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REDUCTION OF WHEAT MIDDLINGS USING A CONVENTIONAL AND EIGHT-ROLLER MILLING SYSTEMS

Aleksandar Z. Fišteš and Đuro M. Vukmirović

Possibilities for the rationalization of the wheat flour milling process using the eight-roller mill on the 1M and 2M passages of the reduction system have been investigated. At the same roll gaps and under the same sieving conditions, the lower flour yield has been obtained using an eight-roller mill compared to the conventional milling system (5-8 %) followed by a higher energy requirements for grinding. By decreasing the roll gap setting and increasing the upper size limit of flour in the process with the eight-roller mill it is possible to increase flour yield and therefore decrease milling energy consumption per unit mass of flour produced without deterioration of flour quality as determined by ash content. With appropriate adjustments of the processing parameters in the eight-roller milling system it is possible to achieve similar milling results to those in the conventional system, while the overall investment, energy and maintenance costs are significantly lower.

KEY WORDS: Wheat flour milling, process rationalization, eight-roller mill

INTRODUCTION

The objective of the wheat flour milling process is to separate the branny cover and germ of the wheat kernel from the endosperm and achieve as high as possible flour extraction with the lowest contamination of bran and germ that increase the ash content. Breaking the wheat kernel is affected by corrugated cast steel rolls that gradually separate the endosperm, bran and germ. Reduction of relatively pure endosperm to flour is achieved by using smooth rolls. Segregation between the kernel parts occurs in plansifters, where sieves separate particles of different size, and in purifires, where sieves and air-flow separate particles of different size, specific gravity and shape (1).

Ever since the grinding of grain has been known to the mankind, possibilities and solutions have been sought out in order to simplify the grinding process and make it more efficient. New concepts and ideas only have chance of being successful if the yield as well as the quality of the finished products are not affected and requirements such as reduction of investment, operating and maintenance cost are met (2). The traditional

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wisdom in flour milling is that after every grinding step the ground material should be sieved and the undersize material removed before regrinding (3). Over the years the main equipment used in the grinding system has been redesigned to such an extent that it has been possible to multiply the throughputs of these machines but flour process technology has not changed fundamentally since the introduction of the roller mill, the purifier and the plansifter (4). This is the reason why the double grinding of intermediate streams before sieving has been one of the most notable process developments in flour milling (3). Eight-roller mill (a total of 8 rolls in one housing) provides two grinding passages without any intermediate sifting. Compared to a conventional process with the four-roller mill, the introduction of the eight-roller mill into the milling flowsheet offers the following advantages (2, 4, 5-8):

- fewer pneumatic suction lifts (conveying the stock from the roll to the sifter) – resulting in lower material and installation costs
- lower pneumatic system air requirements – resulting in lower energy costs and lower filter surface requirements for cleaning the pneumatic conveying air
- reduction of sifter surface
- smaller number of roll stands
- less spouting and auxiliary components
- lower space requirements for equipment installation – resulting in lower building costs for the new milling plants or increase in grinding capacity within existing limited building space
- more compact building design makes it easier to keep clean with less area to fumigate
- with less equipment there is less cleaning and maintenance.

On the other hand, twin stage grinding ignores the milling principle that, after grinding, coarse material is separated from the fines and therefore the conditions for controlled milling are less favorable. The decision as to how many double grinding passages can be applied in the flowsheet depends directly on the finished products to be made. It is not always possible to equip installations exclusively with eight-roller mills (4, 8). This is the reason why it is very important to define the passages and optimal roll parameters that allow the introduction of the eight-roller mill into the milling process without deterioration of the yield and quality of finished products.

Even though the eight-roller mill has found its place in the modern flour milling process relatively little research has been performed on various factors affecting the milling results using this technique mainly focusing on the front passages of the break system (8-11) rather than the passages of the reduction system. It is evident that when the first and second breaks are combined into a twin passage, the particle size distribution of the stock will not be the same as with conventional single break system (2, 8, 11). There are several disadvantages of using this break system. First, it grinds fine material, coarse middlings, that should not pass to the next break roll, whose function is to separate endosperm from bran. Second, it produces more break flour and fine middlings and less coarse middlings and sizings that can be purified to produce clean middlings and low-ash flour. Third, the capacity of the lower roll is limited because the ground material is lower in density, which increases the volume to the roll (5). Tegeler (8) and Wanzenried (7) stated that the granulation from flour produced in the eight-roller mill is finer while the flour color is slightly whiter compared to the ones in the conventional process. The research of Zwingleberg (9) and Zwingleberg and Artz (10) showed that appropriate adjustment of the roll parameters is needed regardless of whether the eight-roller mill is used on breakage or reduction passages.

