

The Critical Role of Milling in Pulse Ingredient Functionality

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ABSTRACT

The milling process is critical for the creation of value-added ingredients from pulses (grain legumes). In this article, we summarize the outcomes of a comprehensive review of the peer-reviewed literature on the milling of pulses. We identify what is already known in wheat milling that could be applied to pulses and point to research issues that should be addressed so that pulses can be consistently milled into high-quality ingredients for the food industry. As in wheat milling, the size and hardness of incoming grain legumes are influential factors affecting pulse flour functionality. However, the relationship between grain hardness and the millability of pulses is not as well understood as it is for wheat flour milling. To allow better comparison of pulse flour functionality from studies in different laboratories, we recommend that wheat flour regulations on maximum particle size be adopted. We also recommend that systematic studies of grain legume microstructure and its relationship to starch damage during milling be conducted. The favorable environmental and nutritional reputation of pulses is an impetus for further development of pulse ingredients for use by the food industry, and understanding the critical role of milling in ingredient functionality is important for the full utilization of pulses.

Pulses, or grain legumes, are a relatively inexpensive source of protein, complex carbohydrates, and fiber (39). The protein content in grain legumes ranges from 22 to 24% compared with the 7 to 15% typically observed in cereals (24). In addition, pulse proteins are a good source of the essential amino acids lysine and leucine, making them highly complementary to cereals from a nutritional perspective (24). Because of these favorable nutrient attributes, and the positive consumer perception of pulses as having a favorable environmental footprint due to their capacity to fix nitrogen (11,17), there has been significant growth in consumer acceptance of pulses. Forecasts for retail utilization of pulses project growth of 9% by 2022 (7).

Transforming pulses into flours that can be utilized as value-added ingredients for a number of cereal-based foods is one means of exploiting the favorable attributes of pulses. Representative products in which pulse flour can be partially substituted for wheat flour include cakes (13,14), cookies (33,50), extruded snack foods (16,19,35), pasta (29), noodles (44), and breads (20,23). The first step in the transformation of grain legumes into pulse ingredients with desired functionalities is the milling process.

A comprehensive review on the milling of pulses has been completed (36) in which we examined pulse milling from a wheat flour miller's perspective. Because wheat flour milling is a mature topic, with process flows optimized for many decades, we identified what is already known in wheat milling that could be applied to pulses and also identified what additional information is needed for pulses to be consistently milled into high-quality ingredients for the food industry. In conducting the review, there was a bias toward roller milling (versus other mill types) for two reasons: there is a tremendous amount of established infrastructure globally (as a result of the international success of roller milling processes), and roller milling allows flour properties to be precisely manipulated to attain the three main purposes of milling (particle size reduction, separation of components, and mechanochemical changes to components).

Purposes of Milling

As an ingredient, pulse particles must mix well with other ingredient particles. Therefore, the size reduction of grain legumes to particles small enough to blend well with other ingredients is a primary purpose of milling (30).

A second purpose of milling is separation of components (2). In pulse milling, one main separation outcome is removal of the hull (seed coat) from the cotyledons (43,49). This is achieved reasonably easily for pea but not for most other pulses. There may be additional separation objectives as well. For example, sieving and air-classification have been used for many years alongside size-reduction processes to separate protein-rich streams from starch-rich streams (40).

A third purpose of milling is to induce mechanochemical changes to components in an ingredient. In wheat flour milling the main outcome is starch damage (32), which results in flour particles with enhanced water absorption capability (8). Starch damage appears to be important to the functional properties of pulse flours as well (22).

A simplified schematic of wheat flour mill flow is shown in Figure 1. The locations for effecting each of these three milling purposes are highlighted. If roller milling processes are to be used to produce functional ingredients from pulses, the location of each purpose within the mill flow (and its magnitude) needs to be understood.

Grain Legumes Entering the Mill

In a recent review, we identified four principal factors that affect the millability of grain legumes (36). None of these will be unfamiliar to wheat flour millers, but the extent to which each factor dominates the conduct of the milling process likely differs when milling a particular grain legume. These factors are seed characteristics, premilling treatments, drying, and post-harvest storage. Only the first two factors will be discussed, although all four were considered in the review (36).

