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Milling Process of Cereal Grains and Quality of Flours

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Abstract: Recently, the great attention to high fibre diet increases the importance of a proper selection of raw materials to be used for producing cereal-based products. In this context, wheat bran turns out to be an interesting ingredient, due to its high fibre contents. Wheat bran can exert many physiological benefits, representing also a good substrate for useful lactic bacteria. The modern milling process based on the use of rollers is a rapid system that allows a gradual reduction of the endosperm to desired particle sizes, but bran and germ are separated. On the contrary, the most ancient milling process uses two stones to grind wheat kernels producing flour rich in vitamins, minerals, fibres and antioxidants. The modern roller milling process replaced the stone mill because is able to work larger amounts of seeds, but the resulting flours are deprived of nutritional compounds, compromised by the high temperature generally reached with the rollers. Technological options have to be adopted when whole wheat or bran enriched flours are used to produce cereal-based products because bran and germ particles generally produce a less homogeneous mixture which can physically interfere with a proper structure development. In the current work an overview of stone mills available at national levels will be presented. A mass balance of raw materials used during milling with stones, compared to process with modern rollers will be also provided. The process variables to be used during food production with enriched flours are also discussed.

Keywords: stone milling, roller milling, cereal chain, flour quality.

Introduction

Cereals and derived products are among the major dietary sources of essential elements for humans. Wheat is the main cereal crop used for human consumption in many areas worldwide. Common wheat (*Triticum aestivum* L.) is widely used for bread making, whereas durum wheat, i.e., *Triticum turgidum* L., is mainly employed in the production of other food items, pasta being the most popular. An increased consumer demand for healthy cereal food has led to considerable efforts to develop bread and pasta that combine health benefits with good sensory properties. The use of wholemeal flour is one strategy for development of healthy products as the consumption of whole grain has been shown to reduce the risk of colorectal cancer, cardiovascular diseases, diabetes and obesity (Slavin, 2004). In addition, wholemeal cereal foods play a key role in energy regulation through lowering postprandial glycemia and appetite. In fact, it is shown that various characteristics of wholegrain products are responsible for the potential health benefits, including a reduced energy density, increased volume and particle size, and a high content of dietary fibre and bioactive micro- and non-nutrients such as betain, magnesium (Mg), calcium (Ca), and B vitamins (Slavin, 2003). In this context, wheat bran turns out to be an interesting ingredient, due to its high fibre content. In fact, wheat bran can be defined as the outer layer of cereal grains that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine (Mongeau and Brooks 2003). Specifically, bran contains a significant amount of fibre in form of cellulose, pentosans and lignin.

The milling of cereals is a critical process that affects the nutritional composition of wheat-derived food products. Moreover, the milling technology has a greater impact on the sensory quality of pasta and bakery products. The modern milling process based on the use of rollers is a rapid system that allows a gradual reduction of the endosperm to desired particle sizes, but bran and germ are separated. Most of the vitamins, minerals, fibre and antioxidants of wheat are found in the bran while the germ is rich in phytosterols, tocopherols, B group vitamins and oil (Rao et al. 1980). On the other hand, millstone process involves grinding of the wheat kernels between two stones producing flour with an extraction rate of 100% (wholemeal flour). Moreover, the stones slowly grind the germ, which is not

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exposed to high temperatures, thus preserving the vitamins from deterioration and do not cause the oxidation of fatty acids. As a result, the roller-milling flour had lower protein and dietary fibre content and higher damage starch with respect to millstone flour. This consideration could promote the use of millstone instead of roller-milling. In the current work some information on the milling process will be provided, together with details on the national diffusion of millstone factory. Both technological and economic aspects deriving from the use of this ancient grinding technique will be also discussed.

