Using the eight-roller mill in the purifier-less mill flow

Aleksandar Fistes · Dušan Rakić

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Abstract Double grinding of mill streams without intermediate sieving, i.e. the eight-roller milling system provides opportunities for significant reduction of capital cost compared to conventional wheat flour milling system. In this study the effects of using the eight-roller mill in the purifier-less mill flow were investigated. Middlings from the break system of commercial flour mill, which would be sent to the purification system, were intercepted and employed in the experiments. Milling results obtained with double grinding of middlings were compared with the results obtained by conventional system with intermediate sifting before regrinding of stock. At the same roll gap setting and under the same sieving conditions, the eight-roller system produced less flour compared to the conventional system. Results showed that the most efficient way to increase flour yield in the eight-roller milling system is to increase the upper size limit of flour by increasing the sieve aperture. This is not followed by the deterioration of flour quality as determined by ash content. Increase of the upper size limit of flour particles is followed by the decrease of the flour ash content suggesting that it is possible to implement the eight-roller mills in the purifier-less mill flow.

Keywords Wheat flour milling · Eight-roller mill · Roll gap · Sieve aperture · Flour release · Flour ash content

Introduction

The objective of the wheat flour milling process is to produce the maximum quantity of flour as efficiently as possible (at the

lowest cost), according to consumer quality requirements. Essentially, it is the process of separating the bran and germ from the endosperm and converting the endosperm into flour. This should be achieved with the lowest possible contamination with bran and germ that increase the flour ash content.

The wheat flour milling is a gradual reduction process consisting of sequential and consecutive particle reduction and particle separation operations (Loza-Garay and Flores 2003). After each grinding stage a mixture of coarse, medium and fine fractions (including flour) is sieved and the undersize material is removed before regrinding. The roller mills are the primary grinders in the flour mill (Posner and Hibbs 2005). In a roller mill, particles are subjected to shear and compressive forces (Haque 1991). Segregation between the kernel parts occurs in plansifters, where sieves separate particles of different size, and in purifiers, where sieves and air-flow separate particles of different size, specific gravity and shape (Posner 2000). The objective of the break system is to open the wheat kernel and remove the endosperm and germ from the bran coat with the least amount of bran contamination, and at the same time, obtain a granulation distribution of maximum large middlings with a minimum of flour and small middlings. However, some shattering of the bran occurs and results in a mixture of endosperm and bran in the released middlings (Posner and Hibbs 2005). The purpose of the purifiers is to separate the endosperm from the branny fragments (endosperm with attached bran and bran particles) that come with middling stocks (Flamer 2008a). Also, it grades the endosperm into particle size ranges. The clean endosperm from the purifier is sent to the reduction system. After grinding in each reduction roll, the stock is sifted, flour is removed and coarser particles are sent to the following reduction rolls (Sakhare et al. 2013).

Modern flour milling is a complex process and millers are constantly looking for the ways to make it more efficient by reducing the investment and production costs so that they can make a profit (Loza-Garay and Flores 2003). Significant

A. Fistes (✉) · D. Rakić
Faculty of Technology, University of Novi Sad, Bulevar Cara Lazara
1, 21000 Novi Sad, Serbia
e-mail: fistes@uns.ac.rs

savings are achieved by reducing the number of machines and amount of floor space required for them (Flamer 2008a). By supplementing the rolls with more auxiliary machines such as impact mills, bran dusters and drum detachors, it was possible to reduce the number of rolls and therefore the number of process steps (Posner and Hibbs 2005; Sakhare et al. 2012).

