Modern Grain Milling Systems
- with a description of the wheat flours produced

From antiquity until the late 1800s grain milling systems were based on the natural *stone mill*. However, in the modern era since the late 1800s, the predominant industrial grain milling system has been based on the *steel roller mill*. Also in this modern era several other grain mill types using metal grinding parts have been introduced. Examples are the *steel burr disk mills* that mimic stone mills in their action, and various impact mills such as the *universal hammer mill*, *the micronizing mill* and the *gap mill*. Composite stone and corundum-ceramic stones have also been introduced as an alternative to natural stone in stone mills.

The following is a basic description of these mills and the wheat flours that can be produced from them. Other grains such as rye and corn can be similarly milled to flours. Greater depth to the information on equipment and methods presented can be found in the various patents granted; these patents are easily accessed via www.google.com/patents, and sometimes from the websites of the mill manufacturer. All flours will have a character typical of the process used for the milling, and the manner in which they have been stored. Beyond milling and storage, it is the grain type and variety, and the particular growing conditions that most determine baking and food use quality.

Grains that we use as basic food are seeds and can be described with an outer covering skin, a small embryo of the new plant at one end and the bulk being a large carbohydrate energy food storage for the developing plant. For wheat and similar grains, these grain parts are known as the *bran*, *germ* and *endosperm* respectively.

A number of chemicals are used during conventional agriculture and storage of grains. There is thus a possibility that the bran and germ would be coated with these chemicals, and that the oily germ would absorb oil soluble chemicals. Using an organic system of agriculture and storage avoids the concern that grains for whole grain end products could be contaminated with toxic agricultural chemicals.

All the nutrients in grains have a function in the development of the new plant, and are also useful to humans when they eat grains as a source of energy-producing carbohydrate. The protective *bran* coating contains protective antioxidant polyphenolics and mineral compounds and is rich in dietary fiber, which carries our food through the digestive tract. The *germ* contains nutritionally important oils; antioxidant vitamin E, which is important in promoting fertility; B-vitamins, which enable the release of energy from the carbohydrates stored in the endosperm; and other components vital to the developing plant and likely also vital to humans. The wheat *endosperm* is built from carbohydrates such as starch, and a smaller amount of endosperm protein (gluten). Eating 100% whole grains instead of refined grain foods and refined sugars, is known to protect against colon cancer, obesity, diabetes and cardiovascular disease.

Relevant enzymes, amylases, involved in mobilizing the carbohydrate components in the grain are located mainly in the bran and germ; these are useful during the dough stage of bread making. Eventually sourdough acidity, and cooking stops the activity of these amylase enzymes.

All milling methods involve friction and so cause the production of heat during the process. Care must be taken in each system to minimize the build up of heat that could damage the grain components, especially the heat sensitive enzymes and germ oils. Proteins and enzymes may be denatured above 122ºF (50ºC); it is therefore best to mill flour below this temperature.

Most milling methods result in a pulverizing action that mixes all the components of the grain together. The exception is roller milling, which effectively disintegrates grains into their component parts. However all methods break down the integrity of the original grain and expose all parts of the grain to air and moisture. The combined effects of air and moisture on the nutrients and enzymes cause changes that are perceptible in the taste of the flours produced. The components most vulnerable to the oxidative effects of exposure to air and moisture are the germ oils, which easily turn rancid. Thus the ideal for any flour is that it should be milled from dry grains and it should be milled close to the time of use; ideally it should be freshly milled within a few days. However many whole grain flours are stored much longer than this before use, and the evidence that changes are occurring can often be detected in the taste. Minerals and dietary fiber in the bran, and starch and protein in the endosperm are broadly unaffected by storage. The B-vitamins degrade relatively slowly over time. However, the germ oils are unsaturated, and easily and quickly oxidize even while there is some protection from the antioxidant polyphenolics in the bran, and the vitamin E in the germ.

Every flour produced is unique in its composition as a result of the particular milling conditions and the manner in which it has been stored. Data on the actual nutrient content of any particular flour must be determined for that flour at a given point in time.

From the following it will become evident that wheat flour can have a wide range of composition with respect to the whole grain. Only flours produced in a single pass starting with the intact grain, and which are collected as flour without any fractionation, sifting, or bolting are clearly seen to be 100% whole grain.