Millstone technology

The grinding of wheat for human consumption is called "milling". The main goal of this process is to separate bran and germ from the endosperm present inside of the seed. After grinding the endosperm, different products are obtained such as middlings, semolina and flour. The origin of the milling technology is uncertain. However, studies show that in the Neolithic period (between 5000 and 3000 BC) people already used mortars or quern, made up of wood or stone, to reduce cereals into flour. From the evolution of quern technology, during Greek-Roman era, the millstones manhandle was born. Later, this technology was improved, the grinders increased in size and rotation was made not only utilizing the human power but also animals or water movement. In the nineteenth century this technology reached excellent performance with high yields of flour.

In Italy the millstones were very common as demonstrated by the thousands structures spread all over the country, above all along the waterways, such as the Belice Valley (Trapani – Sicily), the mill valley in Gragnano (Salerno – Campania), and the Valley of the Mills in Vico del Gargano (Foggia – Apulia) (Cascio 2008).

Traditional mills generally worked utilizing water power, even if today this system is replaced by electricity, that passed out a wheel inserted in vertical or horizontal position and transformed water movement in mechanic power required to grind cereals seed. The adoption of vertical or horizontal wheel depends on the characteristics of the water course: stream with wide, deep and considerable water flow could move vertical wheels, while in the absence of these features it was resorted to horizontal one. In places where no rivers are available, one or more springs located nearby or other sources of energy such as human arms, animals or wind could be used. Generally, these plants were made by two circular stones with different characteristics, the stone that turns is the hardest one, while the fixed stone was the tender one. For this reason it is not suitable to utilize two identical stones that work simultaneously. Furthermore, the distance between the two stones is about 1 cm in the center and less in the border. The surface of the millstone has to be wrinkled by grooves organized radially to allow both the correct friction between stones and seeds and the movement of seeds (Fig. 1). In particular, the main grooves that begin from the hole until the border of the millstone have the main function of cooling the stone, whereas the secondary grooves contribute to equally distribute the product on the stone and help to eliminate the flour. As shown in Fig. 1, the movement of the seeds on the stone is different between the stones. On the former one (A), in fact, seeds are inserted by the hole in the middle of the millstone and move drawing a spiral path, whereas on the latter stone (B) they draw a curve path. Moreover, the hole has a trapezoidal section to allow a regular and uniform distribution of the seeds (Fig. 2A). Then, grains are grounded and powered by the millstone and collected externally, along the border, such as flour or semolina and bran (Fig. 2B). The majority of grain crushing and breaking happens in the final part of the millstones where the distance between the stones is the very small (Belderok 2000).

The millstone process consists of six main stages: 1) cleaning of seeds by aspiration and screening to remove impurities, 2) storage, 3) washing in drinking water, 4) natural drying, 5) grinding and 6) sifting. The seeds washing serves to confer a sufficient seed moisture to improve the separation between bran and endosperm. Sometimes, this process can be omitted and the seed is sent directly to the grinding. The sifting process formed a series of products and by-products which type and quantity depending on the mesh used.

The millstone process can be conducted in three different methods. The first one is the *economic milling*, *French or rough*, which consists in consecutive grinding and sifting operations from which various products and residues can be obtained. This technology requires grinder with 2 meters in diameter and 55-60 rev/min. The second system is the *American milling* or *English milling*, which consists in only one process following by the sifting to separate wheat in different quality. This process produces a small amount of wheat and residues and turns faster than the previous technology (1.30 meters in diameter and 120 rev/min). The third method consists in *Groats milling*, suitable for hard or semi-hard wheat with big and regular seeds to get a fine quality flours. This process involves crushing of seeds to completely decorticate them and then grind several times the groats purified to obtain various types of flours, as reported in Table 1 (Madurei 1995).

A material balance of a stone grinding mill process, still working near to Foggia (South Italy) is also provided (Fig. 3). This mill system produces both durum and soft wheat derived from organically or traditional cultivation. Seeds are not wet, but directly grinding and by-products are generally used as feed for animal husbandry. In Table 2 some further characteristics of the plant are also reported. The material balance calculated was compared with a modern rollers mill. The most striking feature recorded is that no many differences between the two processes were found, although in the stone grinding mills there was more electricity consumption and less by-products production. These variations generally depend on the consistency of seeds and on the quality of flour. In fact, in this process a particular hard variety of durum wheat that required a large amount of energy to be powdered was ground, but the higher cost is compensated by the elevated yield of flour obtained.

