Milling and pasting properties of local and newly introduced rice cultivars; impacted by drying and milling system

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Abstract: Various postharvest parameters have impacts on the milling quality and rheological properties of rice. The objective of this study was to appraise the whole rice kernel percentage and pasting properties of local and newly introduced rice cultivars as affected by drying air temperature at five levels (35 ℃, 40 ℃, 45 ℃, 50 ℃, 55 ℃), grain final moisture content at four levels (8%-9%, 9%-10%, 10%-11% and 11%-12%) and type of rice whitener. The results of whole kernel percentage (WKP) indicated the superiority of abrasive type whitener over the friction type whitener. Bending strength had significantly negative correlation with chalkiness, length, width and length to width ratio of grain. There was no significant correlation between WKP and bending strength. For Gohar, results showed that the drying parameters and type of whitener has a significant effect on final, breakdown, and setback viscosity. These differences, however, were not significant for Hashemi. Furthermore, the highest level of the breakdown viscosity and final viscosity was observed for severe drying accompanied with friction type whitener, while the lowest level of final viscosity belonged to low temperature drying and abrasive type whitener. For both rice varieties, the suitable whitener, drying air temperature and final moisture content were abrasive type rice whitener, 35 ℃ -45 ℃ and 10%-12%, respectively.

Keywords: milling quality, drying methods, rheological properties, whole kernel percentage, viscosity.

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1 Introduction

In the rice mill industry, production of the high quality whole rice kernel is the ultimate goal. Head rice yield (HRY), the primary indicator of milling quality is defined as the mass percentage of rough rice that remains as head rice after complete milling (Lloyd et al., 2001, Ambardekar et al., 2012). The whole kernel percentage (the mass fraction of the head rice over the mass of the total white kernels) was used instead of HRY to directly account for the percentage of the whole kernels in each sample by Zhang et al. (2005). Head rice comprises kernels that are at least three-fourths of their original length (USDA 2010). In Iran, rough rice is usually harvested at moisture content (MC) of around 21% to 26% and is subsequently dried to approximately 8% using fixed-bed dryers. In fixed-bed drying, grains within the entire bed of the dryer cannot be in contact with drying air of the same condition. This problem could be exacerbated by increasing the drying air temperature air flow rate and grain bed depth (Tajaddodi, 2012). Since grains at the bottom layers of the dryer have more opportunity of exposure to the inlet air, they may become over-dried while grains in the top layers are still undergoing drying.

Adsorption and desorption are important factors that could have an impact on the quality of the product. Since rice is a hygroscopic grain that can respond easily to the surrounding air conditions (Champagne, 2004; Wimberly, 1983; Chakraverty and Singh, 2001), it can be expected that grains with lower MC would absorb moisture from grains with higher MC and also from a high relative humidity environment after drying. Sharma and Kunze (1982) stated that fissures caused by moisture adsorption normally propagate during the adsorption process. It was reported that the internal cracks or fissures in rice kernels might occur even during desorption (drying) process

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(Sharma and Kunze, 1982; Jia et al., 2002; Yang et al., 2002). Internal stresses inside the kernels are the negative results of fast drying (Wimberly, 1983). As such, both of them cause grain to fissure and break easily during the milling process.