The Stone Mill

Through the millennia since the beginning of grain agriculture and probably before that, people have aimed to pulverize dry grains of wheat, rye, barley, corn, millet and more, between two stones, to make the grain easier to eat. Developments through our history have involved redesigning the shape and size of the matching grinding stones, and bringing ingenuity to the selection of an energy source to turn one stone against the other. People were the first to pound and turn stones, followed by animals, and then wind and waterpower, and steam power until finally in the modern era the stones are turned by electrical power.

Currently electric-motor driven stone mills, made by Meadows Mills, Inc.[1] are available in the USA. These mills are based on an invention made in the early 1900s and are designed with hard granite stones hung vertically. Several modifications have been incorporated in the design since then. Ultimately the action of the stones in pulverizing dry grains to flour is essentially the same as when the stones were used in a horizontal position and powered by wind or water. Theoretically the basic stone mill can be incorporated into a modern computerized system of controls. The most efficient action in all stone mills is dependent on well-dressed stones, suitably grooved with furrows, and flat lands roughened to grind the grain to fine flour. The grain enters the grinding stones through a central opening, from which it is carried

[1] www.meadowsmills.com
Corn Mill. US Patent 888,631. William C. Meadows & Franklin Dean Meadows. 1908

along the tapered furrows in the stones. The grain is driven through the stones by the force of more grain coming from behind and centrifugal force. Thus the main adjustment in a system with a steadily rotating stone is via the flow rate of the grain into the mill. A reduced flow rate would be appropriate for the hardest wheat varieties in order to minimize the heat produced by friction. In its passage through the furrows the grain is cracked into decreasingly smaller pieces as the furrows become shallower, until the grain pieces are carried across the lands of the mill where they are ground to powder. Product containing all parts of the original grain falls off the outside edge of the stones and is collected from around the stones. The bran and germ parts of the ground grain tend to be flakes and the endosperm grinds to a velvety fine powder. This is true for soft wheat types. However, hard wheat bran is quite brittle so that bran and germ are milled to finer powdery flakes; the endosperm of hard wheat varieties generally grinds to flour with a somewhat sandy feel. If the grinding of hard wheat is intense enough, then the endosperm starch granules from hard wheat can be ruptured or damaged. Damaged starch absorbs more water in dough than undamaged starch. The degree of starch damage in any milling system for wheat needs to be controlled, to provide consistency of water uptake from a given wheat varietal flour. In my own experience, stone milling did not produce very much damaged starch even in the hardest durum wheat flour. Milling with newly dressed stones might produce more significant starch damage.

In the stone milling system, well-dried wheat grains (<12% and preferably <10% moisture) are fed into the grinding stones, in a single pass with the separation distance for grinding stones set to provide the chosen degree of fineness in the flour. *Coarse flour should not be sent back through the mill for a finer grind, since it does not feed rapidly enough through the system, which is designed only for grain throughput*. All of the grain that enters the mill is converted to flour without any removal of grain parts. The flour is 100% whole grain. However if the produced flour is allowed to fall by gravity into a collecting vessel there is a natural separation due to density of the flakier bran and germ particles, which fall down the sides of a cone of collecting endosperm flour. In order to make the whole grain flour homogeneous, the 100% whole grain product from the stone mill needs to be well mixed before packaging or using.

Stone milled whole grain flour can be sifted to separate the flakier bran and germ particles from the finely granulated white endosperm particles. Usually this means that approximately 15 % of the original grain is sifted off as bran and germ. The white flour remaining is approximately 85% of the original grain and is primarily the wheat endosperm; this white flour is said to have an extraction rate of 85%. However, sifted flour from a stone grind contains a small amount of bran and germ particles that are fine enough to pass through the sifter or bolter. This is especially valid for hard wheat varieties that are stone milled. Various modifications of the sifting and bolting systems for stone milled flours have been invented, to increase the effectiveness of separating off the germ and bran particles, away from the endosperm flour. In practice, these methods are never so efficient that the endosperm flour sifted from stone ground wheat can be totally free from bran and germ. Thus sifted stone ground flour from hard red wheat generally still produces a dark colored bread. Prior to the major introduction of hard red wheat onto the American continent in the mid 1800s, soft wheat with a pale golden bran color was preferred for producing light colored breads even from whole grain flour.

Stone mills of all sizes can be installed to suit the home baker, the small bakery, the large bakery and the miller who supplies flour to local bakeries and restaurants. Thus stone mills offer an ideal solution to the currently perceived need to provide whole grain flours fresh to the consumer.

