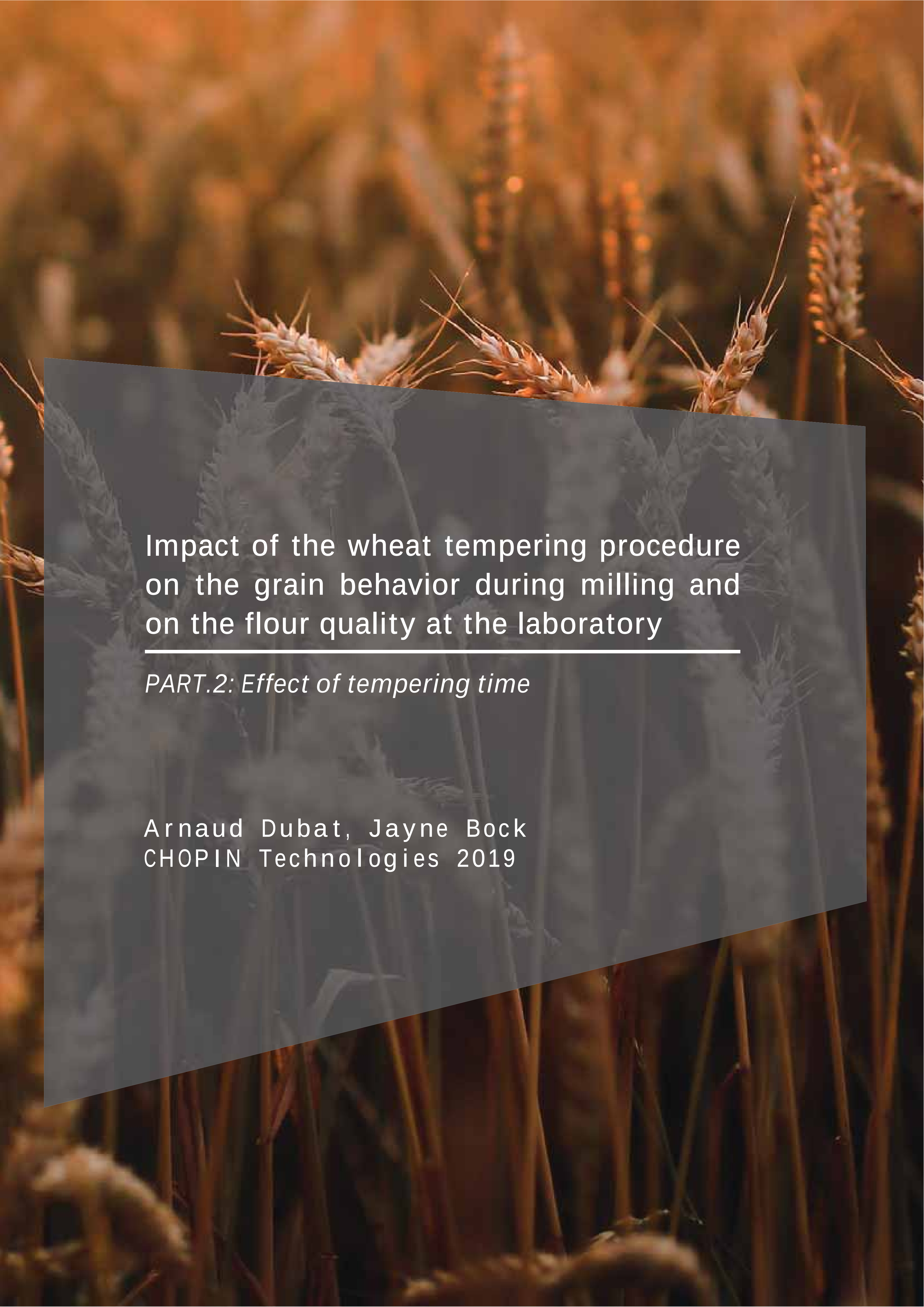

Impact of the wheat tempering procedure on the grain behavior during milling and on the flour quality at the laboratory

PART.2: Effect of tempering time

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Introduction

Experimental milling is a critical point for wheat quality control and R&D laboratories. However, there is always a competition between best practices and the necessity to obtain fast results in a laboratory setting. Best practices call for a time-consuming tempering step prior to milling. In spite of this, the need for more rapid sample throughput causes some labs to either minimize tempering or skip it altogether.

Two critical questions to require attention to resolve this issue: what is the optimal tempering moisture target for a given lot of wheat, and what is the optimum resting time necessary to have the wheat properly tempered?

The first paper in this series summarized the impact of final tempering moisture content (MC) on wheat behavior during milling (*Dubat & Bock, 2019*). The conclusion was that a final MC range 15-17% was recommended with 16% MC being a good compromise. Also, the final tempering MC was not dependent on wheat hardness.

Both hard and soft wheats (and their blends) performed similarly at the same tempering MC in terms of milling behavior and flour quality characteristics.

The second important aspect of wheat tempering concerns the tempering time. We performed a second investigation to determine how the milling behavior and the flour properties evolved over a range of tempering times depending on the wheat hardness. According to Butcher and Stenvert (*1973a*), we expected to measure clear differences between hard and soft wheat as it is well accepted that harder wheat needs longer resting times.

However, because laboratory mills utilize a short flow process, they are different than industrial mills and the resulting milling performance and flour quality may be more or less sensitive to tempering time and levels.

As our first study answered the initial question of optimal final tempering MC for experimental milling, this second part of the two-part series was conducted to answer the question of optimal tempering time. The results indicate that current laboratory tempering guidelines require revision.

Materials and methods

◆ Sample description

Soft wheat was procured from a Spanish mill with a protein content of 8.4% (db), starch damage of 15.7 UCD (Chopin-Dubois Units), and an Alveograph W of 118. Hard wheat was also procured from A US mill with a protein content of 15.4% (db), starch damage of 19.3 UCD (Chopin-Dubois Units), and an Alveograph W of 384. One blend of wheat was created by mixing 50%+50% of hard and soft wheat, respectively, according to Hook et al. (*1984*).

◆ Tempering

Wheat samples were tempered prior to milling to the following levels as described in Dubat and Bock (*2019*): dry (as-is) and 16% MC. Resting times were set as; 0 (just after tempering), 3, 6, 9, 12, 24 and 48 hours. 1 Kg of clean wheat was placed in a flask, dry wheat moisture was measured using NIR transmittance (Infraneo, CHOPIN Technologies, France), and water was added to reach the target moisture. Grain and water were mixed over 15 minutes using an MR2L Mixer (CHOPIN Technologies, France). Tempered wheat was transferred to another flask, tapped, and rested at lab temperature until the complete resting time was achieved.

◆ Milling procedure

All milling was done using a CHOPIN LabMill (Chopin Technologies, France) according to the patented mill flow diagram (Dubat et al., 2015) shown in ***Figure 1***. Tempered wheat is introduced at the B1 hopper and feeds into 2 grooved rolls (roll gap 0.7mm, differential speed 2.5). Ground wheat is separated by a centrifugal sifter into 4 fractions: 1st break flour (<180µ), fine middlings (<450µ), large middlings (<1000µ), and ground wheat that will feed the 2nd break (>1000µ).

The 2nd break is performed by passing the ground wheat through 2 grooved rolls (roll gap 0.1mm, differential speed 3.5, and the same sifter as at B1 again separates the product into 4 fractions: 2nd break flour, fine middlings, large middlings, and coarse bran. Large middlings from B1 and B2 are sent to the sizings stream equipped with 2 smooth rolls (roll gap 0.03 mm, differential speed 1.5). A centrifugal sifter separates the product into 3 fractions: sizings flour (<200µ), fine middlings (<500µ), and fine bran (>500µ).