Milling is a process of applying mechanical loads to rice kernels for removing the bran layers and germ. Rice milling consists of several different stages, each of which must be successfully completed in sequence in order to meet the industry and consumer expectations. Generally, two types of milling actions are used to remove the germ and bran layers from brown rice. The first is an abrasive cutting action and the second is pressure and movement between kernels to produce a friction force for removing the bran layers (Champang, 2004). The abrasive action operates at a relatively low and uniform grain-to-grain pressure, and consequently produces less broken rice grains than friction mills (Champang, 2004; Bond, 2004; Kohlwey, 1992). The friction method, because of its higher pressure, tends to produce more broken than abrasive milling (Champang, 2004). The knowledge of physical and mechanical properties of the agricultural products is of fundamental importance for proper storage procedure and for design, dimensioning, manufacturing, and operating different equipment used in postharvest and processing operations of these products (Corrêa et al., 2007). For rice, mechanical and physical properties need to be identified and then quantified (Champagne, 2004). Generally, there are three methods to analyze mechanical properties of rice including compressive strength (Prasad and Gupta, 1973), tensile strength (Arora et al., 1973; Kunze and Choudury, 1972) and bending strength (Bamrunwong et al., 1987; Chattopadhyay et al., 1979; Siebenmorgen and Qin, 2005; Siebenmorgen et al., 2004; Tajaddodi et al., 2012). Luh and Siebenmorgen (1995) stated that compressive strength is not a good indicator of HRY and that a tensile test requires complicated sample preparation due to the irregular shape of rice kernels. In relation to the applying a three point bending test, good results were reported by Zhang, et al. (2003). Tajaddodi et al. (2012) showed that bending strength, modulus of elasticity and fracture energy increased with decrease in grain moisture content.

Starch is the main component of rice kernels (Zhou et al., 2002; Li et al., 2007; cited by Hai-Yan Jia et al., 2009) and it has very complex structure which contains partly crystalline, partly amorphous polymer (Perdon et al., 2000). Attempts to relate the pasting behaviors of rice flour with cooked rice texture have met with variable success. Limpisut and Jindal (2002) reported that pasting temperature, peak and setback viscosities were the most significant variables in the development of predictive models for evaluating the hardness and adhesiveness of cooked rice. This finding was similar to that reported by Juliano and Pascual (1980) who found that the peak viscosity correlated with hardness and stickiness of cooked rice.

In order to produce more head rice with good quality, selecting the proper drying parameters and suitable milling system is important. The main objective of this study was to improve processing of local (high quality as a reference variety) and newly introduced rice variety. To achieve this aim, the effect of drying air temperature, grain final moisture content and type of whitener on whole rice kernel and rice pasting behavior was investigated.

2 Materials and methods

2.1 Preparation of rice samples

Freshly harvested rough rice, landrace (Hashemi) and newly introduced (Gohar) extra- long cultivars were used in this study. After harvest, the samples were threshed and cleaned properly.

2.2 Drying process

Laboratory paddy dryer with 20 bottom perforated boxes was used for drying. The thickness of paddy sample in all boxes was around 10 cm. During drying, moisture content of samples was checked by grain moisture meter, 303 RS–GMK, Korea. Drying was stopped when moisture content of samples achieved the target final moisture content. Temperature of each dried sample was lowered from air drying temperature to the room temperature in zip-lock plastic bag without air cooling. All treatments were carried out in three replications.

2.3 Grain size determination

Thirty sound rough rice kernels were randomly selected from each treatment and their dimensions, length (L), width (W) and thickness (T) were measured using a digital caliper (a digital caliper with accuracy of 0.01 mm).

2.4 Kernel chalkiness determination

Chalkiness was quantified as the proportion of opaque relative to translucent areas of kernels. From each lot, fifty kernels were selected randomly and shelled by hand. Then chalky kernels were inspected by an enlarger. The chalk percentage for each lot was the average of three measurements of fifty kernels.

2.5 Bending strength

After drying, sixty sound kernels (20 kernels for each replication) were randomly selected from each lot and then each kernel was dehulled by hand to minimize any mechanical damages of rice kernels. Width and thickness measurements of each brown rice kernel were made using a digital caliper. Three bending test method and texture analyzer was chosen for mechanical properties testing. For better estimate of breaking force resulting from bending rather than shearing, a distance between the two supporting points of 3.4 mm was adopted and also a flat versus a rounded loading head was used to allow rapid kernel loading, thereby minimizing kernel movement during loading head contact and bending (Siebenmorgen and Qin, 2005). Loading head had 1.48 mm thickness and 9.9 mm width. Bending strength was calculated by using the following Equations (ASAE, 2008):