Composite stone mills

Alternatives to dressed granite stone are cast composite stone, or corundum in a ceramic matrix. In general cast composite stone consist of natural stone fragments suspended in a hard synthetic matrix. Such stones cannot be dressed to revive the grinding surface if it becomes filled in or glazed by repeated use. The smallest household stone mills available are made with corundum ceramic burrs or stones[2]. These corundum-ceramic burrs seem to be hard enough to remain in continuous household use for perhaps a lifetime. However, if they become smooth and ineffective then the mill needs to be replaced or possibly refurbished by the manufacturer.

Composite stone or corundum is less practical than granite in a commercial setting where the mill is heavily used. Replacement costs for a larger composite stone mill would be too high compared with the labor costs to redress granite stones in house.

Steel Burr Disc mills

Steel burr disc mills mimic stones in stone mills. The steel is patterned with furrows and lands similarly to dressed stones. In practice these steel burrs are now being made with stainless steel, although cast iron burrs are still used in older mills.

Small hand cranked and motorized steel burr mills are sold for home use and for demonstrations. E.g. The Wonder Junior Deluxe Grain Mill. Larger steel burr disc mills are available for commercial use e.g. ABC Hansen Disk Mill, which is described with *steel plate burrs*[3].

The assumed difference in the effect of milling with steel burrs compared with stone burrs results from the heat capacity for each material. It appears that iron has a heat capacity of about half that for granite. The steel burrs may therefore heat up from the friction of milling possibly twice as fast as granite. More attention to the temperature of the flour produced from steel burr milling is needed, to avoid milling at a temperature that would damage the enzymes and other proteins in the flour.

The Roller Mill

Roller milling is the predominant method in current use for the production of most wheat flours. The method was designed in the late 1800s to produce light colored endosperm flour from hard red wheat, such that there would be no coloration of the flour from bran or germ. The Shortflow Mill ® made by Kice in Kansas, is an example of a newer more compact roller milling system[4].

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[2] E.g. The KoMo Mill. www.pleasanthillgrain.com

[3] *The Wonder Junior Deluxe Grain mill and the ABC Hansen Disc Mill are obtainable from*: www.pleasanthillgrain.com

[4] www.kice.com. Kice Shortflow Mill ®. *Simplified method and apparatus for producing white flour from wheat grain.* US Patent 5,192,028 A. by Steven P. Curran. 1993.

The efficiency of the roller milling system for the production of pure endosperm flour is at a maximum for hard wheat, corresponding to an extraction rate of approximately 75% for hard wheat. The extraction rate drops to approximately 66% for soft wheat types; hence the modern miller's preference for hard wheat. Such flour is generally known as *refined* flour. In order to achieve this the grain entering the system is first moistened up to 16% moisture, so that the bran coating on the grain is easily loosened. This moistening process is known as *tempering* or *conditioning* and can take up to 20 hours, and can include heat treatments that somewhat modify the gluten. The roller milling system involves a series of specially grooved cylindrical steel rollers, which may or may not be cooled internally with water[5]. As the moistened grain passes through the first set of rollers the bran is removed in flakes and collected as a separate fraction. The grain then passes through a second set of rollers capable of shearing off the germ in flakes from the end of the grain, and the germ is collected as another fraction from the process. As the grain passes through the third set of rollers the endosperm is pulverized to a finely granulated white flour and is collected as a third fraction, which is *refined* white endosperm flour that is notably free from germ and bran. Sophistication of this system allows for the endosperm flour to be further fractionated by using more or different rollers after the removal of bran and germ. Because the original grain was moistened in this process, the refined white flour from the endosperm is generally packaged and sold at 14% moisture. Other modifications can include initial partial de-branning with an abrasive mill, and impact mills to loosen the germ, before the grain is sent into the roller mill.

In order to produce whole grain flour from the roller milling system, all the fractions separated off must be recombined so that the whole grain flour can be effectively reconstituted. Since the grains are initially moistened, there is high residual moisture in such whole grain flour, and also in the various fractions including the white endosperm flour. In general all flours and fractions produced from the roller milling system are expected to contain approximately 14% moisture, in any case more moisture than in the original grain. This moisture content is intolerably high for the shelf stability of whole grain flour, especially the bran and germ fractions. These fractions are so high in nutrients (vitamins and minerals) that molds would easily grow at this moisture level, and enzymes would cause fast degradation of the germ oils with this much moisture. The high moisture content of the white endosperm fraction is not problematic because there are essentially no residual vitamins to support mold growth, no oily substances that can be easily changed by oxidation, and very few enzymes.