Fine middlings from B1, B2, and sizings are sent to the reduction stream equipped with 2 smooth rolls (roll gap 0.03 mm, differential speed 1.5) and a centrifugal sifter (160µ), separating reduction flour from shorts. The shorts are then gradually reduced by 2 more passages on the reduction side.

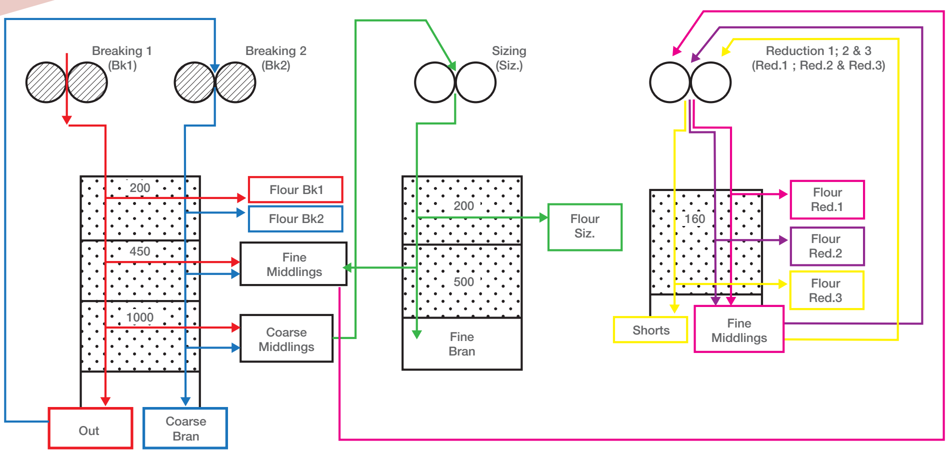

Figure 1: LabMill Diagram

◆ Flour characteristics

Physical flour characteristics such as moisture, protein and ash contents were determined using a Spectralab NIR (Unity Scientific, Milford, MA) device using reflectance in the 1100-2600 nm range.

Starch damage was assessed using the amperometric method with the CHOPIN SDmatic (*AACC Method 76-33.01*). The principle is based on the measurement of an electrical current generated by iodine in suspension. When flour is introduced, the device measures a decrease in electrical current which is proportional to the starch damage in the sample.

Rheological dough properties were measured using the standard method for the CHOPIN Alveolab (*AACC Method 54-30.02*), using the constant hydration procedure. The principle is to produce 5 pieces of dough that will be inflated after a resting period at a certain air flow rate. The device measures dough characteristics such as tenacity (P value), elasticity (Ie value), extensibility (G value), and total baking strength (W Value).

◆ Statistical analysis

The results are expressed as mean ± standard deviation. Significant differences were determined by a one-way analysis of variance (ANOVA) with Tukey's LSD mean differentiation ($p \leq 0.05$) using Minitab 17 software.

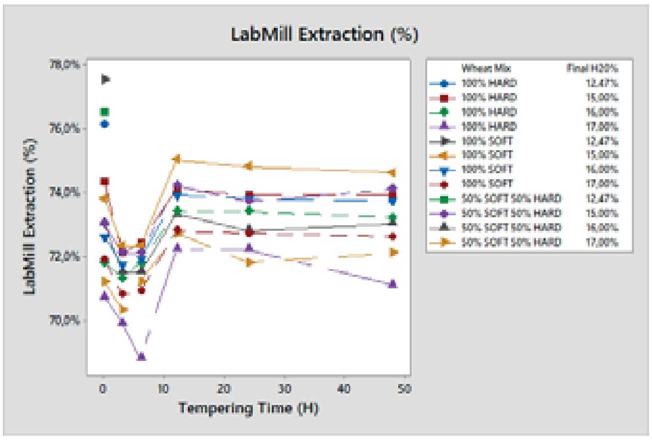

Figure 2: LabMill flour extraction rate (db) as a function of wheat tempering time at 16% MC.

Results and discussion

◆ Influence of the tempering time on milling properties

The impact of tempering time on flour extraction is shown in ***Figure 2***. It shows behavior that is the same regardless of the wheat hardness or the final tempering MC. We will focus on the results obtained using 16% tempering MC.

The first observation from the results is a large drop in flour extraction when wheat kernel is merely put into contact with water (*Warechowska et al., 2016*). The dry wheat sample exhibited a flour extraction rate that was between 76-77.5%. The simple act of adding water, mixing 15 minutes, and resting 30 minutes prior to milling (to allow for uptake of excess water from the kernel surface) leads to a 4% loss of extraction.

Between 0 and 6^h the extraction rate reaches a minimum (~68 – 72%). We can postulate that in this timeframe of 0 to 6 h the water still remains in the outer portion of the kernel as tempering is a diffusion limited process (*Manley et al., 2011; Seckinger et al., 1964; Stenvert & Kingswood , 1976, 1977*). Between 6 and 12^h there is a clear increase in extraction rate, and after 12^h of resting time the flour extraction remains constant.

Extraction rate is a good indicator of tempering progress, but it does not capture all the changes occurring in milling performance over tempering time. A more detailed analysis of the different product streams is required to support the extraction observations.

Table 1 reports all the milling performance indices expressed as a function of the wheat entering the mill. The resistance index (***Figure 3***) represents the kernel resistance to crushing at the first break (B1) stage. For soft wheat, contact with water is enough to start "softening" the kernel, dropping the resistance index from an initial rating of 5 in dry wheat to 4 in the 0 h tempered wheat.

The drop in resistance index rating continues between 0 and 6^h of tempering time, finally resulting in a minimum resistance index of 2. In contrast, the hard wheat resistance index remains constant at a rating of 6 during the 3 first hours of tempering, drops 1-point to a rating of 5 between 3 and 6^h, and thereafter remains stable. The blend exhibited a combination of characteristics from its component wheats: the resistance index exhibits an early 1-point drop from a rating of 5 to 4 between 0 and 3^h, similar to soft wheat, but no further decrease in resistance index is observed thereafter, similar to hard wheat.

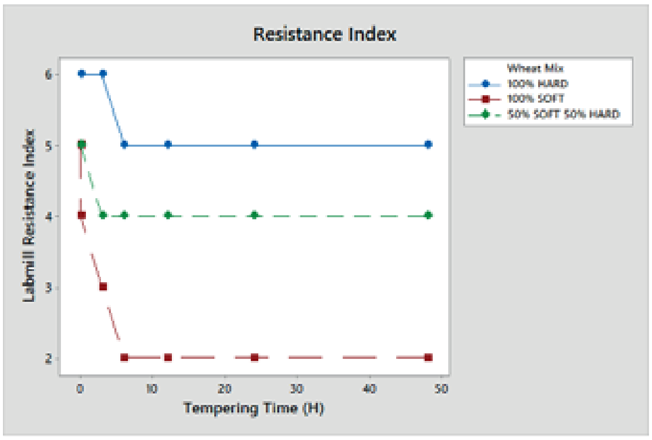

Figure 3: Evolution of the LabMill resistance index as a function of wheat tempering time

Further information was obtained from the apparent hardness index (***Table 1***). Apparent hardness is an indicator of wheat resistance to crushing throughout the milling process as a whole (not only B1). The trends are the same for the 3 samples indicating that the behavior does not depend on wheat hardness. The apparent hardness decreases between 0 and 6^h, increases slightly between 6 and 12 hours, then stabilizes. There is a clear similarity between the flour extraction curve (***Figure 2***) and the apparent hardness curve (***Table 1***).