Under industrial conditions, only the roll gap settings and feed rate (to a limited degree) can be adjusted during the milling process. The aim of this work was to examine and compare the effect that roll gap changes have on the milling results (degree of particle size reduction, flour release, flour ash and milling energy requirements) obtained using the conventional process and process with an eight-roller mill employed on the 1st and 2nd midds (1M and 2M passages) of the reduction system.

EXPERIMENTAL

The samples were obtained from an industrial mill (120 t/day) intercepting the stream (middlings) that would have been sent to the 1M. In this particular mill (having five break, four sizing and six reduction passages) the eight-roller mills are not employed. The samples (50 kg) were separated using the automatic sampler divider (Gompper-Maschinen KG) into 0.5 kg batches and milled on a Variostuhl (model C Ex 2) – laboratory roll stand (Miag). Smooth rolls 0.1 m in length and 0.25 m in diameter were used. Table 1 summarizes the experimental range of variables tested.

The experiments were designed to compare:

a.) conventional milling system – the entire stock following 1M was sieved for 3 min on a Bühler laboratory sifter (model MLU-300) and the part of the stock held on the sieve fitted with 150 µm bolting cloth was milled on 2M

b.) eight-roller milling system – the entire stock following 1M was milled on the 2M without intermediate sifting

Table 1. Summary of experimental range of variables tested

Milling system	Roll surface	Roll gap combinations [mm]	Feed rate [kg/cm/min]	Differential	Fast roll speed [m/s]
Conventional	Smooth	1M-0.10; 2M-0.08 1M-0.10; 2M-0.05 1M-0.08; 2M-0.05	1M-0.20; 2M-0.15*	1.25	5
Eight-roller			1M-0.20; 2M-0.20		

*The slower feed rate on 2M corresponds to the amount of flour removed by intermediate sifting of the stock leaving 1M

Sieve analysis of the entire stock following 2M was performed on the above Bühler laboratory sifter for 3 min. For the conventional milling system the sieve openings were 250, 200 and 150 µm, along with the bottom collecting pan. For the eight-roller milling system three different stacks of sieves were used. The first stack was the same as that mentioned above. In the second, the sieve with the 150 µm bolting cloth was replaced with a sieve having 180 µm bolting cloth, and for the third stack the sieve openings were 250 and 200 µm.

Two samples were milled and sieved under the same conditions. The weight distribution among the streams was highly reproducible. Based on the 3σ rule, the 99.7% estimated confidence interval for the data (weight percentages) presented in the paper is ±0.37%.

Flour yield F (%) in the eight-roller and conventional milling systems was calculated from Equations (Eqs.) [1] and [2], respectively.

$$F(\%) = \frac{m_{2M}}{M} * 100(\%) \quad [1]$$

$$F(\%) = \frac{m_{1M} + m_{2M}}{M} * 100(\%) \quad [2]$$

The symbols *m* and *M* stand for the weights of the flour and native feed, respectively. The subscripts indicate flour following 1M or 2M. The ash content of the total quantity of flour leaving the 2M was determined according to ICC standard method No.104/1 (12).

The milling energy consumption during all grinding runs was determined from the wattmeter fitted as an integral part of the Variostuhl laboratory roll stand. Two different power readings were recorded corresponding to operation with (*P*, kW) and without (P^*, kW) the material flow. The milling energy consumption, *E* kJ/kg, in the conventional and eight-roller milling systems was calculated by Eqs. [3] and [4], respectively.

$$E = \frac{P_{1M} - P_{1M}^*}{m_{1M}} t_{1M} + \frac{P_{2M} - P_{2M}^*}{m_{2M}} t_{2M} \quad [3]$$

$$E = \frac{(P_{1M} - P_{1M}^*) + (P_{2M} - P_{2M}^*)}{m_{2M}} (t_{1M} + t_{2M}) \quad [4]$$

Here *m* (kg) is the mass of flour obtained and *t* (s) is the time of the grinding run determined by the chronometer. The significance of the differences between milling results obtained using investigated milling systems have been tested by the paired Student's t-test.