The roller milling system can be adapted to produce finely graded fractions of the endosperm flour to be made into specialized breads, confectionary cakes, pastries and cookies. Bleaching of refined endosperm flours is also practiced for some specialized confectionary cake uses.

Because refined endosperm flour is so lacking in vitamins, minerals and enzymes that would be found in the bran and germ of the whole wheat grain, such flour intended for bread and other basic foods is legally required to be enriched. The need for this was finally recognized and implemented in the 1940s. The enrichment consists of adding B-vitamins (thiamin, riboflavin, niacin, folic acid) and minerals

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[5] *Hollow water-cooled roller for roller mills*. US Patent 2,650,034. Hermann Kurt Wiemer. 1953.

iron, and calcium. Just as the original plant cannot utilize the carbohydrate in the endosperm without the vitamins and minerals in the bran and germ, people also cannot make proper use of the starch in the endosperm unless these B-vitamins are present. In the case of *organic refined flour* there is currently no legal obligation to enrich the flour in this way; it is often sold in the un-enriched form, which is dangerously deficient when used in a basic food such as bread. People relying on this bread are at risk for the deficiency diseases of pellagra and beriberi. *It is also known that diabetics and pre-diabetics generally have low levels of thiamin in their blood. Replacing refined flour and refined sugar products with whole grain products in the diet can reduce glucose intolerance in the pre-diabetic state.*[6]

To aid fermentation in bread-making, enzymes are added to some refined endosperm flours in the form of enzyme active malted wheat or barley.

Currently a majority of whole grain flours are produced by reconstitution after using the roller milling system. How these whole grain flours are stabilized for shelf stability at 14% moisture, is revealed in the various patents that have been granted for attempts to solve the problem[7]. It is known that heat treatment of the germ and bran fractions will dry them and can also deactivate the enzymes that could otherwise cause the oils to oxidize and become rancid. Generally, there is a flavor change produced by the process. Also, the heat process does not stop the vulnerability of the oils to simple atmospheric oxidation. Omission of the germ fraction has been used as a means of overcoming the problem of shelf stability for recombined roller milled flours, but the flour can no longer be called 100% whole grain. For those who therefore wonder whether these roller milled whole grain flours are truly 100% whole grain, an examination of the nutritional facts label will give some clues. The fat content of whole wheat is generally approximately 2% of the grain, so that if the germ, which holds almost all the fat, has been left out of the flour or is present in reduced proportion, then this fat percentage will be less than 2% of the whole wheat. Similarly the bran contains most of the dietary fiber in the original whole wheat. If there is less than the usual total whole grain amount of dietary fiber (approximately 12% of the whole wheat grain), then some of the bran may have been omitted.

Roller milling systems are complex and require considerable expertise to run them and maintain them. The result has been that they are mostly installed in large centralized milling facilities. It is difficult to supply whole grain flour from these centralized mills in a fresh form, and in any case the enzymes in germ and bran are likely to have been inactivated during the production of these whole grain flours.

Because there is by now increased awareness of the need for 100% whole wheat flour, some roller milling facilities omit the moisturizing step and do not separate the fractions, and so produce a relatively dry 100% whole wheat flour directly from a roller mill.

The variations in modern milling practice make it essential to ask about the particular process used for any flour that you would want to use, so that you can properly understand the nutritional value and the potential baking character.

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[6] S. J. Bakker et al., *The association of dietary fibres with glucose intolerance is partly explained by concomitant intake of thiamine: the Hoorn Study*. Diabetologia. 1998. Oct; 41(10):1168-75

[7] *Production of stabilized whole grain wheat flour and products thereof*. US Patent: 8,455,036. Lynn C. Haynes. 2013.