National diffusion of stone mills

Currently, no national association exists to collect data about stone grinding mills but local agencies, organizations (local exchange trading system, GAL Consortium CILSI - Centro d'Iniziativa Leader per lo Sviluppo dell'Irpinia; Italian Association of Mills Historical Friends – AIAMS, etc.), single firms or “passion-driven person” often make census or give information on the web. For this reason available web information, together with data from local Chamber of Commerce, were used to define the diffusion of stone grinding mills in Italy. This complex survey allowed found 1098 stone grinding mills spitted in four following categories: *teaching/museum* buildings utilized for educational goals (often a historical building restored and utilized as museum); *not working* buildings as old structures that have milling equipment but no more working; *ruins* that are mills abandoned and *commercial* buildings that are old or new structures fully functional that produce and sold flours. The census has showed that 107 buildings belong to the first category, 84 to the second, 747 to the third and 160 to the last category. The majority mills are located in Emilia Romagna (618) and Sardinia (119), even if most of them are ruins (559 and 109, respectively). Some further details on mills distribution are reported in Table 3.

Furthermore, survey has shown that seeds amount processed in the commercial structures varies from a few kilos per day to 3000 kilos per day. So, considering the number of commercial mills (160) the potential amount of seeds processed is about 120.000 tons, equivalent to about 85.000 tons of flour per year, considering 250 working days.

Technological solution to use millstone

It is believed that the high content of dietary fibre in whole grain plays a significant role in the health promoting effect. However, bran (mainly fibres) addition to pasta may cause problems in the cooking quality. Bran interfering with the continuity of the gluten matrix causes weakening of the dough and reduces the mechanical strength and the cooking quality of the bran supplemented spaghetti (Manthey and Schorno 2002). Several reports have been published concerning the quality of spaghetti made with whole wheat or bran-semolina (Aravind et al. 2012; Kordonowy and Youngs 1985; Sahlström, et al. 1993). These works indicated that spaghetti made from whole wheat or bran-semolina was darker and had poorer cooking quality than spaghetti made from traditional semolina (Edwards et al. 1995). On the bread, the wholemeal flour usually weakens the structure and the baking quality of the dough and decreases bread volume and elasticity of the crumb. The presence of bran has been also reported to decrease significantly the loaf volume (Salmenkallio-Marttila, et al. 2001) and enhance bread firmness (Laurikainen et al. 1998). The deleterious effects of fibres addition to dough structure is due to dilution of gluten network and presence of bran particles that force the gas cells to expand in a particular dimension (Gan et al. 1992). Moreover, it has been observed that when bran is added to bread dough the crumb colour changes from creamy white to pale brown and the loaf volume decreases (Ziegler and Greer 1971).

Some technological options have been proposed in the scientific literature to solve the above-mentioned problems. The most common solution to improve the quality of high-fibre wheat foods is the addition of hydrocolloids to the dough formulation. Hydrocolloids are water-soluble polysaccharides that give viscous solutions or form dispersions in water. In general, this criterion of water solubility to yield increased viscosity covers the large majority of gums used in the food industry (Glicksman 1965). Hydrocolloids have colloidal properties and are usually high molecular weight polymers. Chemically, most of them are polysaccharides and few are proteins, such as gelatin and casein (Rodge et al. 2012). In recent years, many synthetic hydrocolloid polymers have been developed. The importance of hydrocolloids in food applications is due to their unique, functional properties, water binding capacity, reduction in evaporation rate, alteration in freezing rate, modification in ice crystal formation, regulation of rheological properties and participation in chemical transformations. These compounds are generally required at usage levels of less than 2 percent to achieve desired properties in food systems (Anonymous 2001). Specifically, hydrocolloids have been widely used in food products to modify texture, improve moisture retention, control water mobility, and maintain overall product quality during storage. Wheat starch is a basic ingredient in most foods. The gums improve granular structure and pasting behaviour of starch during cooking and baking of food products where low gluten flour of soft wheat interacts with low gluten proteins (Christianson et al. 1974). In the baking industry, hydrocolloids are of increasing importance as bread making improvers.