$$\delta = \frac{FLC}{4I} \qquad (1)$$

Where δ is bending strength (Pa); F is peak bending force (N); L is distance between the two supports (m); C is distance from the neutral axis to the outer layer of the rice kernel (m) which can be calculated by $C = D/2$, and I is moment of inertia (m^4). I can be calculated as:

$$I = 0.0049\ B * D^3 \qquad (2)$$

Where B is the major diameter of the ellipse (width of the rice kernel) and D is the minor diameter of the ellipse (thickness of the rice kernel).

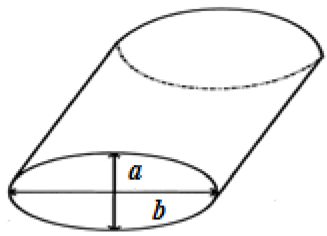


Figure 1 Cross sectional view of rice grain as ellipse

2.6 Milling test determination

Testing Husker (THU- 35A, Satake Engineering Co., LTD), abrasive type whitener (Satake Corporation, Japan) and friction type whitener (Mac Gill No. 2) were used for removing the husk and bran. Three 250g and 150g subsamples from each dried sample were considered for milling by abrasive and friction type whitener, respectively. For abrasive type whitener, paddy in output of husker (mixed brown rice and paddy) was removed manually. Whole rice kernel was separated from broken rice by using Satake testing rice grader (Satake Corporation, Japan). The whole kernel percentage (WKP) was determined from the fraction of whole white rice relative to the mass of total white rice to directly account for the percentage of whole kernels in a sample (Yang et al., 2005).

2.7 Pasting properties

Pasting properties was measured by Rapid Visco Analyser (RVA) (AACC, 1995). Three-gram flour of each sample was weighed into aluminum container and 25 mL distilled water was added. The pasting behavior of each sample (3g) was determined using Rapid Visco Analyser (RVA) (RVA-4, Newport Scientific, Sydney, Australia) at the following 12.5-min test profiles: holding at 50°C for 1 min; followed by a linearly ramped up from 50°C to 95°C for 3.8 min; holding at 95°C for 2.5 min; then cooling back to 50°C for 3.8 min; and finally holding at 50°C for 1.4 min. The measurements were performed under a constant shear velocity of 160 r/m. Viscosity values were recorded in arbitrary units (RVU, where 1 RVU= 10 cP) for peak viscosity (PV), hot paste viscosity (HV), breakdown (BV), final viscosity (FV), and setback viscosity (SV).

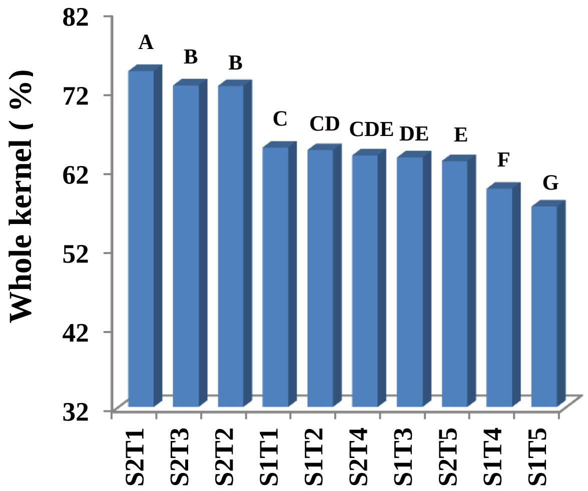
2.8 Experimental procedure and statistical analysis

This research carried out Factorial experiment with complete design with four factors, including rice variety at two levels (Gohar and Hashemi), grain final moisture content at four levels (8%-9%, 9%-10%, 10%-11% and 11%-12%, (w.b.)), drying air temperature at five levels (35 ℃, 40 ℃, 45 ℃, 50 ℃, 55 ℃), type of whitener at two levels (abrasive and friction type) in three replications. Statistical analyses were performed by using the one-way ANOVA and Duncan's multiple range test (DMRT) was used compared with the differences in the mean values at 0.05 confidence level.