Effects of Seed Characteristics on Milling Performance. Genotype and environment ($G \times E$) influence seed characteris-

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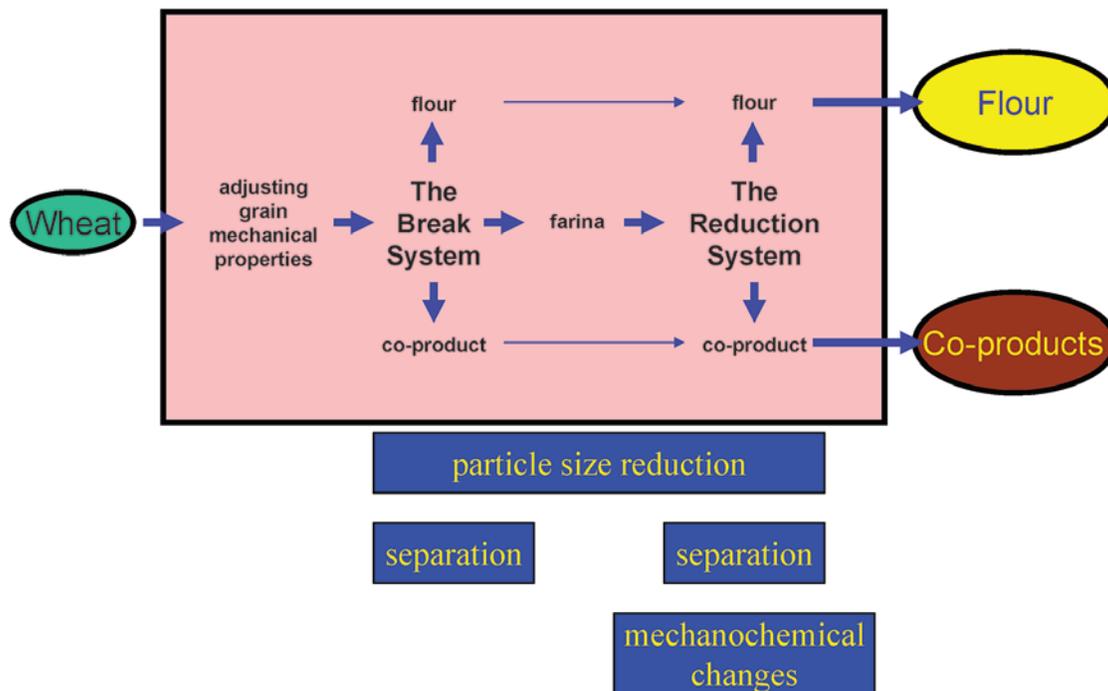


Fig. 1. Schematic of wheat flour mill flow showing where size reduction, separation, and mechanochemical modification occur.

tics, and information on variability in seed characteristics is critical for accurately estimating the milling performance of a particular grain legume entering the mill (46). For millability, two predominant issues related to $G \times E$ effects are variability in grain size, which affects how the mill is set up, and variability in grain hardness, which affects the attainment of one or more of the three milling purposes.

Variability in grain legume seed size is greater than the variability in wheat grain size. As a result, screen sizes need to be carefully set up (15) so roll gaps are adjusted appropriately for the incoming material. An alternative strategy is to use fixed roll gaps but employ presizing operations to attain appropriate particle sizes in the incoming pulse stocks (45).

It is likely that the hardness of grain legumes is as important in pulse milling as it is in wheat milling. According to Pasha et al. (26), endosperm texture in wheat is the principal quality parameter because it is used to grade wheat, affects the conduct of milling and baking processes, and governs the quality of the finished baked products. Therefore, changes in grain legume hardness are highly relevant for optimization of pulse milling processes. However, most research on grain legume hardness has targeted evaluation of the hardness of the cooked whole grain legume because cooked hardness determines sensory acceptability (25).

Some research on the hardness of raw grain legumes has been conducted. For example, a single-kernel characterization system has been used to measure the hardness of mung bean seeds (6). Hardness index increased with increases in moisture content, but only up to 16%. In a study to attain protein-rich streams from pulses, lower seed hardness in lentil compared with chickpea, pea, and bean seeds was deemed responsible for the higher protein content in the fine fraction produced from lentil flour (27). Based on these findings, grain hardness is a critical variable that affects the millability of grain legumes and the characteristics of the resulting pulse flour, just as it does for soft and hard wheats.

