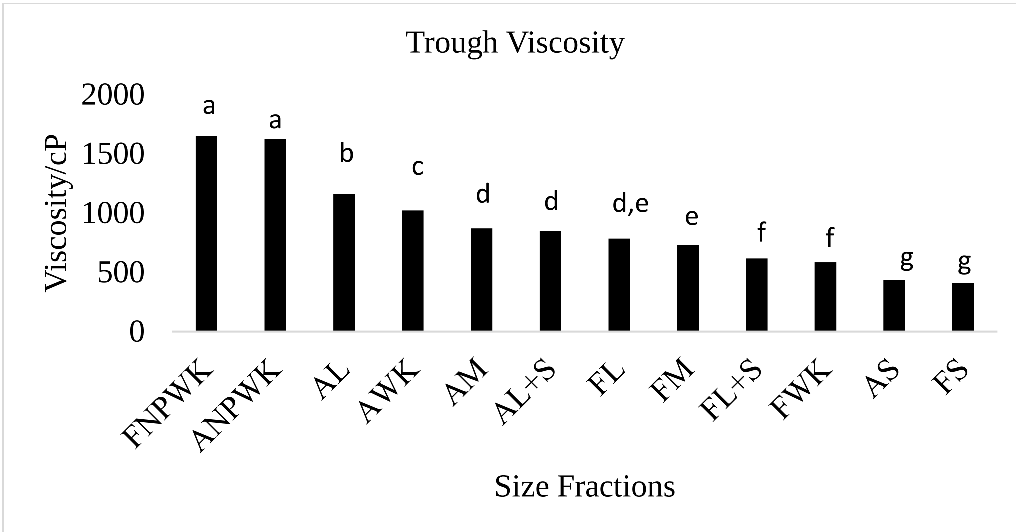

Figure 9. Trough viscosity of aged and fresh rice (non-aged) from parboiling stream. ANPWK- aged non-parboiled whole kernel (aged rice before parboiling), FNPWK- fresh non-parboiled whole kernel (fresh rice before parboiling), AL- parboiled aged large brokens, AWK- parboiled aged whole kernels, AM- parboiled aged medium brokens, AL+S- a 1:1 mixture of parboiled aged large and small brokens, AS- parboiled aged small brokens, FL- parboiled fresh large brokens, FM- parboiled fresh medium brokens, FL+S- a 1:1 mixture of parboiled fresh large and small brokens, FWK- parboiled fresh whole kernels, FS- parboiled fresh small brokens. Values followed by the same letter are not significantly different ($P > 0.05$).