3 Results and discussion

3.1 Rice milling properties

The results of whole kernel percentage indicate the superiority of the abrasive type whitener over the friction type whitener (Figure 2). Similar result was reported by Afzalinia, et al. (2004). They also showed that the milling system containing a friction type whitener had less amount of head rice. Furthermore, increasing the drying air temperature resulted in decreasing the whole kernel percentage (Figure 2). Moisture and temperature gradient and change in thermal properties due to the high drying air temperature could be the main reasons to observe decline in WKP. A rapid increase in the broken rice percentage was reported by Arora et al. (1973) when drying air temperature of about 53 ℃ was used to dry Calora rice variety. They claimed that the increase in thermal expansion due to the high drying air temperature resulted in head rice reduction. Kunze (1979) found that 48.9 ℃ produce a gradient sufficiently steep to make many of the grains fissure. Decrease in WKP by applying the friction type whitener could be related to the negative effect of the heat generation on kernel cracking and subsequent rice breakage. In this regard, grain temperature that was checked by Infrared thermometer immediately after milling was 48 ℃ -56 ℃ and 21 ℃ -35 ℃ for friction type and abrasive type rice whitener, respectively. Negative impact of high temperature milling was reported by Pan et al. (2005); Siebenmorgen et al. (1998) Archer and Siebenmorgen (1995); Mohapatra, and Bal (2004); Saleh; and Meullenet (2015). They used the laboratory friction type whitener in their study. Pan et al. (2005) reported a 1.7% increase in HRY for every 10 ℃ reduction in milled rice temperature. Paddy moisture content had a significant effect on WKP. It was decreased with increased paddy moisture content in abrasive type rice whitener (Figure 2). Similar trends relating the milling MC to HRY has been reported by the other researchers. Afzalinia et al. (2004) found that 12% to 14% MC to be optimal for milling, with regard to minimizing breakage. Maximum WKP was reported when final moisture content (FMC) was around 13% for milling with abrasive type whitener (Tajaddodi et al., 2012). The relationship between grain FMC and WKP indicates with increasing the FMC, WKP was decreased significantly (Figure 2). The results of this study are in agreement with the results of other studies regarding the effect of grain moisture content and drying air temperature. It was reported that HRY increased when the initial MC decreased from 14% to 10% (Andrews et al., 1992; Banaszek et al., 1989; Bennett et al., 1993). Banaszek et al. (1989) showed an increase in HRY with a decrease in MC of rough rice when milling for a constant duration using a McGill No. 2, laboratory friction type whitener. Thompson et al. (1990) reported an increase in HRY with a decrease in milling MC. Kohlwey (1992) cited by Lanning and Siebenmorgen (2011) speculated that bran removal is facilitated by a micro-scale gelatinization of starch, which occurs at the surface of the endosperm due to increased temperature resulting from friction in the milling process. A greater milling MC could result in more endosperm entering the bran stream, which may explain the observations of Figure 2, WKPs tended to be lower as MC increased.



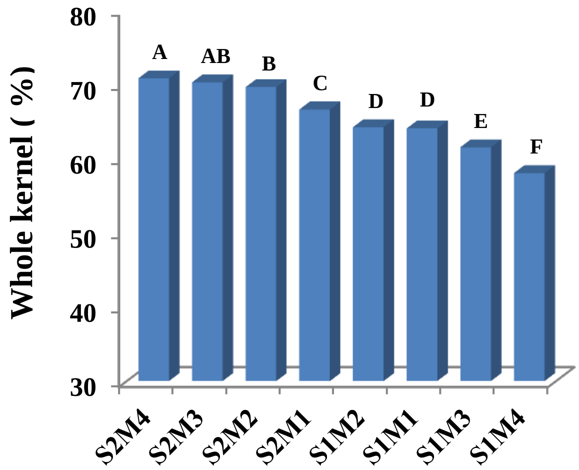


Figure 2 Interaction of drying air temperature (left), grain FMC (right) and type of whitener on whole kernel percentage, S1= Friction type whitener, S2= Abrasive type whitener