Wheat Mix	Tempering Time (H)	Final H20% (real)	LabMill Extraction (%)	Labmill Resistance Index	LabMill Apparent Hardness	Labmill B1 flour (% Wheat)	Fine Middlings from B1 (% Wheat)	Large Middlings from B1 (% Wheat)	Labmill 2nd Break Feed (% Wheat)	Labmill B2 flour (% Wheat)	Fine Middlings from B2 (% Wheat)	Large Middlings from B2 (% Wheat)
100% SOFT	0	Dry	77.5	5	80	10.6	9.8	22.1	57.4	14.5	21.0	12.9
100% SOFT	0	16.85%	72.6±0.9^{a}	4±0.4^{a}	68±3^{a}	11.0±0.2^{c}	10.6±0.2^{b}	23.4±0.5^{a}	54.5±0.5^{a}	12.1±0.2^{d}	17.8±0.2^{a}	10.9±0.3^{a}
100% SOFT	3	16.13%	71.7±0.9^{a}	3±0.4^{ab}	48±3^{b}	14.7±0.3^{b}	11.4±0.2^{a}	18.3±0.4^{b}	55.3±0.6^{a}	12.7±0.2^{c}	16.1±0.2^{b}	9.1±0.2^{b}
100% SOFT	6	16.00%	71.9±0.9^{a}	2±0.4^{b}	46±3^{b}	15.1±0.3^{ab}	11.4±0.2^{a}	17.6±0.4^{b}	55.6±0.6^{a}	13.4±0.2^{b}	16.1±0.2^{b}	9.0±0.2^{b}
100% SOFT	12	16.30%	73.9±0.9^{a}	2±0.4^{b}	50±3^{b}	15.6±0.3^{a}	11.6±0.2^{a}	17.8±0.4^{b}	54.7±0.5^{a}	14.4±0.2^{a}	16.1±0.2^{b}	8.8±0.2^{b}
100% SOFT	24	16.40%	73.8±0.9^{a}	2±0.4^{b}	50±3^{b}	15.6±0.3^{a}	11.5±0.2^{a}	17.7±0.4^{b}	55.1±0.6^{a}	14.6±0.2^{a}	16.4±0.2^{b}	8.9±0.2^{b}
100% SOFT	48	16.20%	73.7±0.9^{a}	2±0.4^{b}	50±3^{b}	15.6±0.3^{a}	11.6±0.2^{a}	17.7±0.4^{b}	55.1±0.6^{a}	14.4±0.2^{a}	16.2±0.2^{b}	9.0±0.2^{b}
50% SOFT 50% HARD	0	Dry	76.5	5	84	9.3	9.0	21.3	60.9	14.2	24.3	14.2
50% SOFT 50% HARD	0	16.37%	73.0±0.9^{a}	5±0.4^{a}	77±3^{a}	9.7±0.2^{c}	9.8±0.2^{b}	21.8±0.4^{a}	58.6±0.6^{a}	11.7±0.2^{c}	21.4±0.2^{a}	12.3±0.3^{a}
50% SOFT 50% HARD	3	15.91%	71.5±0.9^{b}	4±0.4^{a}	65±3^{b}	11.3±0.2^{b}	9.9±0.2^{b}	18.4±0.4^{b}	60.1±0.6^{a}	12.1±0.2^{c}	19.8±0.2^{b}	11.6±0.3^{ab}
50% SOFT 50% HARD	6	15.91%	71.5±0.9^{ab}	4±0.4^{a}	64±3^{b}	11.9±0.2^{ab}	10.1±0.2^{ab}	17.9±0.4^{b}	60.1±0.6^{a}	12.9±0.2^{b}	19.8±0.2^{b}	11.5±0.3^{b}
50% SOFT 50% HARD	12	16.20%	73.3±0.9^{ab}	4±0.4^{a}	65±3^{b}	12.5±0.2^{a}	10.3±0.2^{ab}	18.2±0.4^{b}	58.9±0.6^{a}	13.7±0.2^{a}	19.7±0.2^{b}	10.7±0.2^{c}
50% SOFT 50% HARD	24	16.20%	72.8±0.9^{ab}	4±0.4^{a}	67±3^{b}	12.4±0.2^{a}	10.3±0.2^{ab}	18.2±0.4^{b}	59.0±0.6^{a}	13.5±0.2^{a}	19.8±0.2^{b}	10.7±0.2^{c}
50% SOFT 50% HARD	48	16.00%	73.0±0.9^{ab}	4±0.4^{a}	67±3^{b}	12.4±0.2^{a}	10.5±0.2^{a}	18.2±0.4^{b}	58.9±0.6^{a}	13.7±0.2^{a}	19.8±0.2^{b}	10.7±0.2^{c}
100% HARD	0	Dry	76.1	6	93	7.6	8.0	21.0	64.2	13.9	27.8	15.0
100% HARD	0	16.38%	71.8±0.9^{a}	6±0.4^{a}	87±3^{a}	7.1±0.1^{d}	8.5±0.2^{c}	20.1±0.4^{a}	64.5±0.6^{a}	11.5±0.2^{c}	25.8±0.3^{a}	13.9±0.3^{a}
100% HARD	3	15.96%	71.3±0.9^{a}	6±0.4^{a}	82±3^{ab}	8.4±0.2^{c}	8.5±0.2^{c}	18.4±0.4^{b}	64.8±0.6^{a}	12.3±0.2^{b}	23.8±0.3^{b}	13.3±0.2^{ab}
100% HARD	6	15.80%	71.8±0.9^{a}	5±0.4^{a}	78±3^{b}	9.0±0.2^{b}	9.0±0.2^{b}	18.2±0.4^{b}	63.9±0.6^{a}	12.7±0.2^{ab}	23.6±0.3^{bc}	12.6±0.3^{bc}
100% HARD	12	15.90%	73.4±0.9^{a}	5±0.4^{a}	80±3^{ab}	9.6±0.2^{a}	9.5±0.2^{a}	19.5±0.4^{a}	61.4±0.6^{b}	12.9±0.2^{a}	23.0±0.3^{c}	12.1±0.3^{c}
100% HARD	24	16.00%	73.4±0.9^{a}	5±0.4^{a}	80±3^{ab}	9.5±0.2^{a}	9.6±0.2^{a}	19.6±0.4^{a}	61.3±0.6^{b}	12.8±0.2^{a}	23.2±0.3^{bc}	12.0±0.3^{c}
100% HARD	48	15.90%	73.2±0.9^{a}	5±0.4^{a}	78±3^{b}	9.5±0.2^{a}	9.4±0.2^{ab}	19.2±0.4^{ab}	61.9±0.6^{b}	12.9±0.2^{a}	23.3±0.3^{bc}	12.2±0.3^{c}