Investigations on the compositional and structural bases for grain legume hardness have been conducted. Although protein acts as a structural agent (5), $G \times E$ effects that alter fiber content and its location in the grain legume likely play the predominant role in hardness (38). In a comprehensive study of chickpea genotypes, differences in the amounts of soluble and insoluble nonstarch polysaccharides in the seed coat significantly affected dehulling performance (47). Structural differences at the junctions between the seed coat and cotyledons also played significant roles in milling differences between chickpea genotypes (48).

A number of agencies have defined tests to measure variability in quality parameters. The USA Dry Pea & Lentil Council lists the U.S. grading standards for pea, chickpea, bean, and lentil (41), while the Canadian Grain Commission (CGC) defines quality parameters using tests that include seed color, cooking time, dehulling characteristics, firmness of cooked seeds, 100 seed weight, protein content, seed size distribution, starch content, and water absorption (3). Internationally, the Codex Alimentarius Commission (CAC) and the International Pulse Quality Committee (IPQC) define pulse quality parameters.

Some of these quality parameters relate directly to pulse milling performance (Table I). For instance, the 100 seed weight is relevant to setting the gap between rolls, whereas the various compositional specifications are relevant for millers striving to meet target specifications for a flour (e.g., seed protein content for flours that will be processed into concentrated protein products, such as concentrates and isolates). Nevertheless, the focus of these national and international standards is on the quality of whole or split pulses. A lack of internationally recognized quality standards and accepted nomenclature for the milling performance of grain legumes has slowed the development of milling and processing of pulses relative to that of wheat (37).

Premilling Treatments. A number of premilling treatments have been used to change the quality attributes of pulse flours.

Table I. National and international pulse quality parameters relevant to milling performance

Quality Parameter	Standard Committee
Seed size/shape/weight	US, CAN, IPQC
Moisture content	US, IPQC, CAC
Crude protein content	CAN, IPQC
Starch content	CAN, IPQC
Water absorption	CAN, IPQC
Purity	US, CAC
Defectiveness	US, CAC
Fiber content	IPQC
Maturity	CAC
Antinutrient factors	IPQC

^a US: USA Dry Pea & Lentil Council; CAN: Canadian Grain Commission; IPQC: International Pulse Quality Committee; CAC: Codex Alimentarius Commission.

Traditional treatments, such as soaking and conditioning (typically with water, but sometimes with oil), have a long history of use as dehulling aids (43). Other pretreatments, such as hydrothermal treatments, micronization, and partial germination, have more recent origins.

The effect of germination on the nutritional and culinary properties of pulses has been investigated, but there are few studies of its effect on milling performance. Indeed, for fixed milling conditions, no study has established how premilling treatments such as roasting, partial germination, or micronization affect the particle size of the resultant flour. Some quality outcomes are known, however. Water-holding capacity increases in micronized pulses (31), and flavor profiles improve in pregerminated pulses (1), whereas mixed trends have been reported for fat-holding capacity and foaming characteristics. Given the dissonance in the literature, systematic studies are required to understand the effects of premilling treatment on milling performance (36).

Pulse Milling

Various researchers have determined the particle size distribution of pulse flours, and a wide range of values has been reported. A pronounced effect of mill type on particle size has been observed. Jet and pin mills result in very fine flours (<60 μm), whereas hammer, roller, and stone mills produce a variety of particle sizes depending on their specific configuration. It is extremely difficult, therefore, to compare milling effects on pulse flour functionality in studies where mill type and configuration differ. As a first step toward enabling meaningful comparisons between studies in different laboratories, we recommend that the wheat flour granulation specification be used when the term “pulse flour” is used.

Title 21 of the U.S. *Code of Federal Regulations* defines flour as a powder made from wheat grains where “not less than 98 percent of the flour passes through a cloth having openings not larger than those of woven wire cloth designated 212 μm (No. 70)” (42). As a result, comparisons of functional properties between wheat flours are made with particle granularity defined in this manner. This is not the case in the vast majority of the peer-reviewed literature on pulse flours, where particle size in bakery applications has been reported as ranging from 17 μm (13) up to 1,000 μm (23); this size variability significantly impedes comparisons of pulse flour functionality across different studies.