M1= 8%-9%, M2= 9%-10%, M3= 10%-11%, M4= 11%-12%

T1= 35 ℃, T2= 40 ℃, T3= 45 ℃, T4= 50 ℃, T5= 55 ℃

(Means with same letter are not significantly different at 5% level)

Average bending strength was 25.09 MPa and 21.96 MPa for Hashemi and Gohar, respectively. Results of Table 1 revealed that WKP increased with the increase of the bending strength. However, there was no significant correlation between WKP and bending strength. Bending strength had significant negative correlation with chalkiness, length, width and length to width ratio of grain.

Chalkiness is an undesirable characteristic in rice kernels. The chalky appearance is associated with the development of numerous air spaces between loosely packed starch granules and the resulting change in light reflection (Tashiro and Wardlaw, 1991; Lisle et al., 2000). Rice kernel chalkiness has been reported to be influenced by both cultivar genetics and the production environment (Mackill et al., 1996; Yamakawa et al., 2007). White belly is a chalk spot on the ventral side of the rice grain. It seems to be more stable and predominant than other types of chalkiness and has been considered a varietal factor. In this study, Hashemi is known as resistant variety to chalkiness and Gohar is a susceptible cultivar to chalkiness and break easily during milling process. The results show a negative correlation between chalkiness and bending strength (Table 1). WKP also decreased with the increase of the chalky kernel. Various studies related to the negative impact of chalkiness on HRY have been reported. Cooper et al. (2008) indicated that the level of chalk was strongly and inversely related to HRY. Chalkiness lowers HRY as chalky kernels tend to be weaker and are more prone to breaking during milling than non-chalky, fully translucent kernels (Webb, 1991; Raju et al., 1991; Siebenmorgen and Qin, 2005). As can be seen in Table 1, the correlation between chalkiness and some physical properties such as length, width, and *L/W* was significantly positive. The finding of Raju et al. (1991) that indicated the influence of grain size on white belly concurs with the results of this study. They showed that the width of grain is a factor responsible for WB. Dai et al. (2016) also observed positive correlation between chalkiness and grain length and width. They concluded that this correlation related to quantitative trait loci location and genetic effect. Grigg and Siebenmorgen (2013) stated that chalkiness might be strongly associated with thin, incompletely-filled kernels because of its linkage to starch accumulation in the rice endosperm.

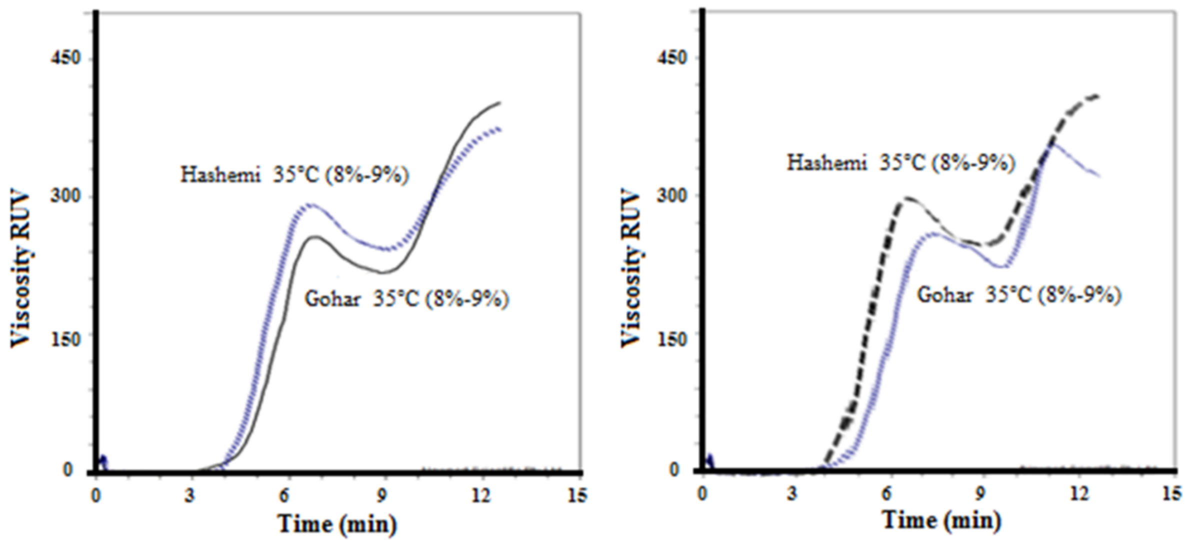
Table 1 Correlation matrix for whole kernel percentage, bending strength and grain physical properties