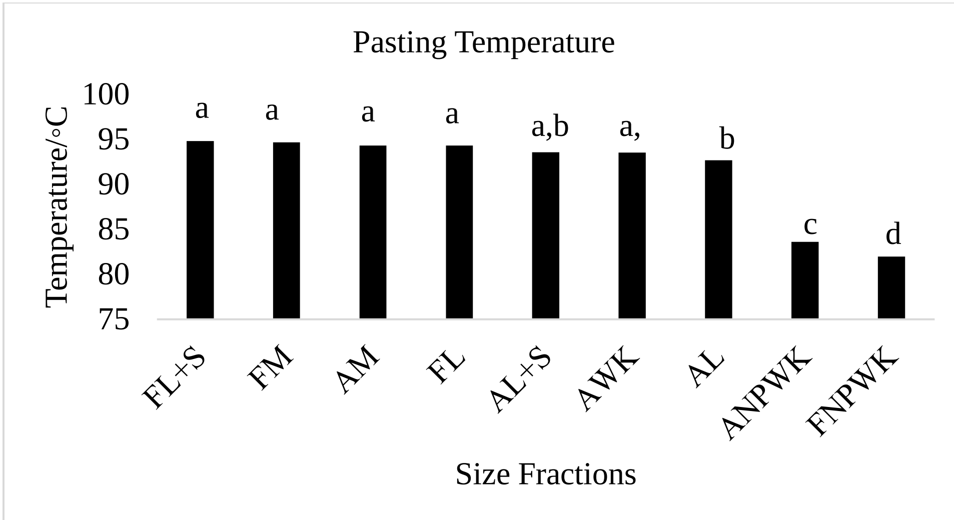

Figure 10. Pasting temperature of aged and fresh rice (non-aged) from parboiling stream. (Samples that have missing pasting temperatures were not included in the graph). ANPWK- aged non-parboiled whole kernel (aged rice before parboiling), FNPWK- fresh non-parboiled whole kernel (fresh rice before parboiling), AL- parboiled aged large brokens, AWK- parboiled aged whole kernels, AM- parboiled aged medium brokens, AL+S- a 1:1 mixture of parboiled aged large and small brokens, AS- parboiled aged small brokens, FL- parboiled fresh large brokens, FM- parboiled fresh medium brokens, FL+S- a 1:1 mixture of parboiled fresh large and small brokens, FWK- parboiled fresh whole kernels, FS- parboiled fresh small brokens. Values followed by the same letter are not significantly different ($P > 0.05$).

Laboratory Samples

The laboratory sample results indicate that size has a significant impact on the PV, FV, BD, SBV, and PT. Size has no significant impact on the pasting temperature. The 6 cultivars are significantly different in their pasting properties. Whole kernels and larger brokens have higher PV, FV, TV and BV than smaller brokens. These pasting properties decrease with decreasing size of the brokens, which is consistent with the findings of Mukhopadhyay and Siebenmorgen (2017) and the results of the commercial samples in this study.

Comingling of large and small brokens in the ratio of 1:1 have pasting properties like either the small or medium broken. Basutkar et al. (2015) analyzed the pasting property of comingled rice of different cultivars and concluded that commingling of cultivar lots did not adversely impact pasting properties because peak, breakdown, and final viscosities of commingled samples either increased or decreased proportionately with the associated increase in the mass percentage of a given cultivar in the commingled samples. However, in this study where the focus is comingling different sizes of brokens, there is observable significant impact in the pasting properties of the comingled samples. This further affirms the theory that the variability in the characteristics of the rice across the kernel length can impact the results of comingled brokens.

Final viscosity (FV) measures the ability of the starch to form viscous paste or gel after cooking and cooling (Maziya-Dixon et al. 2007). Higher FV in the larger sizes of brokens indicate higher carbohydrate content (Ohizua et al. 2017). The setback viscosity informs the retrogradation ability of the product (Ohizua et al. 2017). Medium brokens have higher SBV than other brokens. Amylose content correlates with SBV with higher amylose indicating higher SBV. It is possible that the medium brokens have significantly higher amylose content than the other sizes of brokens. Trough viscosity is a measurement of the ability of the paste or gel formed to withstand breakdown during cooling. (Ayo-Omogie and Ogunsakin 2013). Breakdown viscosity indicates the ability of the flour to withstand heating and shear stress during cooking (Adebowale et al. 2005). TV and BV show similar trends of decreasing viscosities with decreasing size. It can be inferred from this result that smaller brokens have a better ability to withstand shear stress during cooking. Peak time is the time at which peak viscosity occurs in minutes and it is a measure of the cooking duration of the flour (Adebowale et al. 2005). Smaller brokens have significantly lower peak time than other sizes of brokens. Pasting temperature is the temperature at which the first detectable increase in viscosity is measured and it is an index characterized by the initial change due to swelling of starch (Julanti et al. 2015). High pasting temperatures are usually an indication of high water absorption capacity of the flour (Julanti et al. 2015). The lack of differences in the pasting temperatures of the whole kernels and brokens may be an indication of similar water absorption capacity for these samples.

