An Argument for Water Activity as a Specification for Flour Production

by Brady Carter

Wheat is one of the most widely produced grain crops in the world and is the basis for our global diet. To produce a viable food ingredient, most wheat is milled into white flour. Wheat is typically classified as either hard or soft, each with unique end-uses. Hard wheat grain is typically higher in protein, requires a harder grind during milling, produces coarser particle sized flour, and is used for bread production. Soft wheat grain is typically lower in protein, produces finer particle sized flour with less damaged starch, and is used for cookies and crackers (AACC International 2000; Wrigley 2009).

The milling process that transforms wheat grain into flour is a multi-step process of grinding grain into powder and then sieving to produce flour with a range of particle size (Posner 2009). White flour is primarily produced from the endosperm of the grain with the bran and germ removed, while whole wheat flour includes the bran and germ. Whole wheat flour is considered more nutritious, but white flour has a longer shelf life and is easier to work with as an ingredient. Farina is coarser milling product that consists of small amounts of the germ included with white flour and is commonly utilized as a breakfast hot cereal.

Prior to milling, grain must be tempered with moisture to soften the endosperm and toughen the bran to facilitate grinding and separation (Posner 2009). Sufficient liquid water is added to raise the moisture level of the grain to between 12 and 17% and then allow it to equilibrate for 16 through 24 hours before milling. Kweon et al found that the tempering conditions impacted milling performance and flour functionality with flour produced from lower moisture tempering having greater flour yield, but poorer flour quality.

To have value as an ingredient, flour must possess good end-use quality that remains stable while the flour is stored prior to use (Carson & Edwards 2009). The factors that could potentially end the shelf life of flour include: microbial spoilage, caking and clumping, nutritional loss, color loss, and rancidity. The two factors that will most significantly influence the rate of shelf life loss of flour are temperature and moisture level (Bell 2007; Hiatt et al. 2010). Moisture content is commonly required for any flour specification sheet, with 13.5% ideal for soft wheat and 14% ideal for hard wheat (Glen Weaver, Personal Communication).

Moisture content provides useful information about the purity level of the flour and works well as a standard of identity, but unfortunately, is not very helpful in assessing the rate of shelf life loss. All of the shelf life loss factors are better correlated to water activity, a thermodynamic measurement of the energy of water (Barbosa-Canovas et al. 2007). Water activity measurement is typically accomplished in three to five minutes using easy to use instrumentation and helps form the basis for the Food and Drug Administration's definition of potentially hazardous foods (http://www.cfsan.fda.gov/~comm/ift4-3.html). Consequently, including water activity in flour specifications is more critical to ensuring the quality and shelf life of the product than moisture content, yet water activity does not currently appear on any flour specification sheets.

The purpose of this study is to provide an argument for making water activity level a commonly requested specification for flour. More specifically, the study investigates the impact of particle size, tempering conditions, and storage conditions on the water activity, moisture content, and moisture sorption properties of grain, flour, and farina. The information generated in this study should help explain some confusion over recommended moisture levels for flour, highlight the impact of storage conditions on flour moisture, and determine if water activity may be a preferable metric for tracking moisture in grain and grain-based products.

Experimental Procedure
Commercial Hard Red Spring and Soft White Winter grain was obtained and processed by the USDA Western Wheat Quality Lab in Pullman, WA. They tempered the hard and soft grain samples to both 15.5% and 17.0% moisture content for 16 hours. Then 50 gram samples of Dry Whole Wheat (DWW) and Tempered Whole Wheat (TWW) were set aside for water activity and moisture sorption isotherm testing. The rest of the tempered wheat was then milled using a modified Quadrumat experimental mill (Jeffers & Rubenthaler 1977). Break flour and farina samples were obtained from the mill and turned over to Decagon Devices, Inc. in Pullman WA (Figure 1).

Figure 1. Sample types for the study including clockwise from the upper left: whole grain, farina, and break flour.

Our lab technicians analyzed three replicates each of both hard and soft DWW, TWW, Farina and Flour at each tempering level (not DWW) for moisture content using AACC method 44 to 15.02 (AACC International 2000) and water activity using an AquaLab Series 4TE (Decagon Devices, Inc. Pullman, WA). In addition, each of the samples were analyzed for equilibration time and maximum moisture sorption when changing from 30% RH to 65% and 30% RH to 90% RH at 25 °C (weight change %dm/dt trigger setting 0.008/3 events) using the Dynamic Vapor Sorption (DVS) method in the AquaLab Vapor Sorption Analyzer (Decagon Devices, Inc. Pullman, WA). Finally, we analyzed each of the flour and farina samples for sorption isotherm slope and the whole wheat samples for critical water (RHc) at 25 °C using the Dynamic Dew Point Isotherm (DDI) method in the AquaLab Vapor Sorption Analyzer with an initial water activity of 0.10 a_w, a final water activity of 0.90 a_w, and a flow rate of 80 ml/min (Carter & Schmidt 2012).