Usually, the addition of hydrocolloids to dough improves its stability and quality criteria, such as increased water absorption, specific loaf volume and viscoelastic properties (Guarda et al. 2004). Rodge et al. (2012) found that hydrocolloids positively affected dough stability and proved higher water absorption capacity. These compounds also affected the sensory properties of the final products in different ways. For example, guar gum extended shelf life through the moisture retention of bread (Mandala et al. 2007), but only during the first 24 h, then, the staling of bread continued. Besides, Rosell et al. (2001) found better bread volume when added hydroxy-propyl-methyl-cellulose to the wheat flour. Hydrocolloids also are important for pasta making. Tudorica et al. (2002) found that the semolina pasta containing guar gum showed reduced or similar cooking loss values when compared to the control sample. This may be due to the fact that the gum forms a network around starch granules, encapsulating them during cooking, and restricting excessive swelling and diffusion of the amylose content. Such encapsulation and integration of the polysaccharide network may strengthen the structural integrity of pasta. The hydrocolloids can also affect the nutritional quality of cereal products. In fact, they are a good source of soluble dietary fibre. Soluble dietary fibre reduces the concentration of cholesterol and improves gastrointestinal functions and glucose tolerance (Sozer 2009; Tudorica et al. 2002). Moreover, the value of these substances is minimal to zero, hence hydrocolloids are also used as fat-replacing ingredients. From a health perspective, hydrocolloids are used in dough and bread systems to block fat absorption during the baking process so they can develop fatty acids with shorter chains to create nutritional food (Mikuš et al. 2011).

Final considerations

The cereal sector is very complex and strategic because cereal chain is diversified and involves many other sectors. It is related to a primary production structure of farms spread throughout the country. The main products (bread and pasta) have a key role in human nutrition and are important vehicles of the image of Italy country in the world. A crucial role is also represented by the industry and the craft in productions. The Italian industry milling of soft and durum wheat has altogether a position of absolute importance at European and international level. It has undergone a major restructuring with a significant reduction in the number of existing mills, especially in the nineties. The Table 4 reports a summary of the Italian cereal chain in terms of available plants, processed raw materials and amounts of cereal-derived products. The chain of cereal products based on wheat is a mature sector but it can create an interesting market niche through actions aimed to alternative uses and diversified production, through the recovery of traditional varieties with distinctive organoleptic characteristics. The transformation of grains, not hybridized non-GMO, through ancient milling techniques such as millstones, could ensure a greater income from the production of products with high nutritional and health value. Further efforts should be made to spread the diffusion of millstone technique and to this aim, the actions of territorial promotion and the cultural, touristic and gastronomic movement to rediscover the past traditions and sites of industrial archaeology are extremely important. Small and potential production companies could help overcome the difficulties, linked to the forms of grain storage, to guarantee the origin of the product and enable the introduction of the traceability concept. Moreover, it's necessary to consider that cultivation methods with low environmental impact (organic farming and integrated production) and the strengthening of ties between the territory and the final product, through the registration of collective geographical marks, can play a key role in this context. As advocated by the Ministry of Agriculture, there is the necessity to promote a network of quality, enhance raw materials and certify the organizational model of supply chains according to international standards in order to spice this sector which we believe still has unexpressed potentialities.