Wheat Mix	Tempering Time (H)	Final H20% (real)	LabMill Coarse Bran (% Wheat)	LabMill Sizing Feed (% Wheat)	Labmill Sizing flour (% Wheat)	Fine Middlings from Sizer (% Wheat)	LabMill Fine Bran (% Wheat)	LabMill Reduction feed (% Wheat)	Labmill Red1 flour (% Wheat)	Labmill Red2 flour (% Wheat)	Labmill Red3 flour (% Wheat)	LabMill Shorts (% Wheat)
100% SOFT	0	Dry	8.3	35.0	17.7	7.8	8.3	38.6	27.2	4.2	1.3	5.4
100% SOFT	0	16.85%	13.4±0.4^{c}	34.3±0.4^{a}	17.3±0.4^{a}	7.6±0.2^{a}	9.0±0.2^{a}	36.0±0.8^{a}	25.2±1.2^{a}	4.4±0.3^{a}	1.4±0.2^{a}	4.6±0.3^{a}
100% SOFT	3	16.13%	17.3±0.6^{a}	27.4±0.3^{b}	14.3±0.4^{b}	5.9±0.2^{b}	6.9±0.2^{b}	33.3±0.7^{b}	23.2±1.1^{a}	4.6±0.4^{a}	1.3±0.1^{ab}	3.7±0.2^{b}
100% SOFT	6	16.00%	17.0±0.6^{a}	26.6±0.3^{b}	13.7±0.3^{b}	5.7±0.2^{b}	7.0±0.2^{b}	33.1±0.7^{b}	22.9±1.1^{a}	4.6±0.4^{a}	1.3±0.1^{ab}	3.8±0.2^{b}
100% SOFT	12	16.30%	15.0±0.5^{b}	26.7±0.3^{b}	13.6±0.3^{b}	5.5±0.2^{b}	7.3±0.2^{b}	33.3±0.7^{b}	24.6±1.2^{a}	3.7±0.3^{a}	1.0±0.1^{b}	3.5±0.2^{b}
100% SOFT	24	16.40%	15.0±0.5^{b}	26.6±0.3^{b}	13.4±0.3^{b}	5.6±0.2^{b}	7.3±0.2^{b}	33.5±0.7^{b}	24.8±1.2^{a}	3.7±0.3^{a}	1.0±0.1^{b}	3.5±0.2^{b}
100% SOFT	48	16.20%	15.1±0.5^{b}	26.7±0.3^{b}	13.4±0.3^{b}	5.5±0.2^{b}	7.3±0.2^{b}	33.3±0.7^{b}	24.3±1.2^{a}	4.1±0.3^{a}	1.1±0.1^{ab}	3.6±0.2^{b}
50% SOFT 50% HARD	0	Dry	8.0	35.4	17.0	8.7	9.6	42.0	29.7	5.1	1.5	5.9
50% SOFT 50% HARD	0	16.37%	12.7±0.4^{d}	34.2±0.4^{a}	16.0±0.4^{a}	8.6±0.2^{a}	9.4±0.3^{a}	39.8±0.9^{a}	28.2±1.3^{a}	5.3±0.4^{a}	1.6±0.2^{a}	4.7±0.3^{a}
50% SOFT 50% HARD	3	15.91%	16.1±0.5^{a}	30.0±0.4^{b}	14.1±0.4^{b}	7.6±0.2^{b}	7.9±0.2^{b}	37.3±0.8^{b}	25.7±1.2^{a}	5.2±0.4^{a}	1.6±0.2^{a}	4.2±0.3^{ab}
50% SOFT 50% HARD	6	15.91%	15.9±0.5^{ab}	29.3±0.4^{bc}	13.4±0.3^{b}	7.4±0.2^{bc}	8.3±0.2^{b}	37.3±0.8^{b}	26.3±1.2^{a}	4.9±0.4^{a}	1.6±0.2^{a}	4.1±0.3^{ab}
50% SOFT 50% HARD	12	16.20%	14.6±0.5^{bc}	28.9±0.3^{c}	13.6±0.3^{b}	7.0±0.2^{c}	8.0±0.2^{b}	37.0±0.8^{b}	26.1±1.2^{a}	5.2±0.4^{a}	1.4±0.2^{a}	3.8±0.3^{b}
50% SOFT 50% HARD	24	16.20%	14.7±0.5^{bc}	28.9±0.3^{c}	13.5±0.3^{b}	7.1±0.2^{bc}	8.2±0.2^{b}	37.2±0.8^{b}	25.2±1.2^{a}	5.8±0.4^{a}	1.6±0.2^{a}	4.1±0.3^{ab}
50% SOFT 50% HARD	48	16.00%	14.3±0.5^{c}	29.0±0.3^{c}	13.2±0.3^{b}	7.1±0.2^{bc}	8.4±0.2^{b}	37.4±0.8^{b}	26.4±1.2^{a}	5.2±0.4^{a}	1.5±0.2^{a}	4.0±0.2^{ab}
100% HARD	0	Dry	7.3	36.0	15.9	9.6	10.4	45.4	31.2	6.3	1.8	6.3
100% HARD	0	16.38%	12.6±0.4^{c}	34.0±0.4^{a}	13.5±0.3^{ab}	9.5±0.2^{a}	10.3±0.3^{a}	43.8±1.0^{a}	29.7±1.4^{a}	6.6±0.5^{a}	1.9±0.2^{a}	4.7±0.3^{a}
100% HARD	3	15.96%	14.9±0.5^{a}	31.7±0.4^{b}	12.3±0.3^{c}	9.2±0.2^{ab}	8.9±0.2^{b}	41.5±0.9^{ab}	27.6±1.3^{a}	6.7±0.5^{a}	2.1±0.2^{a}	4.5±0.3^{a}
100% HARD	6	15.80%	14.4±0.5^{ab}	30.8±0.4^{b}	12.7±0.3^{bc}	8.8±0.2^{bc}	8.8±0.2^{b}	41.4±0.9^{ab}	27.7±1.3^{a}	6.6±0.5^{a}	2.0±0.2^{a}	4.6±0.3^{a}
100% HARD	12	15.90%	13.2±0.4^{bc}	31.6±0.4^{b}	13.8±0.3^{a}	8.5±0.2^{c}	9.0±0.2^{b}	41.0±0.9^{b}	28.3±1.3^{a}	6.4±0.5^{a}	1.7±0.2^{a}	4.2±0.3^{a}
100% HARD	24	16.00%	13.0±0.4^{c}	31.6±0.4^{b}	13.9±0.3^{a}	8.6±0.2^{bc}	9.2±0.3^{b}	41.3±0.9^{ab}	29.1±1.4^{a}	5.8±0.5^{a}	1.7±0.2^{a}	4.3±0.3^{a}
100% HARD	48	15.90%	13.1±0.4^{c}	31.4±0.4^{b}	13.4±0.3^{ab}	8.6±0.2^{bc}	9.2±0.3^{b}	41.3±0.9^{ab}	29.0±1.4^{a}	6.1±0.5^{a}	1.6±0.2^{a}	4.3±0.3^{a}

Table 1: Milling results obtained on the 3 wheat blends at different tempering times and same moisture level time (16%). Results are expressed as a function of the wheat entering 1st break.

B1 is an informative stream to study because it directly receives the wheat kernel after tempering (*Campbell & Webb*, *2001*). The first observation is that B1 fine particles (flour and fine middlings) follow the same trend: a significant increase between 0 and 12^h tempering time followed by a plateau. This illustrates the fact that water has diffused from the outer layers of the kernel to the interior within 12^h, regardless of wheat hardness, increasing flour production to a maximum that cannot be exceeded by longer resting times.

Large particles from B1 exhibit more complex behavior. Between 0 and 3^h the quantity of large particles sent to B2 increases. These large particles are mostly composed of large bran particles with significant amounts of endosperm adhering to them (*Butcher & Stenvert*, *1973b*). Concomitantly, we can see a drop in the amount of B1 large middlings produced. Our hypothesis is that, at this time, the majority of the water is still on the periphery of the kernel, hydrating the bran and making it softer (*Dubat & Bock*, *2019*).

A softer bran is more susceptible to break into larger particles, which increases the B2 feed at the expense of the B1 large middlings. As water migrates to the center of the grain between 6 and 12^h of tempering time, the outer part becomes somewhat "drier".

The bran breaks into smaller particles, thus reducing the amount of B2 feed while increasing the quantity of B1 large middlings. After 12^h the process stabilizes and no more changes are observed. ***Table 2*** shows the results as a function of the quantity of product entering the stream.

In the case of B2 (and subsequent streams), the observations from ***Table 1*** are impacted by the fact that, depending on the crushing behavior of the wheat at B1, more or less product is sent to the following stream. In the case of B2 flour, the analysis remains the same regardless of the point of reference. The dry sample (i.e. no tempering) clearly exhibits higher flour extraction as observed in B1.