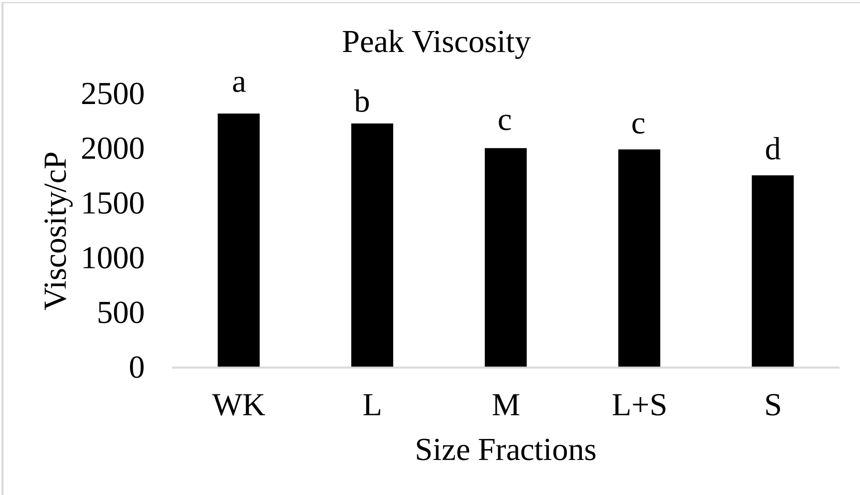

Figure 11. A plot of the least square mean of peak viscosity against size fractions for all 6 laboratory generated samples. WK-whole kernels, L- large brokens, M-medium brokens, L+S- a 1:1 mixture of large and small brokens, S-small brokens. Values followed by the same letter are not significantly different ($P > 0.05$).

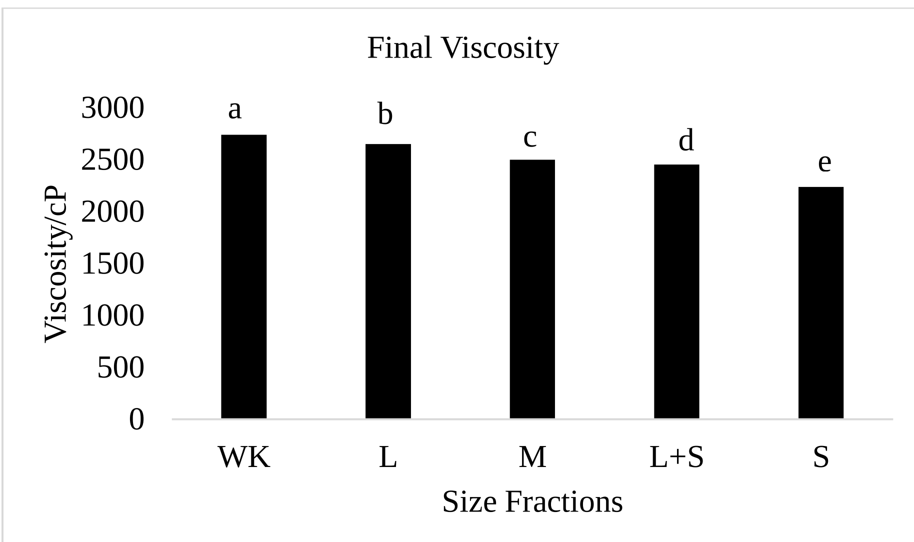

Figure 12. A plot of the least square mean of final viscosity against size fractions for all 6 laboratory generated samples. WK-whole kernels, L- large brokens, M-medium brokens, L+S- a 1:1 mixture of large and small brokens, S-small brokens.