Characters	WKP	Bending	Chalkiness	Length	Width	Thickness
Bending	0.341^{NS}					
Chalkiness	-0.496**	-0.551**				
Length	-0.584**	-0.638**	0.900**			
Width	-0.576**	-0.407**	0.453**	0.644**		
Thickness	0.146^{NS}	0.081^{NS}	-0.110^{NS}	-0.097^{NS}	0.111^{NS}	
L/W	-0.445**	-0.595**	0.900**	0.940**	0.347^{NS}	-0.157^{NS}

Note: WKP: Whole kernel percentage *L/W*: Length/Width NS: Not significant **: significant at 1% level

3.2 Rice pasting properties

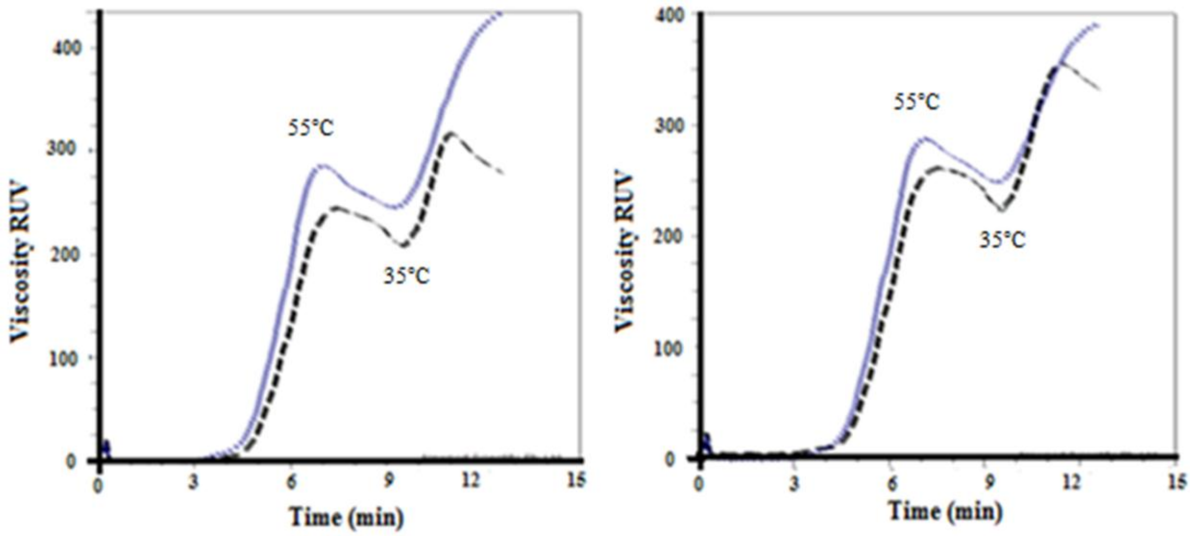
The RVA profiles such as PV, Trough, FV and derived parameters such as BV and SV are important predictors of rice eating, cooking and processing quality characteristics (Juliano 1985; Shu et al. 1998). Yan et al. (2005) claimed that good quality varieties usually have high BV and low SV and FV. A high BV value will be good in palatability and a low SV value is related to softness after cooking (Zulueta et al. 2000). In Iran, Hashemi is used as a reference variety in research programs and market evaluation. For Gohar, results showed that the drying parameters and type of whitener has significant effect especially on FV, BV, and SV (Figure 3). These differences, however, were not significant in Hashemi. This could be related to a cultivar disparity in terms of sensitivity or response to drying air temperature and milling temperature. Patindal et al. (2003) also reported a similar result in relation to the response of two rice varieties, Bengal and Cypress, to drying air temperature and relative humidity treatments. Their results showed that the differences in pasting properties and head rice yield were significant for Bengal and not of Cypress.