Wheat Mix	Tempering Time (H)	Final H20% (real)	LabMill Extraction (%)	Labmill Resistance Index	LabMill Apparent Hardness	Labmill B1 flour (% Wheat)	Fine Middlings from B1 (% Wheat)	Large Middlings from B1 (% Wheat)	Labmill 2nd Break Feed (% Wheat)	Labmill B2 flour (% Stream)	Fine middlings B2 (% Stream)
100% SOFT	0	Dry	77.5	5	80	10.6	9.8	22.1	57.4	25.4	36.7
100% SOFT	0	16.85%	72.6±0.9^{a}	4±0.4^{a}	68±3^{a}	11.0±0.2^{b}	10.6±0.2^{a}	23.4±0.5^{a}	54.5±0.5^{a}	22.3±0.3^{c}	32.7±0.4^{a}
100% SOFT	3	16.13%	71.7±0.9^{a}	3±0.4^{ab}	48±3^{b}	14.7±0.3^{a}	11.4±0.2^{a}	18.3±0.4^{b}	55.3±0.6^{a}	22.9±0.3^{c}	29.0±0.3^{b}
100% SOFT	6	16.00%	71.9±0.9^{a}	2±0.4^{b}	46±3^{b}	15.1±0.3^{a}	11.4±0.2^{a}	17.6±0.4^{b}	55.6±0.6^{a}	24.1±0.3^{bc}	29.0±0.3^{b}
100% SOFT	12	16.30%	73.9±0.9^{a}	2±0.4^{b}	50±3^{b}	15.6±0.3^{a}	11.6±0.2^{a}	17.8±0.4^{b}	54.7±0.5^{a}	26.3±0.3^{ab}	29.5±0.3^{b}
100% SOFT	24	16.40%	73.8±0.9^{a}	2±0.4^{b}	50±3^{b}	15.6±0.3^{a}	11.5±0.2^{a}	17.7±0.4^{b}	55.1±0.6^{a}	26.5±0.3^{a}	29.8±0.3^{b}
100% SOFT	48	16.20%	73.7±0.9^{a}	2±0.4^{b}	50±3^{b}	15.6±0.3^{a}	11.6±0.2^{a}	17.7±0.4^{b}	55.1±0.6^{a}	25.3±0.3^{ab}	30.3±0.3^{ab}
50% SOFT 50% HARD	0	Dry	76.5	5	84	9.3	9.0	21.3	60.9	23.3	39.9
50% SOFT 50% HARD	0	16.37%	73.0±0.9^{a}	5±0.4^{a}	77±3^{a}	9.7±0.2^{c}	9.8±0.2^{b}	21.8±0.4^{a}	58.6±0.6^{a}	20.0±0.3^{c}	36.5±0.4^{a}
50% SOFT 50% HARD	3	15.91%	71.5±0.9^{a}	4±0.4^{a}	65±3^{b}	11.3±0.2^{b}	9.9±0.2^{b}	18.4±0.4^{a}	60.1±0.6^{a}	20.1±0.3^{c}	32.9±0.4^{a}
50% SOFT 50% HARD	6	15.91%	71.5±0.9^{a}	4±0.4^{a}	64±3^{b}	11.9±0.2^{ab}	10.1±0.2^{ab}	17.9±0.4^{a}	60.1±0.6^{a}	21.5±0.3^{b}	33.0±0.4^{a}
50% SOFT 50% HARD	12	16.20%	73.3±0.9^{a}	4±0.4^{a}	65±3^{b}	12.5±0.2^{a}	10.3±0.2^{ab}	18.2±0.4^{a}	58.9±0.6^{a}	23.2±0.3^{a}	33.5±0.4^{a}
50% SOFT 50% HARD	24	16.20%	72.8±0.9^{a}	4±0.4^{a}	67±3^{b}	12.4±0.2^{a}	10.3±0.2^{ab}	18.2±0.4^{a}	59.0±0.6^{a}	22.9±0.3^{a}	33.6±0.4^{a}
50% SOFT 50% HARD	48	16.00%	73.0±0.9^{a}	4±0.4^{a}	67±3^{b}	12.4±0.2^{a}	10.5±0.2^{a}	18.2±0.4^{a}	58.9±0.6^{a}	23.2±0.3^{a}	33.7±0.4^{a}
100% HARD	0	Dry	76.1	6	93	7.6	8.0	21.0	64.2	21.6	43.4
100% HARD	0	16.38%	71.8±0.9^{a}	6±0.4^{a}	87±3^{a}	7.1±0.1^{d}	8.5±0.2^{c}	20.1±0.4^{a}	64.5±0.6^{a}	17.9±0.3^{d}	40.1±0.4^{a}
100% HARD	3	15.96%	71.3±0.9^{a}	6±0.4^{a}	82±3^{ab}	8.4±0.2^{c}	8.5±0.2^{c}	18.4±0.4^{b}	64.8±0.6^{a}	19.0±0.3^{c}	36.8±0.4^{b}
100% HARD	6	15.80%	71.8±0.9^{a}	5±0.4^{a}	78±3^{b}	9.0±0.2^{b}	9.0±0.2^{b}	18.2±0.4^{b}	63.9±0.6^{a}	19.8±0.3^{b}	37.0±0.4^{b}
100% HARD	12	15.90%	73.4±0.9^{a}	5±0.4^{a}	80±3^{ab}	9.6±0.2^{a}	9.5±0.2^{a}	19.5±0.4^{a}	61.4±0.6^{b}	20.9±0.3^{a}	37.5±0.4^{b}
100% HARD	24	16.00%	73.4±0.9^{a}	5±0.4^{a}	80±3^{ab}	9.5±0.2^{a}	9.6±0.2^{a}	19.6±0.4^{a}	61.3±0.6^{b}	20.9±0.3^{a}	37.8±0.4^{b}
100% HARD	48	15.90%	73.2±0.9^{a}	5±0.4^{a}	78±3^{b}	9.5±0.2^{a}	9.4±0.2^{ab}	19.2±0.4^{ab}	61.9±0.6^{b}	20.8±0.3^{a}	37.7±0.4^{b}