In the conventional milling system, intermediate sifting occurs after every roller milling operation. Double grinding of intermediate streams before sieving has been one of the most notable process developments in flour milling (Owens 2001). The eight-roller mill (8 rolls in one housing), also known as two high or double high roller mill, provides two grinding passages without any intermediate sifting. Many flour mills introduced eight-roller mill in order to reduce capital cost. With this milling concept there is less installation, energy and maintenance cost, with fewer sifters, pneumatic lifts, filters, number of roll stands, spouting and auxiliary components and less space requirements (Baltensperger 1993, 1997, 2001; Posner and Hibbs 2005; Eugster 2001; Wanzenried 1991; Tegeler 1999). On the other hand, disadvantages of the eight-roller mill concept are mainly coming from the fact that the undersize material produced on the upper pair of rolls is not removed before regrinding on the lower pair of rolls which are not design to mill them (Flamer 2008b). Hence, it is very important to define the passages and optimal processing parameters that allow the introduction of the eight-roller mill into the milling process without disturbing the

flowsheet. By achieving similar milling results to those obtained with the conventional system, the mill streams and the overall extraction rates of flour in the mill would not be affected as well as flour quality as perceived by the end users.

In recent years, the role of purifiers in the mill flow has diminished as millers have evaluated their costs effectiveness. Some of the disadvantages are that they: require monitoring and constant adjustment by the miller, have high capital, maintenance and operating costs, the air used for stratification dries the material which increases bran breakage in the reduction system, and have low capacity per unit of floor space (Posner and Hibbs 2005; Flamer 2008a). The use of debranning machines to remove the bran ahead of the first break results in less bran in the middlings and decreases the need for purifiers (Posner and Hibbs 2005; Dexter and Wood 1996). Also, demands towards higher ash in baker's flour and less demand for low ash flour (patent), decreases the need for extensive purification (Posner and Hibbs 2005). Flamer (2008a) indicated that absence of purifiers can be compensated with careful planning of the mill flow, by using the modern plansifters that are capable of stratifying the stock in much the same way a purifier does, by optimizing the sifter surface allocation and by adjusting the roll parameters such as roll fluting, roll spirals, etc.

Even though the eight-roller mills have found a place in the modern flour milling process, relatively little research has been performed on various factors affecting the milling results

Table 1 Flour release following 2R in the conventional (C) and eight-roller (E) milling systems

Roll gap [mm]	Flour release (%)											
	<132 μm		<150 μm		<180 μm		<200 μm		<212 μm		<224 μm	
	C	E	C	E	C	E	C	E	C	E	C	E
1R-0.15 2R-0.07	8.4	7.1	10.8	10.3	12.7	12.1	14.8	13.9	17.4	16.3	20.4	18.6
1R-0.15 2R-0.05	9	7.8	11.7	10.7	13.5	12.6	15.6	14.6	18.3	17.1	21.6	19.9
1R-0.15 2R-0.04	9.4	7.7	12.3	11.3	14.3	13.3	16.7	15.4	19.7	17.9	23.3	20.6
1R-0.11 2R-0.07	9.8	8.4	12.2	11.5	14.1	13.3	16.4	15.4	19.3	17.9	22.7	20.4
1R-0.11 2R-0.05	9.3	8.1	12	11.7	14	13.7	16.3	15.8	19.3	18.4	23.1	21.6
1R-0.11 2R-0.04	9.8	8.2	13	12	15.1	14	17.5	16.3	20.8	19.1	25.1	22.4
1R-0.08 2R-0.07	10.1	8.7	12.8	12.2	15	14	17.4	16.7	20.6	19.4	23.6	22.3
1R-0.08 2R-0.05	10.4	9.1	13.6	13.4	15.8	15.7	18.2	18.2	21.5	21.3	25.8	24.7
1R-0.08 2R-0.04	10.7	10.1	14.6	14	17.1	16.4	19.7	19.2	23.4	22.6	27.8	26.1
<i>t</i> -test	$p=0.000002$		$p=0.000179$		$p=0.000208$		$p=0.000402$		$p=0.000104$		$p=0.000011$	

Table 2 Flour release and ash content in the flour following 2R in the conventional and eight-roller milling systems