(a) Friction type whitener (b) Abrasive type whitener

Figure 3 Pasting profile of the effect of rice variety, drying air temperature and grain FMC on pasting properties

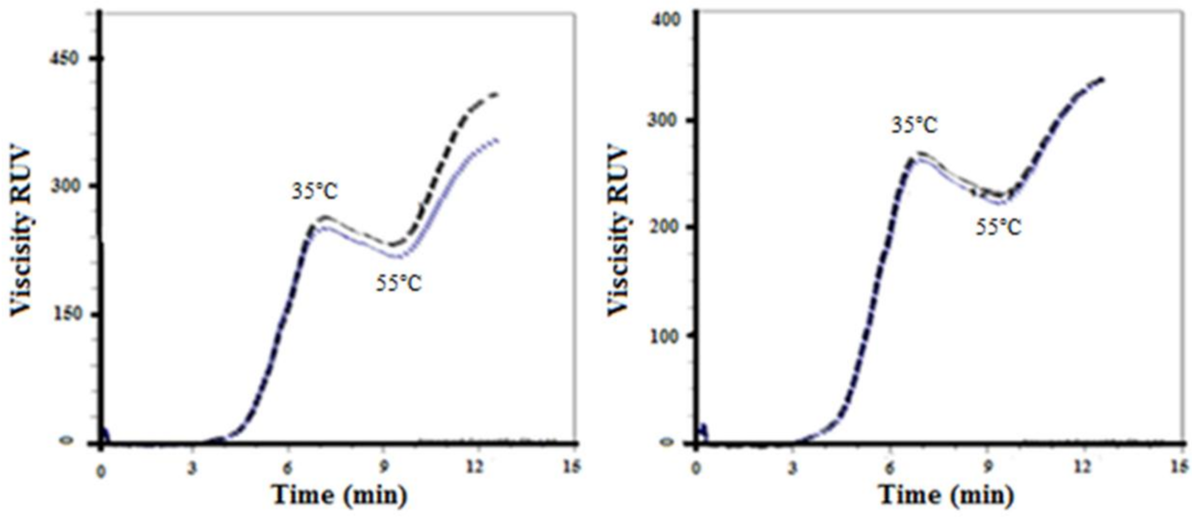
As can be seen in Figures 4 and 5, the breakdown viscosity and final viscosity were the highest for severe drying accompanied with friction type whitener, while the final viscosity was the lowest for low temperature drying and abrasive type whitener. This value may show the different retrogradation behavior of rice starches. On the other hand, it could be expected that cooked rice to remain softer after cooling due to the low temperature drying and milling with abrasive type whitener. Yan et al. (2005) claimed that the good quality varieties usually have higher breakdown viscosity, lower setback and final viscosity. Furthermore, since the final viscosity indirectly reflected the cool rice texture, the low final viscosity was required for good quality. The combination effect of drying air temperature, grain moisture content on pasting properties of newly introduced rice variety in abrasive and friction type whitener are shown in Figures 4 and 5, respectively. As can be seen in Figure 4, in abrasive type whitener for grain with both FMC (8%-9% and 11%-12%), peak viscosity, breakdown, setback and final viscosity increased with the increase of the drying air temperature from 35 ℃ to 55 ℃.