Wheat Mix	Tempering Time (H)	Final H20% (real)	Large Middling B2 (% Stream)	LabMill Coarse Bran (% Stream)	Sizing Flour (% Stream)	Sizing Fine Middlings (% Stream)	Labmill Fine Bran (% Stream)	Red1 Flour (% Stream)	Red2 flour (% Stream)	Red3 Flour (% Stream)	Red3 Shorts (% Stream)
100% SOFT	0	Dry	22.5	14.4	50.5	22.2	23.7	70.4	38.9	19.5	80.8
100% SOFT	0	16.85%	20.0±0.4^{a}	24.6±0.8^{c}	50.6±1.3^{a}	22.1±0.6^{a}	26.2±0.7^{ab}	70.0±3.3^{a}	45.1±3.6^{a}	24.9±2.7^{a}	81.2±5.1^{a}
100% SOFT	3	16.13%	16.5±0.4^{b}	31.4±1.0^{a}	52.4±1.3^{a}	21.5±0.6^{a}	25.2±0.7^{b}	69.6±3.3^{a}	50.9±4.0^{a}	27.6±3.0^{a}	76.7±4.8^{a}
100% SOFT	6	16.00%	16.3±0.4^{b}	30.6±1.0^{ab}	51.5±1.3^{a}	21.3±0.6^{a}	26.2±0.7^{ab}	69.1±3.3^{a}	50.2±4.0^{a}	27.1±3.0^{a}	79.6±5.0^{a}
100% SOFT	12	16.30%	16.2±0.4^{b}	27.4±0.9^{bc}	50.9±1.3^{a}	20.7±0.6^{a}	27.3±0.8^{a}	74.0±3.5^{a}	47.0±3.7^{a}	23.4±2.6^{a}	80.3±5.1^{a}
100% SOFT	24	16.40%	16.2±0.4^{b}	27.3±0.9^{bc}	50.4±1.3^{a}	21.0±0.6^{a}	27.5±0.8^{a}	74.2±3.5^{a}	46.3±3.6^{a}	23.5±2.6^{a}	80.8±5.1^{a}
100% SOFT	48	16.20%	16.7±0.4^{b}	27.4±0.9^{bc}	50.4±1.3^{a}	20.8±0.6^{a}	27.5±0.8^{a}	72.8±3.4^{a}	49.5±3.8^{a}	25.0±2.8^{a}	79.4±5.0^{a}
50% SOFT 50% HARD	0	Dry	23.2	13.2	48.1	24.7	27.2	70.7	41.2	20.4	81.0
50% SOFT 50% HARD	0	16.37%	21.0±0.5^{a}	21.7±0.7^{c}	46.7±1.2^{a}	25.1±0.7^{a}	27.6±0.8^{ab}	70.9±3.3^{a}	48.0±3.8^{a}	26.3±2.9^{a}	77.0±4.8^{a}
50% SOFT 50% HARD	3	15.91%	19.3±0.4^{b}	26.8±0.9^{a}	47.2±1.2^{a}	25.3±0.7^{a}	26.5±0.7^{b}	69.0±3.3^{a}	49.4±3.9^{a}	29.3±3.2^{a}	74.8±4.7^{a}
50% SOFT 50% HARD	6	15.91%	19.0±0.4^{b}	26.5±0.9^{ab}	45.7±1.2^{a}	25.1±0.7^{a}	28.1±0.8^{ab}	70.4±3.3^{a}	48.4±3.8^{a}	28.0±3.1^{a}	74.6±4.7^{a}
50% SOFT 50% HARD	12	16.20%	18.2±0.4^{b}	24.8±0.8^{ab}	47.2±1.2^{a}	24.1±0.6^{a}	27.9±0.8^{ab}	70.5±3.3^{a}	50.4±4.0^{a}	27.5±3.0^{a}	74.0±4.7^{a}
50% SOFT 50% HARD	24	16.20%	18.2±0.4^{b}	24.9±0.8^{ab}	46.6±1.2^{a}	24.4±0.6^{a}	28.2±0.8^{ab}	67.9±3.2^{a}	50.7±4.0^{a}	28.9±3.2^{a}	71.9±4.5^{a}
50% SOFT 50% HARD	48	16.00%	18.2±0.4^{b}	24.3±0.8^{b}	45.5±1.1^{a}	24.5±0.6^{a}	29.0±0.8^{a}	70.5±3.3^{a}	49.2±3.9^{a}	27.1±3.0^{a}	73.5±4.6^{a}
100% HARD	0	Dry	23.4	11.4	44.2	26.6	28.9	68.6	44.2	22.3	78.4
100% HARD	0	16.38%	21.6±0.5^{a}	19.6±0.6^{b}	39.6±1.0^{c}	27.9±0.7^{a}	30.2±0.8^{a}	67.7±3.2^{a}	50.8±4.0^{a}	29.3±3.2^{a}	72.9±4.6^{a}
100% HARD	3	15.96%	20.5±0.5^{ab}	23.0±0.8^{a}	40.9±1.0^{bc}	28.9±0.8^{a}	27.9±0.8^{b}	66.5±3.1^{a}	51.5±4.1^{a}	32.3±3.6^{a}	70.3±4.4^{a}
100% HARD	6	15.80%	19.7±0.5^{b}	22.5±0.7^{a}	41.5±1.0^{abc}	28.5±0.7^{a}	28.6±0.8^{ab}	66.8±3.1^{a}	51.2±4.0^{a}	31.7±3.5^{a}	72.3±4.6^{a}
100% HARD	12	15.90%	19.7±0.5^{b}	21.4±0.7^{ab}	43.9±1.1^{a}	27.0±0.7^{a}	28.5±0.8^{ab}	68.9±3.2^{a}	52.2±4.1^{a}	28.1±3.1^{a}	71.0±4.5^{a}
100% HARD	24	16.00%	19.6±0.5^{b}	21.1±0.7^{ab}	43.9±1.1^{a}	27.1±0.7^{a}	29.0±0.8^{ab}	70.5±3.3^{a}	49.5±3.9^{a}	28.6±3.2^{a}	71.8±4.5^{a}
100% HARD	48	15.90%	19.8±0.5^{b}	21.2±0.7^{ab}	42.8±1.1^{ab}	27.3±0.7^{a}	29.2±0.8^{ab}	70.3±3.3^{a}	51.5±4.1^{a}	27.9±3.1^{a}	74.6±4.7^{a}

Table 2: Milling results obtained from 5 wheat blends at different tempering times and same moisture level time (16%). Results are expressed as a function of the amount of product feeding the particular stream.

As also seen previously in B1, adding water without resting time (i.e. 0 h tempering time) results in a large drop in flour production (-3.5%) at B2 that then gradually increases until 12 h where it remains stable across longer tempering times (***Figure 4***). The increase in flour production observed between 0 and 12^h tempering time is quite constant at ~4% for all samples. For the B2 fine middlings, there is a drop in production between 0 and 6 h with no subsequent change for longer tempering times. The same finding applies for B2 large middlings, but the time to reach stability is 12^h. There is a clear effect of resting time that allows for more flour and fewer middlings at B2, which illustrates the gradual improvement in ease of fractionation of the grain (i.e. a softer kernel).

Coarse bran production (***Figure 5***) exhibits an interesting pattern with increasing tempering time. Whatever the wheat type, there is an increase in coarse bran production between 0 and 3^h followed by a decrease between 6 and 12^h at which point the curve plateaus. Here again we hypothesize that this is an expression of the water migration from the bran to the center of the grain. This coarse bran pattern, as with B1 and B2 stream patterns, demonstrates that significant physico-mechanical changes occur during 0 – 12^h tempering, and these changes are more or less stable or complete for tempering times longer than 12^h.

Because large middlings production from B1 and B2 tend to decrease with tempering time, the quantity of product feeding the sizings also decreases. The sizings feed represents about 34% of the wheat at B1 for both hard and soft wheats. After 12^h it is stable at 32% for hard wheat (-3%); 29% for the 50/50 blend (-5%), and 27% for soft wheat (-7%). Hard wheat tends to produce a larger quantity of large middlings after 12^h than soft wheat because hard wheat endosperm is more resistant to crushing. This observation is a direct expression of wheat hardness and agrees with the findings of various authors (*Campbell et al., 2007; Dobrasczyk, 1994*).