Roll gap [mm]	Conventional system		Eight-roller system					
	<132 μm		<132 μm		<180 μm		<224 μm	
	Flour release (%)	Ash content (%) _{dm}	Flour release (%)	Ash content (%) _{dm}	Flour release (%)	Ash content (%) _{dm}	Flour release (%)	Ash content (%) _{dm}
1R-0.15 2R-0.07	8.4	0.55	7.1	0.61	12.1	0.53	18.6	0.51
1R-0.15 2R-0.05	9.0	0.56	7.8	0.60	12.6	0.53	19.9	0.51
1R-0.15 2R-0.04	9.4	0.56	7.7	0.65	13.3	0.55	20.6	0.53
1R-0.11 2R-0.07	9.8	0.57	8.4	0.60	13.3	0.53	20.4	0.52
1R-0.11 2R-0.05	9.3	0.56	8.1	0.58	13.7	0.52	21.6	0.50
1R-0.11 2R-0.04	9.8	0.57	8.2	0.55	14.0	0.49	22.4	0.48
1R-0.08 2R-0.07	10.1	0.55	8.7	0.56	14.0	0.49	22.3	0.47
1R-0.08 2R-0.05	10.4	0.57	9.1	0.54	15.7	0.50	24.7	0.48
1R-0.08 2R-0.04	10.7	0.57	10.1	0.51	16.4	0.47	26.1	0.46
Conventional system <132 μm			$p=0.346593$		$p=0.000964$		$p=0.000074$	
Eight-roller system <132 μm					$p=0.000006$		$p=0.000003$	
Eight-roller system <180 μm							$p=0.000008$	

p -values refer to paired t-tests between ash contents

obtained using this technique. In our previous work (Fistes et al. 2008) we compared the milling results obtained using a conventional process and process with an eight-roller mill employed on the front passages of the reduction system. Actually, the stream leaving the purifier was intercepted and employed in the experiment. With the combination of the eight-roller mills and without using the purifiers in the process, it is possible to significantly reduce the investment and operating costs. This is the reason why this paper investigates the possibilities of employing the eight-roller mills in the purifier-less mill flow, that is for grinding the stocks that would go from the break system into the reduction system without purifying.

Materials and methods

Material

The samples were obtained from a commercial mill having five break (B1-B5), four sizing (1R-4R) and six reduction (1 M-6 M) passages with a milling capacity of 120 tons per day. Coarse middlings from the second break plansifter having a particle size range between 530 and 1000 μm were intercepted and employed in the experiments. According to the mill flowsheet, this stream would have been sent to the purification system. Following the purification the clean separations would be sent to the head end of the sizing system (1R milling passage).

Milling procedure

The samples were separated using the automatic sampler divider into 1 kg batches and milled on the Variostuhl (Miag) laboratory roll stand. Smooth rolls 0.1 m in length and 0.25 m in diameter were used. A differential of 1.25 was employed relative to a fast roll speed of 5 m/s. Experiments

Table 3 Analysis of variance for selected factorial model

Flour release				
Parameter	Sum of Squares	F-Value	p -value	Contribution (%)
A	41,70889	320,2673	0.0001	4,680209
B	10,73389	82,42161	0.0001	1,204464
C	818,7756	6287,079	0.0001	91,87587
AB	1,203333	9,239957	0.0070	0,135028
AC	6,3075	48,43299	0.0001	0,707773
BC	3	23,0359	0.0001	0,336634
A ²	0,806667	6,194099	0.0228	0,090517
C ²	8,64	66,34341	0.0001	0,969506
Flour ash content				
Parameter	Sum of Squares	F-Value	p -value	Contribution (%)
A	0,0162	79,94517	0.0001	29,84087
B	0,000939	4,63331	0.0437	1,729461
C	0,030422	150,1302	0.0001	56,03861
AB	0,002133	10,52776	0.0041	3,929662
AC	0,001008	4,976011	0.0373	1,857379
C ²	0,003585	17,69248	0.0004	6,604015

were designed to simulate the conventional and eight-roller milling systems.

For conventional milling system the entire stock following the first grinding passage (1R) was sieved for 3 min (laboratory sifter MLU 300, Bühler). The part of stock held on the sieve fitted with 224 μm bolting cloth was milled on the second grinding passage (2R). The feed rate to 1R was 0.35 kg/cm/min. The feed rate to 2R was slower according to the mass of flour removed by intermediate sifting, while the time of the grinding runs were the same for both milling passages (17 s).

For the eight-roller milling system, the entire stock following 1R was milled on the 2R without intermediate sifting. On both milling passages the samples were fed at the rate of 0.35 kg/cm/min.