We then used a two-way ANOVA to determine if particle size, hardness level, tempering level, and their interactions were significant sources of variation in the moisture content, water activity, isotherm slope during adsorption, equilibration time, and maximum moisture sorption (Minitab 17 Statistical Software 2010. State College, PA: Minitab, Inc. www.minitab.com). For treatments that were shown to be significant, Tukey's multiple means comparison were used to determine which treatment levels were significantly different.

Results
As expected, the water activity of the dry whole grain had the lowest water activity while the tempered wheat had the highest water activity (Table 1). The water activity of hard grain, flour, and farina was always higher than its soft counterpart regardless of the tempering level (Tables 1 and 2). The water activity of the 17% tempered wheat was above the minimum growth

Table 1. Water activity and moisture conternt of Hard and Soft whole wheat grain that is dry, tempered to 15.5%, and tempered to 17%.

Moisture Value	Dry		15.5% Tempered		17.0% Tempered	
	Soft	Hard	Soft	Hard	Soft	Hard
Water Activity	0.410	0.502	0.660	0.707	0.749	0.794
Moisture Content (%)	10.8	12.0	15.5	15.5	17.0	17.0

Table 2. Water activity and moisture content of hard and soft flour and farina tempered to 15.5% and 17.0%.

Moisture Value	Dry		15.5% Tempered		17.0% Tempered		17.0% Tempered	
	Soft Flour	Hard Flour	Soft Farina	Hard Farina	Soft Flour	Hard Flour	Soft Farina	Hard Farina
Water Activity	0.639	0.664	0.622	0.671	0.699	0.751	0.696	0.746
Moisture Content (%)	13.9	14.2	13.6	14.2	14.9	15.7	14.7	14.7

Table 3. Maximum water sorption and equilibration time at 65% and 95% relative humidity for Hard and Soft flour and farina.

Moisture Value	65% Relative Humidity				90% Relative Humidity			
	Soft Flour	Hard Flour	Soft Farina	Hard Farina	Soft Flour	Hard Flour	Soft Farina	Hard Farina
Maximum Sorption (%)	14.2	14.3	13.5	13.6	20.3	20.4	20.6	20.3
Equilibration Time (h)	4.6	8.0	5.4	6.2	11.0	14.5	17.3	23.4

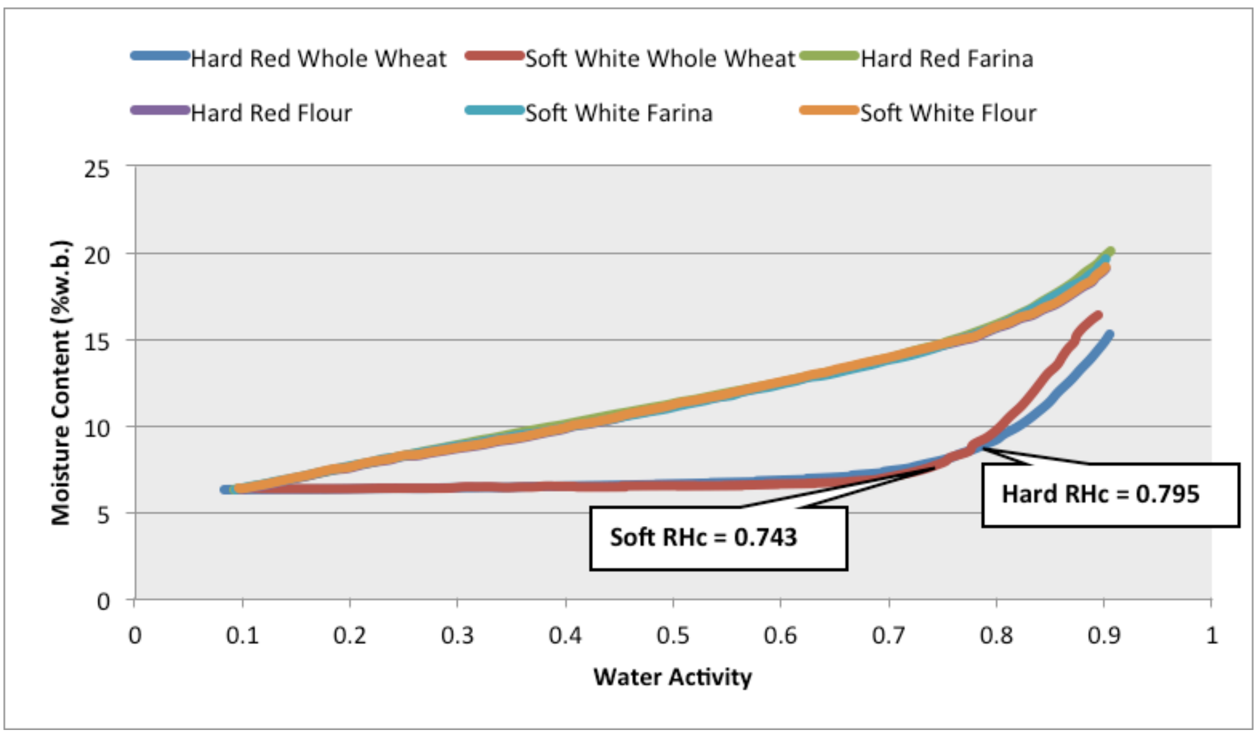

Figure 2: Dynamic isotherms for hard and soft grain, flour, and farina at 25°C. Inflection points in the dynamic curves for grain indicate the critical water activity (RHc) while the slope of the dynamic curves of flour and farina indicate relative Hygroscopisity.