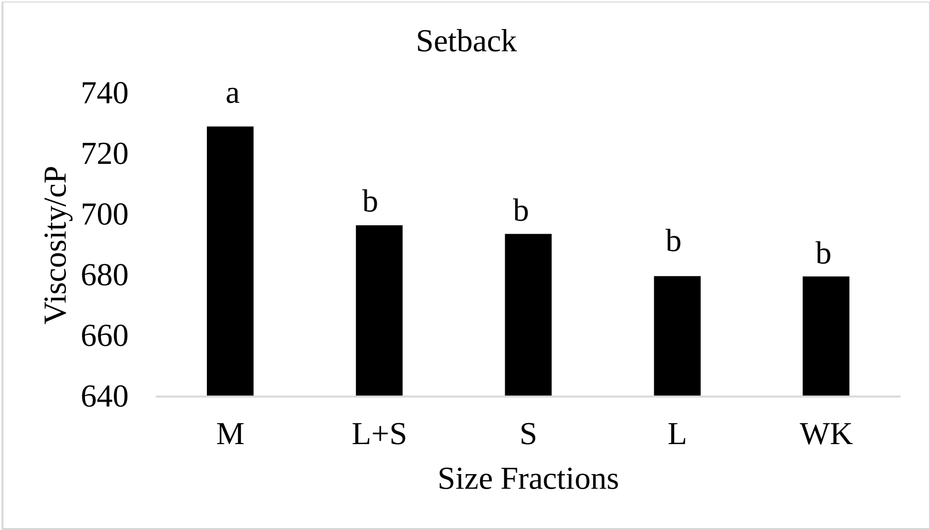

Figure 13. A plot of the least square mean of setback viscosity against size fractions for all 6 laboratory generated samples. WK-whole kernels, L- large brokens, M-medium brokens, L+S- a 1:1 mixture of large and small brokens, S-small brokens.

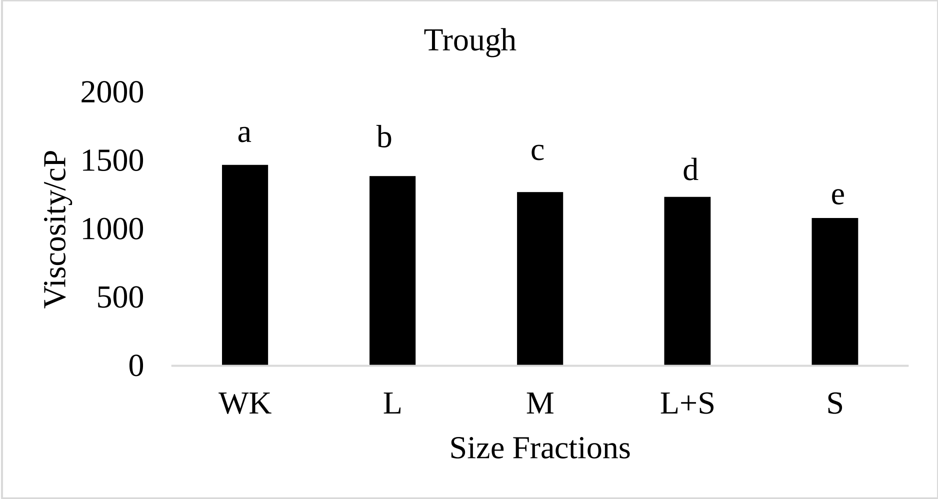

Figure 14. A plot of the least square mean of trough viscosity against size fractions for all 6 laboratory generated samples. WK-whole kernels, L- large brokens, M-medium brokens, L+S- a 1:1 mixture of large and small brokens, S-small brokens.

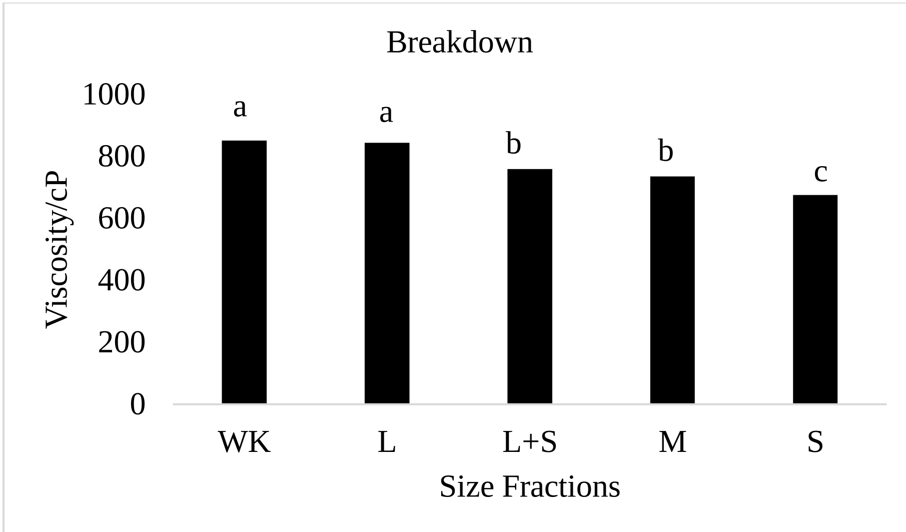

Figure 15. A plot of the least square mean of breakdown viscosity against size fractions for all 6 laboratory generated samples. WK-whole kernels, L- large brokens, M-medium brokens, L+S- a 1:1 mixture of large and small brokens, S-small brokens.