For both milling systems the 1R feeds were milled at three roll gaps 0.15, 0.11 and 0.08 mm. The gap settings

for the 2R rolls were set at 0.07, 0.05 and 0.04 mm. The stock following the second grinding passage (2R) was sieved for the 3 min using the sieve with 224 μm bolting cloth. Flour obtained on 1R and 2R in conventional system, and on 2R in the eight-roller system, was additionally sieved using the sieve openings of 212, 200, 180, 150 and 132 μm , along with the bottom collecting pan. The stock held on each sieve and pan was weighed. The ash content in flour fractions were determined according to ICC standard method No.104/1 (ICC 1990).

Statistical analysis

Two samples were milled and sifted at the same conditions and a total of 72 grinding runs were performed, 36 on each 1R and 2R. Based on the 3σ rule, the 99.7 % estimated confidence interval for the data presented in the paper is ± 0.37 %.

Fig. 1 Pareto chart of effects of main parameters and their interactions on (a) flour release and (b) flour ash content

Fig. 2 Influence of main parameters on flour release in the eight-roller milling system: (a) 1R roll gap, (b) 2R roll gap and (c) sieve aperture

Milling results obtained with a conventional and eight-roller milling systems were compared by the paired Student's *t*-test. The significant level was established at $p < 0.05$. A full factorial design (3^3) was used to study the effect of 1R roll gap (parameter A), 2R roll gap (parameter B) and sieve aperture (parameter C), as well as their interactions, on flour release and flour ash content in the process with the eight-roller mill (Anderson and Whitcomb 2007; Antony 2003; Montgomery 2001). The studied independent factors were: 1R roll gap (0.15, 0.11 and 0.08 mm); 2R roll gap (0.07, 0.05 and 0.04 mm) and sieve aperture (132, 180 and 224 μm). Contribution and significance of main factors and their interactions are presented by Pareto chart. The suitability for ANOVA application within the factorial design was checked by plotting a normal plot of residuals and residuals vs. predicted plot. Calculations were obtained by Design-Expert 7.0 (trial version).

Results and discussion

At the same roll gap setting and with the same sieve size, the eight-roller system produces less flour compared to the conventional system (Table 1). The difference is statistically

significant ($p < 0.05$) and it is a constant trend regardless of the actual sieve that has been used. This is similar to the results obtained in previous studies on the effects of using the eight-roller mill on the head end passages of the reduction system (Fistes et al. 2008). The under sized material (flour) produced during the first grinding step (the upper pair of rolls) is not removed before regrinding. These particles take on some of the stresses in the grinding zone of the lower pair of rolls therefore reducing the grinding efficiency which results in lower flour release. Posner and Hibbs (2005) stated that the lower pair of rolls should be considered to be 0.75 of their actual length because regrinding the material made up of significantly different particle sizes and quality is less effective. In conventional milling system the flour is removed by intermediate sifting and the stresses in the grinding zone act on the remaining coarse particles in the stock. However, in contrast to clean separation from the purifier, coarse middlings released in the break system represent a mixture of pure endosperm, endosperm with attached bran and bran particles. In the smooth roll grinding zone, especially with small roll differential, the compressive forces are dominant. While wheat endosperm exhibits brittleness when fracturing, bran is tough and fibrous and it is flattened under the dominant

Fig. 3 Influence of main parameters on flour ash content in the eight-roller milling system: (a) 1R roll gap, (b) 2R roll gap and (c) sieve aperture

Fig. 4 Normal plot of residuals and residuals vs. predicted plot for flour release

compressive forces. These branny particles also absorb some of the stresses in the grinding zone of the lower pair of rolls which otherwise would be used to grind the coarse endosperm particles.

One of the main advantages of the eight-roller milling system is a significant reduction of sifter surface. On the other hand, this means that there is less sifter surface to get the flour out. Since the flour is not removed after the first grinding step the mass fraction of flour in the stock following the second grinding step is

much higher compared to the appropriate milling passage in the conventional system. In addition to that, by regrinding the flour released through the first passage, flour granulation becomes finer which makes it even more difficult to be sifted efficiently. Tegeler (1999) stated that the granulation from flour produced on the eight-roller mill is considerably finer with hard wheat and slightly finer with soft wheat.