RESULTS AND DISCUSSION

Changes in the particle size distribution of the stocks leaving 2M, brought about by the decrease of the roll gap, followed the same trends in both milling systems. Considering that the 2M feeds were different for the two milling systems, yields of the size fractions of the milling output are not to be compared because the cumulative size distributions (Fig. 1a and 1b) were given relative to the mass of the material milled on the 2M and only serve to show the general trends. By decreasing the roll gap, the quantity of material >200 µm (size fractions >250 µm and 250/200 µm) tends to decrease while the flour yield (<150 µm) increased.

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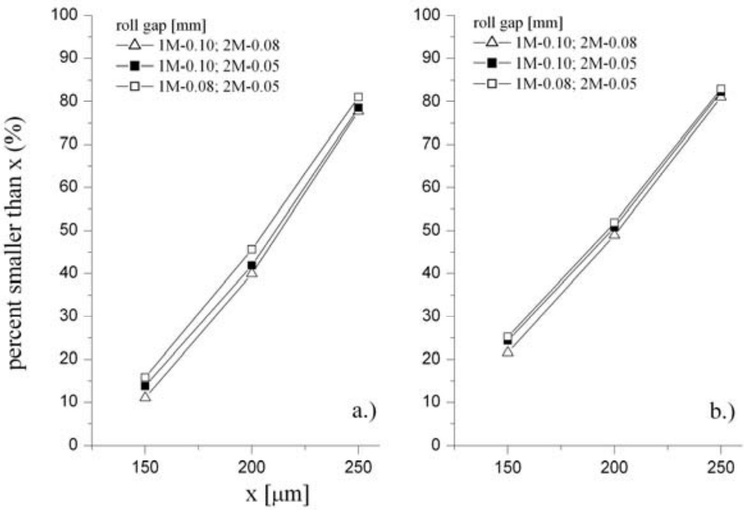

Fig. 1. Cumulative size distributions of the stocks following 2M milled through different roll gaps in the a) conventional milling system and b) eight-roller mill system

The factors affecting particle size reduction can be classified into those arising from the physicochemical properties of the material and those related to the design and operation of the milling equipment (13). In a roller mill particles are subjected to shear and compressive forces. The nature of deformation depends not only on the applied stresses but also on the particle components upon which the stresses act. Compressive stresses are more effective in causing the disintegration of the brittle endosperm material while bran (tough and fibrous) is more prone to the ductile fracture imparted by shear forces. The roll parameters such as roll gap, uniformity and the feed rate of stocks to rolls, roll velocities, differential and the type and condition of roll surface influence the magnitude of the stress and the relative contributions of compressive and shearing forces (14). Middlings are composed primarily of endosperm (they also contain adhering bran and germ) exhibiting viscoelasticity when fracturing. With roll differential closer to 1 the compressive forces dominate in the grinding zone. As the roll differential increases, greater shear stresses are imposed. Under the present grinding conditions, using the smooth rolls and relatively small differential – 1.25 (usual for this stage of grinding process), as the roll gap decreases greater compressive forces are imposed, thereby increasing the number of endosperm fractures creating more flour. Simultaneously, the tougher branny particles are flattened and remain in the coarsest size fractions of the milling output (>200 μm). In addition to that, decreasing the roll gap increases the grinding zone size (14) so the grinding action, under predominant compressive forces, is prolonged and also contributes to the greater flour release as a result of increased number of endosperm fractures. Ash is concentrated in the bran, with over half the total in the pericarp, testa and aleurone and the ash content increases from the inner (endosperm) to the outer (bran)

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part of the wheat kernel (15). The increase of the ash content of the coarsest fraction of the stock following 2M, while roll gap had no influence on flour ash content (Table 2), proves that bran particles remain intact. Scanlon and Dexter (16) and Scanlon, Dexter and Biliaderis (17), in their studies of the effect of smooth roll grinding conditions on reduction of wheat farina, also reported similar findings.

