# EVALUATION OF MILLING METHODS AND PULSE SEED PRE-TREATMENTS (MOISTURE CONDITIONING AND MECHANICAL SCOURING) ON PULSE FLOUR CHARACTERIZATION

by

**Kristin Choo**

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Department of Biosystems Engineering

University of Manitoba Winnipeg, Manitoba, Canada

R3T 5V6

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# THESIS ABSTRACT

Dry legumes and pulses are becoming highly valued in food processing due to their usage as highly nutritious and functional food ingredients. Pulse flour utilization in a wide variety of food applications (e.g. breads, pastas, noodles, cookies) is extensively reported in published literature. It has been frequently established that food products containing pulse flours are acceptable in taste and increasingly desired by today's health-conscious consumer. However, due to the high proprietary nature of pulse flour production, little is understood about pulse flour milling and the associated flour quality. The aim of this thesis was to determine if the quality of compositional (moisture, protein, ash), functional (water-holding capacity), and physical (L*a*b* colour, particle size distribution) flour properties of green lentil, yellow pea, chickpea, and navy bean cultivars would be impacted by the type of milling method used (single-stream (Ferkar mill) and gradual reduction (roller mill)). In addition, properties of green lentil and chickpea flours were analyzed after they were pre-treated to varying moisture conditioning levels (0%, 0.5%, or 1% w/w) and mechanically scoured prior to being roller milled. The roller milling method produced green lentil, yellow pea, and navy bean flours that were more uniform and refined compared with Ferkar milling. Roller milling generally produced brighter flours, which was most evident for green lentil. Effects of the seed pre-treatments (i.e. moisture conditioning and scouring) were found statistically significant ($P<0.05$) for several of the flour properties. However, the results showed that these differences were very small between the pre-treatment conditions, indicating that seed moisture conditioning and scouring do not strongly affect the quality of roller milled legume flours. The key findings establish that the type of flour milling method affects pulse flour quality, and that each pulse cultivar responds differently to the milling process.

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## MANUSCRIPT SUBMISSIONS

The following thesis chapters were submitted to peer-reviewed journals:

Chapter 3: Choo, K, Puthukulangara Ramachandran, R., Sopiwnyk, E., & Paliwal, J. Effect of milling methods on pulse flour characterization. *(Submitted to Journal of the Science of Food and Agriculture)*

Chapter 4: Choo, K., Puthulangara Ramachandran, R., Sopiwnyk, E., & Paliwal, J. Effects of seed moisture conditioning and mechanical scouring pre-treatments on roller milled green lentil (*Lens culinaris*) and chickpea (*Cicer arietinum*) flours. *(Submitted to Food and Bioprocess Technology)*

Some of the work that was completed for this thesis project helped our collaborators from the University of Saskatchewan complete their research paper that was published in *Cereal Chemistry* peer-reviewed journal:

Guldiken, B., Franczyk, A., Boyd, L., Wang, N., Choo, K., Sopiwnyk, E., House, J. D., Paliwal, J., & Nickerson, M. (2022). Impact of milling on the functional and physicochemical properties of green lentil and yellow pea flours. *Cereal Chemistry*, *99*(1), 218–229. https://doi.org/10.1002/cche.10504

# 1. Introduction

Pulses are the edible dried seeds of the legume (*Fabaceae*) family of plants. This plant commodity is grown in many geographical regions around the world including Canada, where the most commonly grown pulse crops are lentils (*Lens culinaris*), dry peas (*Pisum sativum*), chickpeas (*Cicer arietinum*), and dry beans (*Phaseolus vulgaris*). Commercial processing of dry legumes has produced pulse ingredients that come in many different forms – whole, split, canned, flour, and fractions (protein, starch, fibre). In many regions of the world, pulses are consumed as a dietary staple because of their high nutritional value (high protein, fibre, vitamin, and mineral contents), low glycemic index, and lower cost in comparison to animal-based food sources such as meat and eggs. In addition, pulses do not contain gluten (proteins present in cereal grains such as wheat, barley, rye, and triticale), making this plant commodity suitable for consumers living with celiac disease. Improvements in human health and disease prevention have been linked to the regular consumption of pulses (Mudryj, Yu, & Aukema, 2014; Abdullah et al., 2017).