Since there is less equipment in the process, every roll adjustment and the separation of each sifter passage is very

Fig. 5 Normal plot of residuals and residuals vs. predicted plot for flour ash content

important. Improper roll adjustments mean less separation on the sifter and more product carryover to the next passage (Tegeler 1999). The majority of the roll parameters are not adjustable during the actual flour milling process. However, the roll gap can be adjusted during the process and at the same time it is a parameter with the strongest influence on milling results as confirmed by number of previous studies (Scanlon and Dexter 1986; Scanlon et al. 1988; Campbell and Webb 2001; Campbell et al. 2001). The reduction of grinding efficiency in the eight-roller milling system could be overcome by decreasing the roll gap setting thereby imposing the greater compressive forces in the grinding zone. Sifting efficiency also depends on a number of different factors such as disposable sifter area, cloth tension, number of gyrations per minute, feed rate to the sifter, flour flowability, etc. (Curran et al. 1994; Wingfield and Ferrer 1984; Neel and Hosene 1984). Under industrial conditions, replacement of the sieve frames in plansifter with different sieve aperture is probably the easiest way to influence sifting efficiency.

In order to study the effect of 1R roll gap (parameter A), 2R roll gap (parameter B) and sieve aperture (parameter C), as well as their interactions, on flour release and flour ash content in the process with the eight-roller mill, a factorial design (3^3) was used. The model resulted in 27 different combinations of experiment (Table 2).

Table 3 (ANOVA table) and Fig. 1 (Pareto chart) clearly show that the change of sieve aperture has the highest influence on flour release (Fig. 1a) with contribution >90 %, as well as on ash content in the flour following 2R (Fig. 1b) with contribution >56 %. In contrast to flour release, the flour ash content is much more influenced by 1R roll gap (29.8 %). The increase of sieve aperture causes significant increase of flour release, while the decrease of the roll gap setting on both 1R and 2R has been followed by the slight increase of flour release (Fig. 2). The increase of the sieve aperture and decrease of 1R roll gap is followed by the decrease of the flour ash content (Fig. 3). Note that in Figs. 2 and 3 values of other two parameters (which are not observed in particular case) are set on the medium level. In addition, normal distribution of residuals and homogeneity of variances are confirmed by Fig. 4 (flour release) and Fig. 5 (ash content), since the points are distributed across a straight line on the normal plot of residuals, i.e. has a random scatter on the residuals vs. predicted plot.

At the same roll gap setting and with same sieve opening (132 μm) the difference between the ash content of the flour obtained in conventional and eight-roller milling systems (Table 2) is not statistically significant ($p>0.05$). By increasing the upper size limit of flour in the eight-roller system, from 132 μm to 180 μm , flour ash content decreased and the difference is statistically significant ($p<0.05$). Further increase from 180 μm to 224 μm also resulted in significant decrease ($p<0.05$) of flour ash content. This is favorable for the eight-roller milling system. The reason for these trends lie in a fact

that double grinding of middlings stock before sifting, with dominant compressive forces in the grinding zone, helps flatten the bran flakes and therefore makes it easier to scalp them off. Increase of the upper size limit of flour particles, followed by the increase of flour yield is not followed by increased grinding of the bran which would otherwise pass into flour and increase flour ash content. This suggests that it is possible to implement the eight-roller mills in the purifierless mill flow. However, certain shift in particle size distribution of flour is to be expected.

Conclusion

The introduction of the eight-rollers into the milling process provides numerous advantages compared to the conventional system considering investment, operating and maintenance costs. Without using the purifiers in the process these costs can be further reduced. However, if these advantages are to be fully exploited the flour yield and quality should not be compromised. At the same rolls and sifter adjustment, double grinding of unpurified coarse middlings from the break system produces less flour compared to conventional system. By appropriate increase of the sieve aperture it is possible to increase flour yield in the process with the eight-roller mill. At the same time, this change of the sieving condition is followed with the decrease of flour ash content.

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