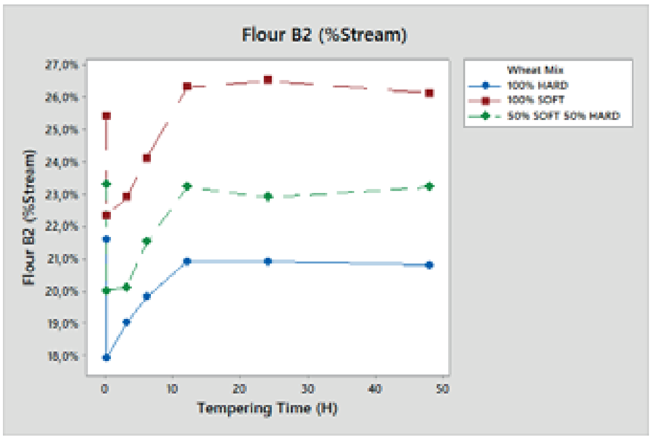

Figure 4: Flour production at B2 as a function of tempering time

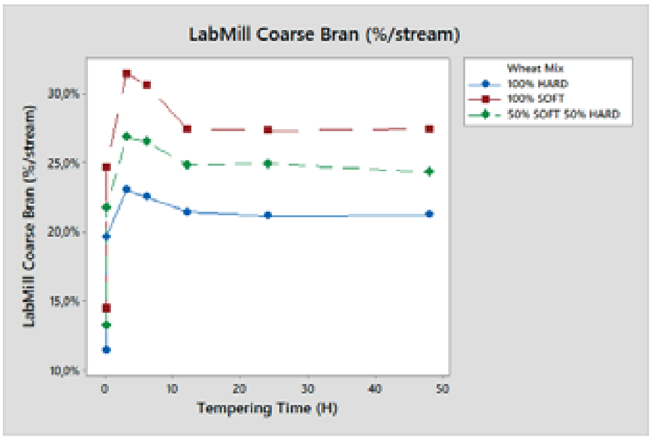

Figure 5: Coarse bran production as a function of tempering time

Figure 6 illustrates trends in the fine middlings feeding the sizings stream. The behavior observed in the curve is related to the ease of water penetration into the kernel (depending on the wheat hardness) and its effect on the grain milling properties. The fine middlings production from soft wheat is relatively constant with a slight decreasing trend between 0 and 12^h tempering time. We propose that, as the water penetrates the soft wheat endosperm, the mellowing of the structure facilitates the extraction of flour, thus producing less fine middlings.

For hard wheat there is an initial increase in fine middlings production concomitant with lower flour production. This pattern in hard wheat is related to water diffusing more slowly into harder grain, thus the inner endosperm remains harder (i.e. “drier”) for a longer time and fractionates into larger particles rather than flour. The 50/50 sample supports this idea by exhibiting behavior in between that of hard and soft wheats. For fine bran and flour the situation between 0 and 12^h is a global tendency to increase and then stabilize. Some authors also came to the conclusion that even the bran composition would be responsible for a faster or slower water penetration into the kernel (*Lee & Stenvert, 1973*).

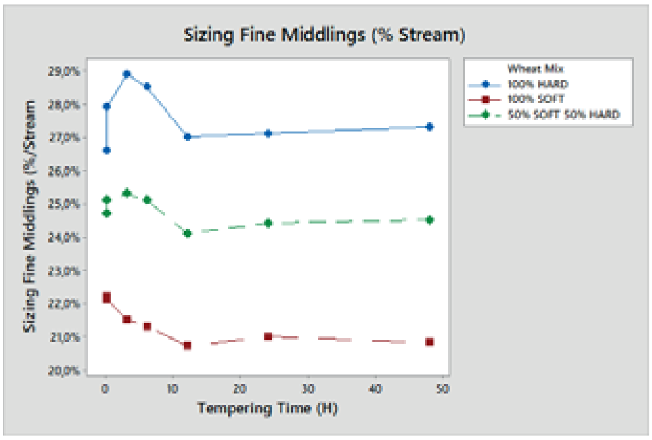

Figure 6: Sizings fine middlings production as a function of tempering time

The reduction feed decreases from dry wheat to 3^h of tempering time where it reaches a plateau. Few additional differences are seen at this stage of the milling process in agreement with the findings of Hook et al. (*1982*) and of Hook et al. (*1984*).

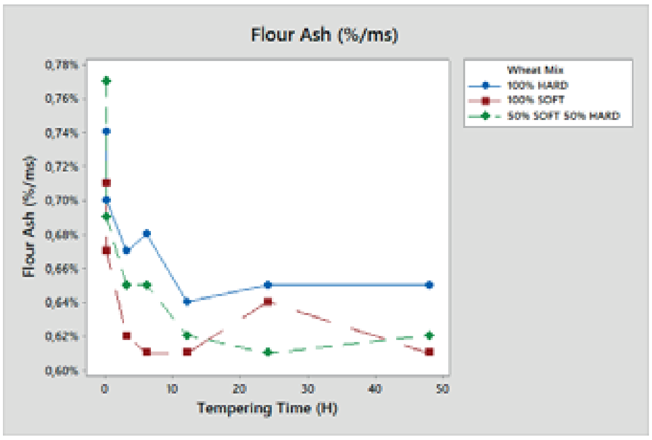

Figure 7: Influence of wheat tempering time on flour ash content

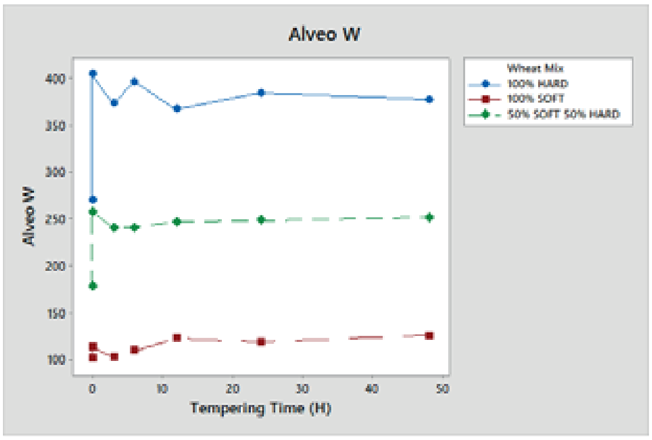

Figure 8: Influence of wheat tempering time on flour Alveograph W value

◆ Influence of the tempering time on flour quality

Table 3 shows the flour characteristics and quality from the milled samples. Except for dry wheat where it is slightly higher, the protein content is not dependent on the tempering time. The situation is significantly different for ash content (***Figure 7***). Dry-milled wheat exhibits a high ash content, confirming that the bran breaks into small particles that are not easily separated from the flour fraction. There is a clear decreasing trend in ash content between 0 and 12^{h} of tempering time with soft wheat hitting its minimum value earlier than hard wheat. After 12^{h} a plateau reached at minimum ash content for both wheats.

Similarly, starch damage is the greatest for dry-milled wheat. For the Alveograph data (P, G, Ie, W) the tests done on dry-milled wheat are significantly different. Between 0 and 12^{h}, flour quality varies according to the effect of tempering time on milling behavior. These variations are due to changes in factors such as damaged starch and ash contents, as noted above.

Especially in the dry samples, the presence of more small bran fragments, as evidenced by the higher ash content (***Figure 6***), results in lower P and W values (***Table 3***, ***Figure 7***) because these particles weaken the gluten protein network (*Dubois, 2005*). This is especially relevant for the hard wheat and blended samples where harder kernels result in an increased tendency for bran to shatter on crushing.

Once water is introduced to the process at 0^{h} tempering, the tendency to produce many small bran particles is reduced compared to dry wheat. However, the water has not fully migrated into the kernel, thus starch damage remains relatively high, especially in hard wheat samples. This drives an increase in P and W values as damaged starch is known to increase water absorption (*Dubois, 2005*). After 12 hours, the ash content has reached an minimum and levels of damaged starch have decreased and stabilized, thus Alveograph results do not vary for longer resting times.