(a) Grain FMC of 8%-9% (b) Grain FMC of 11%-12%

Figure 4 Effect of drying air temperature, grain FMC on RVA pasting profile in abrasive type whitener for Gohar

In friction type whitener, there were no significant differences between the results, especially for grain with FMC of 11%-12% (Figure 5). In addition, peak viscosity, breakdown, setback and final viscosity increased in all treatments. No significant differences between the results in Figure 5 could be associated to the effect of high temperature drying accompanied with the high temperature milling on the chemical constituents of rice specially protein and it's interaction with starch. As is mentioned before the rice temperature after milling was high (56 ℃) for friction type whitener. Therefore, it could be expected that the rice temperature during milling with friction type whitener might be above the detected temperature. A denaturation temperature at 60.1 ℃ was reported for rice globulin by Gorinstein et al. (1996). Increased FV and SB values also reported when rice stored at high temperature (Ward, 2012; Kanlayakrit and Maweang, 2013) and during milling process (Saleh and Meullenet, 2015). Peak viscosity (PV) is the maximum viscosity attained by gelatinized starch during heating in water. The formation of starch protein networks is believed to provide mechanical support for starch granules and protect them against rupture. This in turns inhibits the thixotropic (shear thinning) nature of rice pastes, resulting in greater forces required to shear the paste slurry and consequently greater peak viscosity. Hamaker and Griffin (1993) also reported a potential effect of proteins on starch gelatinization. The endosperm matrix protein and protein associated with starch granules, respectively, were indicated to influence rice flour starch gelatinization properties. Breakdown is usually associated with the tendency of gelatinized starch granules to break during holding at high temperature, accompanied with continuous shearing (Han and Hamaker, 2001).



(a) Grain FMC of 8%-9% (b) Grain FMC of 11%-12%

Figure 5 Effect of drying air temperature, grain FMC on RVA pasting profile in friction type whitener for Gohar

The increase in rice flour breakdown viscosity suggests a greater protection of the starch granule integrity. This probably is due to the increased affinity of proteins to interact with starch, as a result of protein denaturation. The resulting formation of protein starch complexes tends to increase rice flour peak viscosity. Retrogradation (setback) is the re-association of starch polymer molecules. Leached starch and denatured protein molecules are believed to re-associate during the cooling step of the flour paste formation process. This indicates a greater impact of starch protein interactions during retro-gradation on rice flour paste. It occurs when molecules that have become disordered during cooking begin to re-associate in an ordered structure (Hood, 1982). In the initial phases of retrogradation, linear segments of two or more starch chains may form a simple juncture point that may develop into more extensively ordered regions. Ultimately, under favorable conditions, a crystalline order appears which results in gelation or precipitation (Francis, 1999). Furthermore, an increase of SB value indicates a higher degree of retrogradation as a result of rice firmness was increased (Tulyathan and Leeharatanaluk, 2007).

4 Conclusions

(1) The results of whole kernel percentage indicated the superiority of the abrasive type whitener over the friction type whitener.

(2) Whole kernel percentage (WKP) decreased with the increase of the chalky kernel.

(3) Bending strength had significant negative correlation with chalkiness, length, width and length to width ratio of grain.

(4) For newly introduced rice variety, Gohar, results showed that the drying parameters and type of whitener has significant effect especially on FV, BV, and SV. As a result, the cooking quality of Goahar was affected by the type of whitener.

(5) For Gohar and Hashemi rice cultivars, suitable drying air temperature and final moisture content were 35 ℃-45 ℃ and 10%-12%, respectively.

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