Table 2. Ash content in flour (<150 μm) and the coarsest fraction (>250 μm) of the stock following 2M in the conventional and eight-roller milling systems

Roll gap [mm]	**Ash content (%)$_{dm}$**			
	Conventional system		**Eight-roller system**	
	>250 μm	<150 μm	>250 μm	<150 μm
1M-0.10; 2M-0.08	1.16	0.38	1.12	0.37
1M-0.10; 2M-0.05	1.22	0.35	1.15	0.37
1M-0.08; 2M-0.05	1.27	0.35	1.17	0.38

At the same roll gap setting and under the same sieving conditions, the flour release was lower in the process involving the eight-roller mill compared to the conventional milling system (Fig. 2) and the difference is statistically significant ($p<0.05$). In the conventional system, flour particles are removed from the stock before regrinding on 2M by intermediate sifting, while in the absence of intermediate sifting remain in the material feeding the lower pair of rolls of the eight-roller mill (stock following 1M).

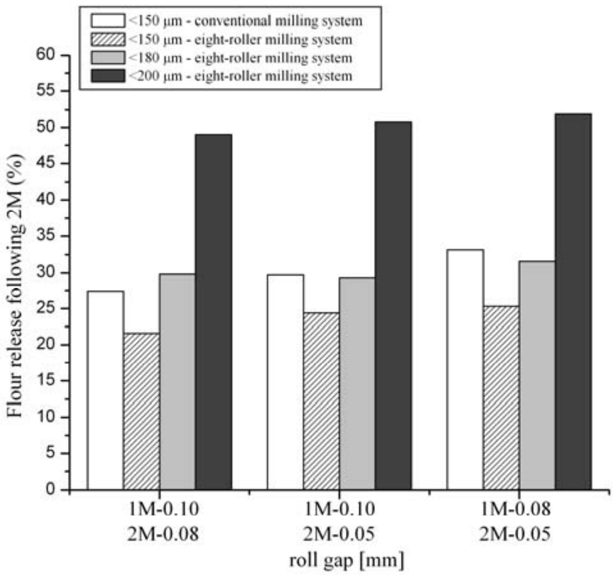

Fig. 2. Flour release following 2M in the conventional and eight-roller milling system

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These particles take on some of the stresses in the grinding zone which otherwise would be used to reduce the remaining middlings to flour, thereby explaining the lower flour release in the process with the eight-roller mill as well as the finer flour granulation as a result of further grinding of flour particles. Only one sifting operation in the process with eight-roller mill, compared to two in the conventional system, also contributed to lower flour yield. The amount of the flour in the stock following 2M is considerably higher in the eight-roller mill process, so the other probable cause could be inefficient sifting of the flour. Sifting efficiency depends on a number of different factors such as disposable sifter area, cloth tension, number of gyrations per minute, feed rate to the sifter, etc. (18,19). However, under industrial conditions, replacement of the sieves in the plansifter (changing the sieve aperture) is probably the easiest way to change the sieving conditions and therefore influence the sifting efficiency. At the same, roll gap setting in both milling systems, by replacing the 150 μm bolting cloth with sieves having 180 and 200 μm bolting cloths in the process with eight-roller mill, similar ($p>0.05$) or significantly higher ($p<0.01$) flour yield has been achieved compared to the one in the conventional system (Fig. 2). It needs to be pointed out that increasing the sieve size contributes to more efficient sifting but at the same time increases the upper size limit of flour, both causing the increase of the flour release.

By decreasing the roll gap setting in the process with the eight-roller mill compared to the gap in the conventional system, without changing the sieving conditions, it is possible to increase flour yield and it comes as a result of greater compressive forces imposed on the particles of the stock. Neither the roll gap adjustments nor the sieving conditions changes resulted in deterioration of flour quality since the flour ash remained constant ($p>0.05$) (Table 3). It shows that previously mentioned adjustments in the process were not followed by increased grinding of the bran which would otherwise pass into flour and increase flour ash.