Wheat Mix	Tempering Time (H)	Final H20% (real)	Flour Moisture (%)	Flour Protein (% ms)	Flour Ash (% ms)	Starch Damage (UCD)	Alveo P	Alveo G	Alveo W	Alveo Ie
100% SOFT	0	Dry	13.0%	8.6%	0.71%	17.4	39	24.2	101	38.1
100% SOFT	0	16.85%	15.8±0.2^{a}	8.3±0.2^{a}	0.67±0.02^{a}	16.8±0.6^{a}	48±1.9^{a}	19.0±0.5^{c}	113±5^{abc}	47.0±0.5^{c}
100% SOFT	3	16.13%	15.8±0.2^{a}	8.1±0.2^{a}	0.64±0.02^{ab}	15.1±0.6^{b}	40±1.6^{bc}	20.1±0.5^{bc}	102±4^{c}	48.6±0.5^{ab}
100% SOFT	6	16.00%	15.9±0.2^{a}	8.1±0.2^{a}	0.62±0.02^{ab}	15.0±0.6^{b}	39±1.6^{c}	20.9±0.5^{ab}	109±4^{bc}	49.1±0.5^{ab}
100% SOFT	12	16.30%	15.8±0.2^{a}	8.3±0.2^{a}	0.61±0.02^{b}	15.9±0.6^{ab}	44±1.8^{ab}	21.2±0.5^{ab}	122±5^{a}	49.2±0.5^{a}
100% SOFT	24	16.40%	15.9±0.2^{a}	8.4±0.2^{a}	0.61±0.02^{b}	15.7±0.6^{ab}	41±1.6^{bc}	22.1±0.6^{a}	118±5^{ab}	47.8±0.5^{bc}
100% SOFT	48	16.20%	15.8±0.2^{a}	8.2±0.2^{a}	0.61±0.02^{b}	16.1±0.6^{ab}	42±1.7^{bc}	22.3±0.6^{a}	125±5^{a}	48.6±0.5^{ab}
50% SOFT 50% HARD	0	Dry	12.7	11.9	0.77	19.2	50	29.5	177	43.8
50% SOFT 50% HARD	0	16.37%	15.3±0.2^{a}	11.5±0.2^{a}	0.69±0.02^{a}	18.6±0.6^{a}	63±2.5^{a}	27±0.7^{a}	257±10^{a}	53.3±0.5^{c}
50% SOFT 50% HARD	3	15.91%	15.4±0.2^{a}	11.5±0.2^{a}	0.65±0.02^{ab}	17.0±0.6^{ab}	55±2.2^{b}	27.6±0.7^{ab}	240±10^{a}	54.7±0.5^{ab}
50% SOFT 50% HARD	6	15.91%	15.5±0.2^{a}	11.5±0.2^{a}	0.65±0.02^{ab}	16.4±0.6^{b}	54±2.2^{b}	27.8±0.7^{ab}	240±10^{a}	54.7±0.5^{ab}
50% SOFT 50% HARD	12	16.20%	15.7±0.2^{a}	11.5±0.2^{a}	0.62±0.02^{b}	15.9±0.6^{b}	57±2.3^{ab}	27.3±0.7^{ab}	246±10^{a}	55.7±0.5^{a}
50% SOFT 50% HARD	24	16.20%	15.7±0.2^{a}	11.5±0.2^{a}	0.61±0.02^{b}	18.2±0.6^{a}	53±2.1^{b}	29±0.7^{a}	248±10^{a}	54.7±0.5^{ab}
50% SOFT 50% HARD	48	16.00%	15.5±0.2^{a}	12.0±0.2^{a}	0.62±0.02^{b}	17.5±0.6^{ab}	58±2.3^{ab}	27.8±0.7^{ab}	251±10^{a}	54.2±0.5^{bc}
100% HARD	0	Dry	12.7	15.7	0.74	20.1	70	28.8	270	48.1
100% HARD	0	16.38%	15.4±0.2^{a}	15.0±0.2^{a}	0.70±0.02^{a}	18.2±0.6^{a}	87±3.5^{a}	27.5±0.7^{c}	404±16^{a}	59.4±0.5^{a}
100% HARD	3	15.96%	15.3±0.2^{a}	14.9±0.2^{a}	0.67±0.02^{ab}	18.4±0.6^{a}	78±3.1^{b}	28.1±0.7^{bc}	373±15^{a}	59.1±0.5^{a}
100% HARD	6	15.80%	15.4±0.2^{a}	15.0±0.2^{a}	0.68±0.02^{ab}	18.8±0.6^{a}	77±3.1^{b}	29.5±0.7^{ab}	396±16^{a}	59.4±0.5^{a}
100% HARD	12	15.90%	15.6±0.2^{a}	15.4±0.2^{a}	0.64±0.02^{b}	19.1±0.6^{a}	78±3.1^{b}	28.3±0.7^{bc}	367±15^{a}	57.3±0.5^{b}
100% HARD	24	16.00%	15.6±0.2^{a}	15.4±0.2^{a}	0.65±0.02^{ab}	19.3±0.6^{a}	77±3.1^{b}	30.5±0.8^{a}	384±15^{a}	56.1±0.5^{b}
100% HARD	48	15.90%	15.6±0.2^{a}	15.4±0.2^{a}	0.65±0.02^{ab}	19.2±0.6^{a}	78±3.1^{b}	29.5±0.7^{ab}	377±15^{a}	56.3±0.5^{b}

Table 3: Quality attributes of 5 wheat blends after laboratory milling procedures at different tempering times and same moisture level time (16%).

Conclusions

This project aimed at studying the impact of tempering time on 3 wheat samples varying in hardness (soft, hard, and a 50/50 blend) tempered to 16% MC. Observations from the flour extraction rates after different tempering times showed the same trends regardless of the sample hardness.

Our first observation is that removing the tempering step entirely has a major impact on wheat performance during milling. Dry samples generate flour with much higher ash content and starch damage. For these reasons dry milling is not representative of tempered wheat behavior during milling nor does it produce flour of similar quality. For these reasons, milling of dry grain is not a best practice at the laboratory level.

For tempered wheat we observe 2 primary groupings based on tempering time. The first grouping occurs between 0 and 12^h of tempering time and is characterized by major changes in wheat performance during milling. It is also a period of changes in terms of flour quality. These changes are due to the time-related migration of water to the center of the kernel. The speed with which these changes occur are influenced by the wheat hardness. Because of this period of instability, the authors would not recommend selecting a tempering time of less than 12^h for laboratory purposes.

This seems contradictory with the results of Finney and Andrews (*1986*) who recommended a 30 minute conditioning method. But is must be stressed that they focused on extraction rate and ash content of SRWW and did not include any observations on flour rheological properties. The second grouping was observed between 12 and 48^h of tempering time.

In this area all indicators (milling performance and flour quality) were stable. It appears that the tempering process has achieved a point of stability at 12^h and beyond, and it is therefore recommended to mill the grain during this period. Furthermore, our results did not show or showed only limited influence of the initial wheat hardness on the milling performance and flour quality, meaning that a different tempering time and/or protocol for hard vs. soft wheat is not necessary at the laboratory level.

Some of the findings might not be in complete agreement with milling at the industrial level. Our findings demonstrate that what is mandatory at the industry level is not necessarily mandatory at the laboratory level. It should be stressed that the objectives and tools are very different between industry and the laboratory. Where industry tries to maximize the extraction of a certain quality of flour using a longer, more complex mill flow with many streams, the laboratory aims to produce as much flour as possible of a representative quality.

Achieving this result with a reduced mill flow (6 streams in our study) necessarily requires a much less rigorous approach. Being more aggressive, laboratory mills can lose part of the sensitivity achievable in a complete industrial mill flow. From our study it appears that basic best milling practices must be followed at the laboratory level (tempering) because they clearly impact the milling performance and the final flour quality. But it also appears that tempering wheat as a function of its hardness does not bring any beneficial effect.

Based on this series of studies, our recommendations for laboratory milling are:

- Wheat must be tempered before milling,
- Separate tempering protocols for hard and soft wheats are unnecessary, and
- Tempering time should be at least 12^h with a final tempering moisture content between 15 and 17% (16% recommended).

This final recommendation is in agreement with ISO 27971 Standard recommending 16% moisture content and 24^h resting time.

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