Typical commercially milled pulse ingredients include whole pulse flours; dehulled/decorticated pulse flours; fiber-rich, starch-

rich, and protein-rich fractions; and concentrates and isolates made from these fractions (9). All but whole pulse flours require the milling process to not only reduce particle size but also to separate components. Particle size plays a significant role in how effectively components can be separated. Protein or starch enrichment obtained according to differences in the particle size of starch granules and protein bodies is fairly well established (27). However, a wide range of sizes of starch-, protein-, and fiber-enriched particle is evident for different pulses generated by similar mill flows, so any definition of coarse and fine needs qualification. Nevertheless, milling of grain legumes to an appropriate particle size is a prerequisite for the manufacture of pulse ingredients that are enriched in a particular component.

Various milling conditions have been studied with respect to starch damage in flour. In wheat flours, an inverse relationship between particle size and starch damage is observed (8,32). In pulse flours, many studies have shown that starch damage increases when high-speed milling is used to create small particles (e.g., in hammer milling of cowpea) (18). Jet milling of pea at high classifier speeds generated greater starch damage in flours than did impact milling in a study reported by Pelgrom et al. (28). However, assessing the effect of milling process on starch damage alone (and therefore its impact on pulse flour functionality) is difficult because there are no studies that have disentangled the influences of mill type, mill configuration, and particle size from starch damage.

Due to the lack of research on how starch is damaged during pulse milling, it is recommended that systematic studies be conducted on this subject. Roller milling should be employed for at least part of this research because the degree of compression and shear imposed during size reduction can be manipulated independently (32).

Products Prepared from Pulse Flours

Pulse flours have been used as ingredients in many cereal-based products, including cold- and hot-extruded products (e.g., pasta, noodles, and snacks) and various baked products (e.g., cakes, cookies, breads, and gluten-free products). The application of several pulses, and fractions derived from them, in baked, cold-extruded, and other products was recently reviewed (10,34). One of the issues in comparing studies with differently milled pulse flours is that poor miscibility of ingredients (as a result of large particle size) can significantly influence quality assessments of the finished product. In our recent review (36), we focused only on the literature that reported how the milling process itself impacted the quality of the products in which the pulse flour had been incorporated.

Particle size plays a significant role in baked product quality. Some appreciation of this can be gleaned from the bakery application shown in Figure 2, in which milled pea hull flour was added to wheat flour. Reducing the particle size clearly depressed loaf volume, even though the same quantity of pulse hull flour was incorporated into each bread formulation. In contrast, sponge cakes with higher volume have been produced from finer pulse flours (14). A particle size effect was observed also for cookie formulations, in which finely milled pulse flours decreased dough spread and increased cookie hardness (50). Some pulses have been studied extensively in baked product formulations, whereas others (e.g., black bean, pigeon pea, and black-eyed pea) require further research to fully understand their functionality in baked goods.

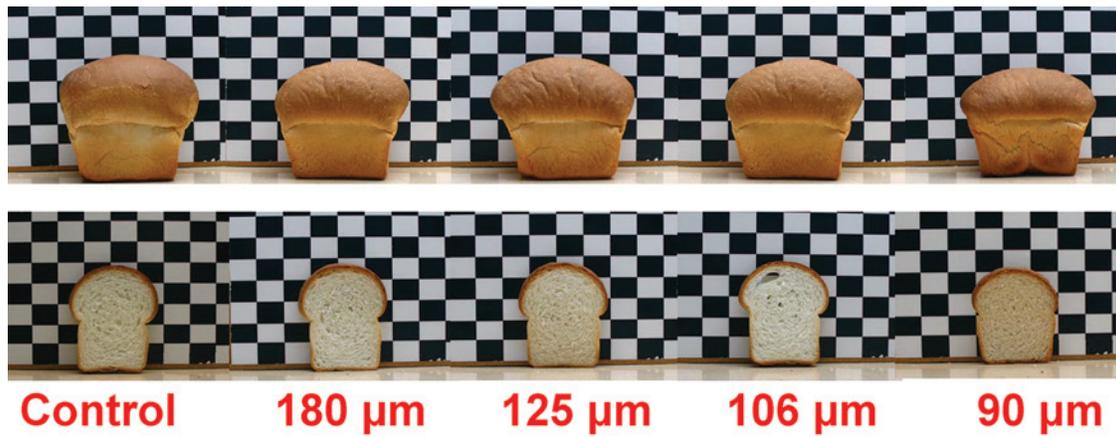


Fig. 2. Changes in loaf volume and crumb structure for a bread formulation with 2 g of milled pea hull (of various particle sizes) per 100 g of wheat flour (from A. L. Shum and M. G. Scanlon, *unpublished results*).