limit for mold (0.70 a_w) for both hard and soft wheat, but only for hard wheat at 15.5%. The typical 16 to 24 hour hold time for tempered wheat should not be long enough for mold to grow. If the hold time was extended, any tempered wheat with water activities higher than 0.70 a_w would likely experience mold growth.

The water activity and moisture content of the flour and farina was always lower than the tempered whole wheat before milling due to removal of moisture during the milling process (Table 2). Flour and farina had similar water activities after milling for a given hardness and tempering level. The water activities (<0.70 a_w) and moisture contents (13.5% for soft, 14.0% for hard) of both flour and farina from 15.5% tempering were within acceptable limits. For 17.0% tempering, the water activity of the hard flour and farina was above the critical 0.70 a_w value, but not the soft flour and farina. Still, the moisture content levels for all products at the 17.0% level would be considered too high. The slopes of the dynamic isotherms for all flour and farina samples were not significantly different ($p<0.05$), indicating equivalent levels of hygroscopisity (Figure 2). In fact, there was very little difference in the DDI curves of all the flour and farina samples and the sorption curves were essentially linear up to 0.75 a_w.

The DDI curves of the whole grain samples were significantly different from the flour and farina, and initially almost flat (Figure 2). This is typical of materials with hard coatings that limit the penetration of water into the interior. Then, the sorption isotherm curves of the whole grain experienced a sudden change in sorption properties where the samples began to absorb much more moisture causing an inflection in the DDI curve. The water activity associated with this change was identified as the RHc and represents the point where water begins to penetrate the pericarp of the grain. This RHc occurred at a lower water activity for soft grain (0.743 a_w) than for hard grain (0.795 a_w). A review of table 1 also indicates that these RHc values for the grain were similar to the water activities of the 17.0% tempered whole grain wheat.

The DVS results in Table 3 indicate that when flour is exposed to 65% relative humidity, its moisture will be roughly 14.0%. At 90% relative humidity, the moisture content will be roughly 20% with no significant differences between hard and soft flour. The time required to move to 65% and 90% RH from 30% RH was longer for hard flour, but was only 14.5 hours at the longest. The results were similar for farina, except the moisture at 65% RH was only 13.5% and equilibration to 90% relative humidity required up to 24 hours. If flour or farina is exposed to high humidity (>70%), the water activity will be above the growth limit for microbial growth and the moisture levels will be deemed unacceptable. The maximum time it will take for exposed product to move to unacceptable levels is only 24 hours (Table 3). Humidity levels of 60 to 70% should not be problematic since the water activity and moisture levels will be acceptable, but lower relative humidities will dry flour to unacceptable moisture levels.

Summary

Considering that the current suggested moisture content levels for flour and farina correspond with water activity levels right at the cutoff point for mold growth, it behooves the flour industry to consider including a water activity specification to ensure microbial safety. In addition, since lower water activities are better correlated with lower rates of rancidity than moisture content, it would make more sense to focus on optimizing water activity level and then confirm that the moisture content is acceptable rather than rely on just a moisture content specification.

Based on the connection between the RHc value of whole grain and current tempering moisture levels, it is feasible to temper to a constant water activity rather than to a moisture level. Based on the preliminary results of this study, a recommended water activity specification for tempered wheat would be 0.75 a_w. This water activity level would achieve tempering conditions similar to those currently being used, but with more consistency since water activity is more precise than moisture content and can be easily monitored with instrumentation to determine when tempering is complete. Finally, tempering the grain to 0.75 a_w could be achieved by vapor equilibration to 75% RH (using saturated NaCl) which is more uniform than adding liquid water. The equilibration time should be similar to current tempering hold times, so mold growth should not have time to begin. Finally, having a consistent starting water activity for tempered wheat will consistently result in flour or farina water activities less than 0.70 a_w, preventing mold growth and reducing the rate of rancidity.

The suggested specification for flour and farina would be 0.62 to 0.68 a_w. As indicated in this study, this water activity range corresponds with ideal moisture levels for hard and soft flour. In addition, this water activity range would assure no mold growth and minimize the rate of rancidity. Finally, water activity measurement can be accomplished using easy-to-use instrumentation that is verifiable and more precise than moisture content testing, at roughly the same cost.

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