Table 3. Ash content in the total amount of flour following 2M in the conventional and eight-roller milling systems

Roll gap [mm]	Ash content $(\%)_{dm}$			
	Conventional system	Eight-roller system		
	<150 [μm]	<150 [μm]	<180 [μm]	<200 [μm]
1M-0.10; 2M-0.08	0.39	0.37	0.38	0.36
1M-0.10; 2M-0.05	0.36	0.37	0.36	0.35
1M-0.08; 2M-0.05	0.36	0.38	0.37	0.37

Eqs. [3] and [4] define milling energy consumption relative to the mass of flour obtained. Under the same roll and sifting conditions, the energy required for grinding tends to be higher in the eight-roller mill process compared to that in the conventional milling system (Fig. 3) ($p<0.01$). It is mainly due to the lower flour yield in the eight-roller mill process. The heavier load in the 2M grinding zone in the process with eight-roller mill increases the power requirements in the operation with the material flow (P) and also

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contributes to higher energy consumption. The higher feed rate to the lower pair of rolls of the eight-roller mill, compared to feed rate on appropriate milling passage in conventional milling system, is unavoidable because there is no intermediate sifting and therefore no removal of the undersized material before regrinding. By increasing the flour release in the process with the eight-roller mill, by appropriate adjustment of the sieving conditions and/or roll gap (following the data presented on Fig. 2), it is possible to reduce the energy required for grinding (Fig. 3).

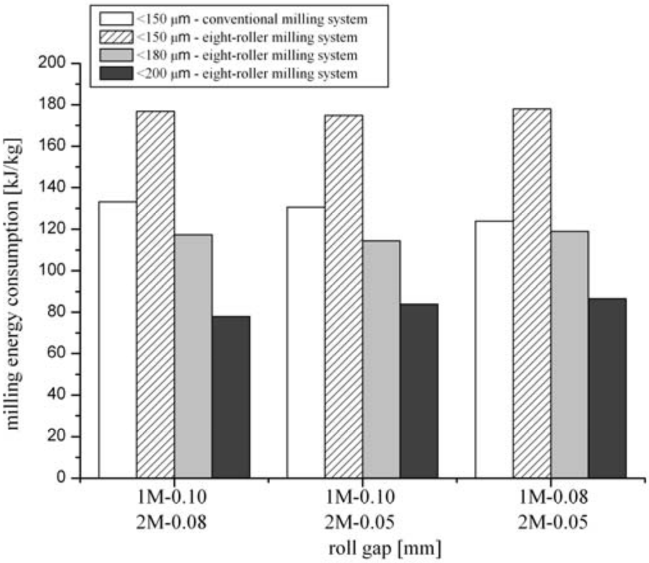

Fig. 3. Energy consumption in conventional and eight-roller milling systems

CONCLUSION

Compared to conventional milling system, the introduction of the eight-roller mill into the milling flow sheet offers numerous advantages which significantly contribute to the reduction of the production costs. With the appropriate adjustments of the sieving conditions or/and roll gap setting in the process with the eight-roller mill it is possible to achieve similar milling results to those in conventional milling system. This justifies the use of the eight-roller mill on the 1st and 2nd midds (1M and 2M passages) of the wheat flour milling process.

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ЕФЕКТИ МЛЕВЕЊА ПШЕНИЧНОГ ГРИЗА У КЛАСИЧНОМ И ПОСТУПКУ СА ОСМОВАЉНОМ СТОЛИЦОМ

Александар З. Фиштеш и Ђуро М. Вукмировић

Испитивана је могућност рационализације технолошког поступка млевења пшенице укључивањем осмоваљне столице на пролазиштима млевења гриза 1М и 2М. При истом вођењу ваљака и при употреби истог слога сита за просејавање млива, у поступку са осмоваљном столицом остварује се мањи принос брашна него у класичном поступку (5-8%), док је специфични утрошак енергије по јединици масе брашна већи. Нижим вођењем ваљака у поступку са осмоваљном столицом разлика у оствареном приносу брашна у поменутим поступцима се смањује без промене садржаја пепела у брашну. Корекцијом слога сита у поступку са осмоваљном столицом (повећањем величине отвора сејног ткива за одсејавање брашна) значајно се повећава принос брашна у поменутом поступку, што доприноси смањењу специфичног утрошка енергије за уситњавање. Такође, при томе није констатована промена садржаја пепела у брашну. Одговарајућим прилагођавањем процесних параметара могу се у поступку са осмоваљном столицом остварити ефекти уситњавања блиски ефектима у класичном поступку, а истовремено се остварују значајне инвестиционе и енергетске уштеде, што доприноси рационализацији технолошког поступка млевења пшенице.

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