In expanded snack and breakfast foods, blends of air-classified pea starch and field pea flour have produced acceptable extrudates (16). Extrudate quality does decline, however, with an increase in protein content: increased hardness is an outcome of lower expansion indices. A challenge for pulse flours in these applications is their lower starch content. A minimum starch content of 60% has been recommended for expanded cereal products (4), so innovative processes (19) or reformulation strategies (35) may be required to optimize pulse flour functionality in these applications.

Research Gaps

Extensive milling studies on wheat have clearly established a number of millability parameters that govern the quality of the resulting wheat flour (30). However, these parameters have not been well defined for pulse milling. Differences in milling performance arising from variability in seed characteristics have been established for certain pulses, but further investigation is essential to enable breeding programs to develop pulses with high milling efficiency. Although investigations of pulse drying and storage have provided valuable insights into their effects on nutritional and culinary qualities, there is a lack of studies relating drying and storage effects to the millability of pulses. Changes in the physical properties of pulses arising from pre-treatment processes, such as partial germination and micronization, also need to be linked systematically to milling behavior.

Understanding how microstructure affects fracture paths in comminuted pulse particles is essential for devising milling processes that will yield pulse flours with functionalities that produce high-quality end products. Some microstructural studies related to starch damage and protein separation arising from the size reduction process do exist. However, a general perspective based on a thorough assessment of the literature is that the relationship of microstructure to grain legume hardness and its effect on the millability of pulses requires systematic study.

A number of questions with respect to milling of grain legumes into pulse flours need to be answered, including the following questions:

- Is there a desired degree of size reduction for good miscibility of ingredients?
- Does the target particle size differ according to pulse type and according to the product being made from the pulse flour?

- How must separation operations in the mill be configured for different pulses?
- Is there a reliable means of defining separation efficacy in pulse flour milling, analogous to control of wheat flour mill extraction rate by ash measurement?
- Are there defined enrichment targets for components in pulse ingredients akin to wheat flour protein specifications?
- If these enrichment targets are met, are costream(s) still valuable as ingredients?
- What is the correct amount of starch damage for pulse flours for specific applications?
- Do starch damage assays for wheat flour correctly measure starch damage in pulse flours?

One important additional research gap relates to the nutritional reputation of pulses. Starch digestibility impacts the nutrient quality of pulse-fortified foods produced using different processing methods (12). Milling is one such processing technique, and it appears that flour particle size effects on nutrient availability cannot be ignored (21). Systematic studies in this area, preferably studies investigating the underpinning microstructural mechanisms, are required.

Conclusions

The literature on the effects of milling on pulse flour functionality is rather fragmented. There is a clear need to evaluate separately the effects of the three primary purposes of milling (particle size reduction, separation of components, and mechanochemical changes to components) on pulse flour properties. There also is a need for fundamental research on the effects of the composition and structure of pulses on their millability, and much of this research should be tailored to the specific end use of the pulse flour as an ingredient.

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M.S. degree from the University of Saskatchewan, focusing on the incorporation of pulse ingredients in meat products.



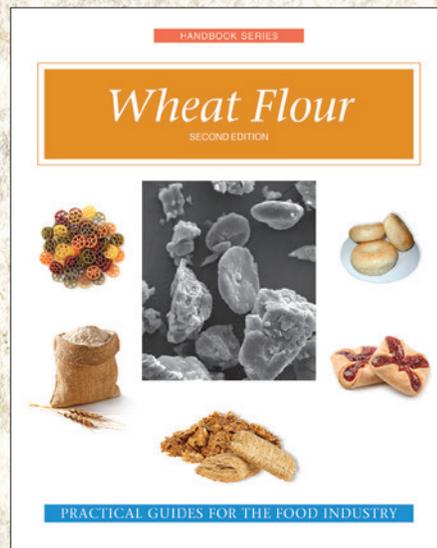
Jitendra Paliwal is a professor of biosystems engineering and associate dean (graduate programs) in the Faculty of Agricultural & Food Sciences at the University of Manitoba. He received a bachelor's degree in agricultural engineering from G.B. Pant University (India) and then obtained master's and doctoral degrees in biosystems engineering, both from the University of Manitoba. His research expertise is in the area of storage of grains, oilseeds, and leguminous crops, with special emphasis on their structure-function relationships.

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