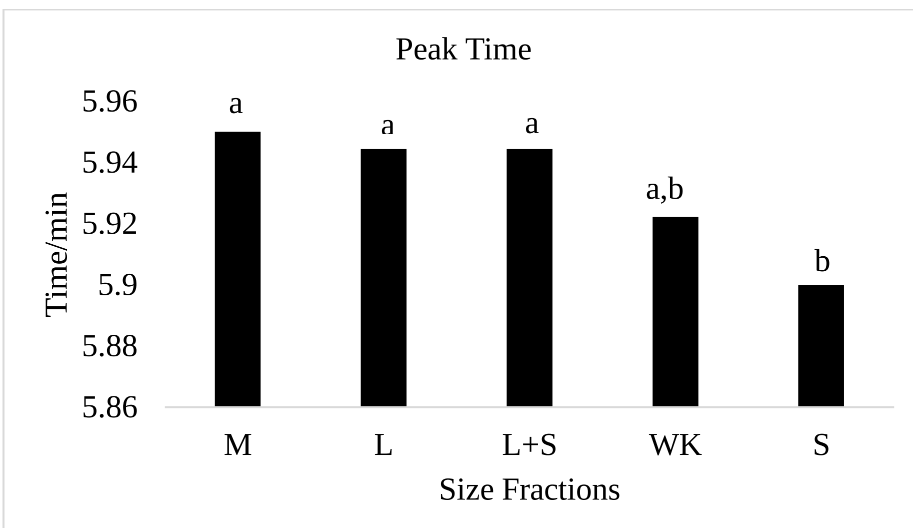

Figure 16. A plot of the least square mean of peak time against size fractions for all 6 laboratory generated samples. WK-whole kernels, L- large brokens, M-medium brokens, L+S- a 1:1 mixture of large and small brokens, S-small brokens.

E. CONCLUSIONS

Larger brokens had better pasting properties than smaller brokens. Smaller brokens have higher protein contents than larger brokens and whole kernels. Comingling of large and small brokens in the ratio of 1:1 produces viscosity like either medium or small brokens (cultivar dependent). Aging rice before parboiling gives higher pasting property than parboiled fresh rice. Size has a significant impact on the PV, FV, BD, SBV, PT and no significant impact in the pasting temperature of laboratory generated brokens (figures 11-16). The chemical properties of brokens are affected by the degree of size fractionation. Size classification of brokens is important in maintaining consistency in the pasting properties of the broken rice flour and resulting products.

It is recommended that the intrinsic factors responsible for the differences in the characteristics of the size fractionated brokens should be studied. Also, the impact of drying temperature on the characteristics of the brokens should be studied since brokens can be obtained from milling streams that dry rice at either high or low temperatures. Size fractionated brokens showed some desirable properties, which should be considered in product development to enhance the net value of rice as commodity and increase returns to rice growers.

F. ACKNOWLEDGEMENTS

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III. CONCLUSIONS

Different sizes of broken rice (brokens) are different in functionality and can be directed to different end-use. The results from this study showed that, larger brokens had better pasting properties than smaller brokens. Smaller brokens had higher protein contents than larger brokens and whole kernels. Comingling of large and small brokens in the ratio of 1:1 produced viscosity like either medium or small brokens (cultivar dependent). Size and cultivar of brokens had significant impacts on protein content, peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity and peak time of brokens. Rice aging influences pasting property. The moisture content (MC) of rice before parboiling affects the pasting property of the parboiled broken rice flour, thus rice parboiled at 12.5% MC (aged rice) had higher peak viscosity and final viscosity than rice parboiled at 18% MC (fresh rice). Size fractionation of brokens provides the opportunity to better understand the functionality of brokens, control comingling practices, direct brokens to the right end-use processes and to maximize the potential of this by-product in producing premium products.