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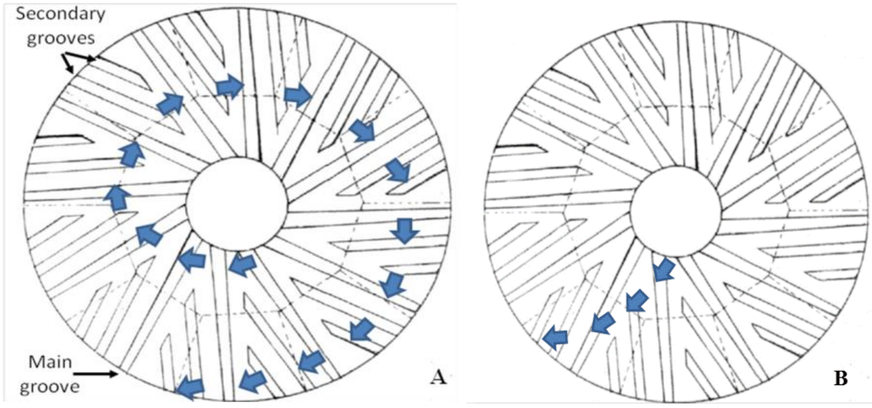
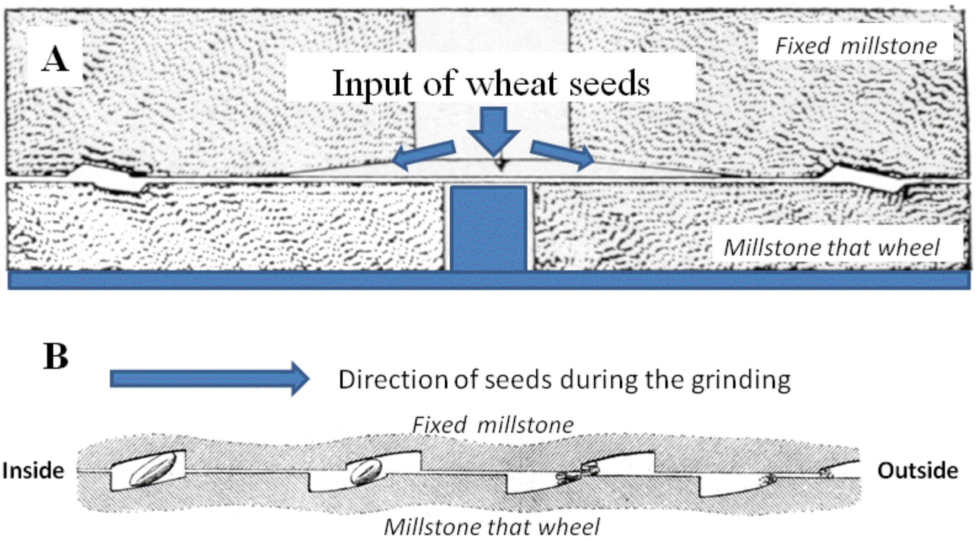


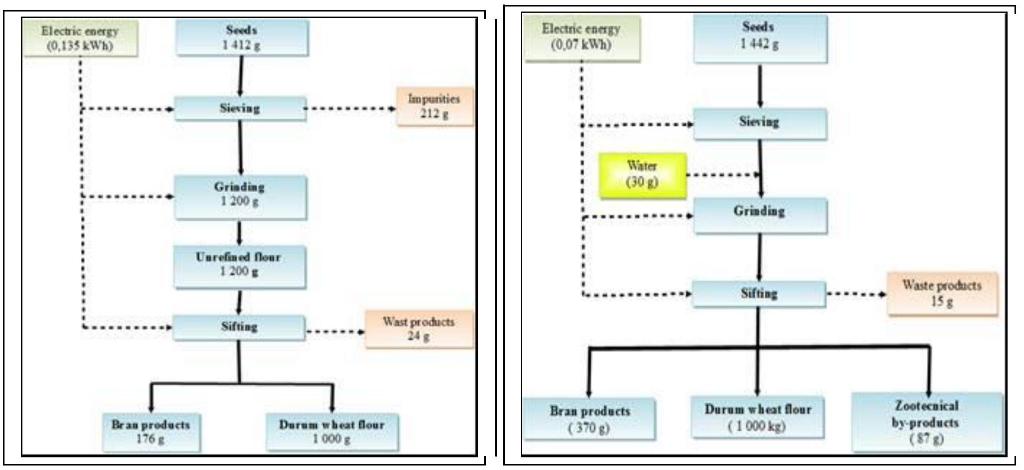
(Source: modified from Maier G. 2007. Practical aspects of stone milling. Tecnica Molitoria, 58: 141-150).