The Gap Mill [8]

Quoting from their brochure: *The Bauermeister Gap Mill is a unique design for fine grinding down to 25 microns size. The proven design features an adjustable gap between the conical shaped rotor and a corrugated baffle. This combination delivers improved grinding performance and accurate particle sizing without screens. The conical shape of the rotor allows the mill to impact the product with increased tip speeds as the particles pass through the grinding area. This design allows the mill to grind particles finer in one pass where competitive mills often require internal recirculation to achieve the same results.*

When roller milled wheat flour fractions are recombined to reconstitute whole grain flour, the endosperm flour fraction is very fine, but the bran and germ are in relatively large flakes. Even though nutritionists consider these larger bran flakes to be the most beneficial to the digestive system, many bakers consider these large flakes to be coarseness in the flour, and ask the miller for the germ and bran to also be finely granulated in whole grain flour. To solve this dilemma millers have resorted to separately further milling the bran and germ flakes in an impact mill, before recombining them with the endosperm flour. One of the most effective and sophisticated impact mills in use for this is the gap mill used by Ardent Mills[9] to produce their Ultragrain ® fine whole wheat flour, from hard white wheat. The gap mill produces a particularly fine granulation of the bran and germ, which is then mixed with the corresponding amount of endosperm flour to produce 100% whole wheat flour. Because the bran color is very pale on their specially bred hard white wheat, the final whole grain flour is both finely textured and light in color. In this system, the germ and bran enzymes are inactivated before they are finely milled.

The gap mill used alone can also be used to produce 100% whole grain flours directly from the grain in a single pass.

The Hammer Mill

The hammer mill can be described as similar in action to a home Vitamix[10] or blender in that the very dry grains are enclosed in a chamber while a steel blade system is rotated to break and grind the grains until they are reduced to increasingly fine particles. A screen generally surrounds the industrial hammer mill chamber, which allows passage of the grain particles of small enough size to leave the chamber. The milling is continued until all the original grain is ground sufficiently finely to leave the chamber through the screen. The screen size can be selected to provide a particular granulation size range, whether the particles are from bran, germ or endosperm parts of the grain.

The product is the same in composition as the original grain entering the milling chamber. The product can be 100% whole grain flour and have the same moisture content as the original grains; usually this is below 12%, and optimally below 10% moisture. Oxidizing enzyme activity is minimized when the grain moisture is below 10%. The granulation for bran, germ and endosperm will be within a narrow range and will be determined by the screen size used in the hammer

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[8] www.bauermeisterusa.com

[9] *Whole grain flour and products including same*. US Patent 8,852,665 B2. Elizabeth A. Arndt and Theodore Korolchuk.

[10] www.vitamix.com

milling process. Perhaps one disadvantage is that excessive heat can build up while milling to the required fine granulation.

Various hammer mill mechanisms are available and have been developed sufficiently to be called universal mills, suited to milling grains as well as a wide range of other food seeds; except oily seeds.

The Micronizing Impact Mill

A miniaturized micronizing chamber (impact mill) is used in some home mills e.g. WonderMill Grain Mill[11]. The grain flows from a hopper into a small chamber inside two facing counter-rotating stainless steel cups with gaps on the sides, and lined with fins. The grains break apart inside these rapidly rotating cups and leave the milling chamber through the gaps, in finely divided form. It is essential to use the driest possible grains for this method of milling, since in their dry form they are the most brittle. Heat build-up can be a problem.

The product composition will be the same as the original grains entering the mill. Micronizing tends to produce finely flaked bran and germ and a very fine endosperm granulation. The product will be 100% whole grain flour, with low oxidizing enzyme activity if the original grains are very dry at less than 10% moisture.

In summary, milling the intact whole grain of wheat to 100% whole wheat flour is most economically accomplished with a granite stone mill. Soft wheat is best suited to the stone milling system.

Modern metal impact mills are also used to process whole grains to whole grain flour in a single step, and their advantage is that bran and germ, as well as the endosperm are generally also finely granulated. Heat build up is more likely to be problematic in metal impact mills.

The roller-milling system involves complex equipment intended to separate the bran and germ away from the endosperm, of hard wheat. Thus recombining the separated fractions in an attempt to produce 100%whole wheat flour is inevitably complicated and uneconomical. Even if roller-milling systems are used to granulate without moisture tempering or fractionating, the system is still unnecessarily cumbersome for the job. As well there are the possibilities that bran and germ components are separately treated during the roller milling process, or omitted instead of producing the desired 100% whole wheat flour. The roller milling system was designed to produce refined white endosperm flour from hard wheat, and is relatively inefficient for soft wheat.

[11] *WonderMill Grain Mill shown at* www.pleasanthillgrain.com