Figure 1. Example of grooving in a millstone. The blue arrows show the direction of movement of seeds during grinding. (A) Seed movement on the stone that wheels; (B) Seed movement on the stone that remains fixed.



(Source: modified from the paper: Maier G. 2007. Practical aspects of stone milling. Tecnica Molitoria, 58: 141-150).

Figure 2. A) Section of grinder and input of seeds. B) Action of grinder on the seeds during the movement of millstone.



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(*Source: modified from the paper: Notarnicola B., Nicoletti G. M. 2001. Analisi del ciclo di vita della pasta e del cuscus. Tecnica Molitoria, 19-27).

Figure 3. Comparison of material balance of stone grinding mills (A) with a modern rollers mill (B). Input and

output date are referred to a production of 1000 g of durum wheat flour.

Table 1. Material balance of stone grinding process (kg/q of wheat seed grinding).

	Economic milling	Rough milling
Products: White Flour 1° sifting (1° quality) 2° sifting (groat flour) 3° sifting (groat fluor)	- 38.33 19.16 8.51	60.00 - - -
Products: Greu Fluor 4° sifting (groat flour) 5° sifting (groat flour)	- 5.00 3.33	14.00 - -
By-products: Rough or subtle Bran 1° residue 2° residue	 10.82 6.80 5.70	 24.00 - -
Loss	2.35	2.00

(Source: Madureri, 1995)

Table 2. Characteristics of stone grinding mill process.

Characteristics	Parameters
Total electrical energy consumption	13.5 kWh
Millstone diameter	120 cm
Millstone turn	80 rev/min
Production capacity	1 q/h

Table 3. Italian distribution of stone grinding mills.

Region	Stone mill category				TOTAL
	Teaching /museum	Not working	Ruins	Commercial	
Emilia Romagna	14	13	559	32	618
Piemonte	3	1	6	16	26
Toscana	24	22	11	18	75
Veneto	5	16	0	12	33
Lombardia	13	1	26	14	54
Friuli Venezia Giulia	7	11	0	6	24
Abruzzo	1	1	8	4	14
Sicilia	6	0	4	11	21
Lazio	0	2	1	11	14
Puglia	4	0	0	5	9
Umbria	2	10	1	9	22
Sardegna	6	0	109	4	119
Liguria	0	0	0	2	2
Basilicata	2	0	0	2	4
Marche	2	2	1	8	13
Campania	0	3	4	1	8
Calabria	0	1	15	2	18
Trentino Alto Adige	9	0	0	1	10
Valle d'Aosta	9	0	2	1	12
Molise	0	1	0	1	2
TOTAL	**107**	**84**	**747**	**160**	**1098**

Table 4. Data of Italian cereal chain.

Industry of common wheat	
Number of milling plants	259
Production capacity	8.800.000 tons
Amount of processed wheat	5.140.000 tons
Amount of produced flour	3.800.000 tons
Plants utilized	58%
Amount of bread	2.588.000 tons
Amount of bakery products	575.000 tons
Amount of products for pizza and others	519.000 tons
Amount from house use	55.000 tons
Export	61.000 tons
Industry of durum wheat	
Number of milling plants	133
Production capacity	6.100.000 tons
Amount of processed wheat	5.160.000 tons
Amount of produced flour	3.500.000 tons
Plants utilized	85%
Amount of pasta	3.196.000 tons
Amount of bread	170.000 tons
Other uses	30.000 tons
Export	93.000 tons

(Source: Italmopa, 2012).