Utilization of pulses as food ingredients is a growing area within pulse science and technology. Many studies published throughout the years have demonstrated the functionality, potential uses, and added benefits of including pulse flours in processed food formulations (Zhao et al., 2005; Anton et al., 2008; Kohajdová, Karovičová, & Magala, 2013). The flours used in these studies are typically processed by a commercial flour manufacturer, or they are milled in a laboratory- or pilot-scale research facility using a variety of different milling equipment. The proprietary nature of pulse flour production poses obstacles to fully understanding what factors are influential to pulse flour quality and how pulse-based food applications are impacted by the pulse flour milling process. The lack of both globally recognized standards and standardized analytical testing methods for pulse flours are additional challenges that subsequently make the study of pulse flours inconclusive (Thakur et al., 2019). Although legume flours are recognized as having a lot of potential in food processing applications, what remains to be established is a firm understanding of how the initial quality of these flours influences the overall quality of finished end-products. For this to be accomplished, the specific study of pulse flour processing requires strong consideration from research scientists. Processing operations for milling and isolating major components of whole pulse seeds (protein, starch, and fibre fractions) is a procedure commonly known as flour fractionation, and is a category within pulse flour milling technology that has been given a lot of attention by research scientists over many years (Tyler, Youngs, & Sosulski, 1981; Boye, Zare, & Pletch, 2010; Schutyser & van der Goot, 2011). By comparison, milling conditions in relation to the quality of whole seed legume flours have been examined minimally at this time. Most flour milling studies that examine pulse flours are done by using one mill type to produce flour, often from one single pulse type. These types of milling studies are unable to draw meaningful insight into what aspects of the flour milling method have critical effects on the characteristics of the produced flours. A few researchers have sought to address this gap in knowledge by processing pulses using different types of flour mills (Maskus et al., 2016; Fernando & Manthey, 2021).

The present project was undertaken to address the necessity for additional study of pulse flour milling technology as it relates to the quality of flour properties. This was done by milling different types of whole pulses (green lentils, yellow peas, chickpeas, navy beans) using a Ferkar mill (single-stream type) and a roller mill (gradual reduction type), and evaluating compositional (moisture, protein, ash), physical (L*a*b* colour, particle size distribution), and functional (water-holding capacity) flour properties. The second part of this project examined how the flour properties of roller milled green lentils and chickpeas were affected by a combination of two pre-milling treatments (seed moisture conditioning, mechanical seed scouring).

### 1.1. Thesis Objectives

The objectives of this project were to determine if the milling method and pre-milling seed treatments would have any effect on the flour property characteristics of different pulse types. Differences in operating conditions between the Ferkar and roller mill are expected to result in quality differences between the flours produced using the two milling methods. Varying the levels of seed moisture conditioning and mechanical seed scouring pre-treatments should also produce pulse flours that differ in quality. It is uncertain as to what extent the milling methods and seed pre-treatments in these studies will affect pulse flour quality given that there were no similar studies published at the time of initiating this project.

The analytical findings derived from this project will contribute valuable information that can help research scientists determine appropriate research designs and analytical methods for pulse flour milling studies moving forward, as well as increase knowledge regarding optimal flour processing methods for producing pulse flours best suited for use as ingredients in commercial food formulations.

### 1.2. Thesis Layout

Included in this thesis is a literature review (Chapter 2) which is intended to provide the reader an overview on pulses, proximate composition of pulses, flour milling technology, and pulse flour research (food applications, flour milling), all of which provides background information to accompany the two research papers that follow in Chapter 3 and Chapter 4. Both research papers presented in this thesis are written in a scientific paper format (abstract, introduction, materials, methods, results, discussion, conclusions, references). The research papers in Chapter 3 (titled "Evaluation of milling methods on pulse flour characterization") and Chapter 4 (titled "Effects of seed moisture conditioning and mechanical scouring pre-treatments on roller milled green lentil (*Lens culinaris*) and chickpea (*Cicer arietinum*) flours") have been submitted as manuscripts to peer-reviewed scientific journals. Chapter 5 presents the summary and overall conclusions of the thesis, followed by Chapter 6, which discusses recommendations for future research.

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# 2. Literature Review

## 2.1. Pulses – An Overview

### 2.1.1. Pulse Origins

Pulses are the dry seeds of the *Fabaceae* or *Leguminosae* family (FAO, 2016) of flowering plants. These ancient crops were first sited approximately 90 million years ago, and are estimated to have been first diversified approximately 65 million years ago, in the early Tertiary period (FAO, 2016). Pulse crops can grow and thrive in very hot and cold climates throughout the world, excluding the north and south poles and infertile desert regions (FAO, 2016). Many varieties of pulses that were originally grown in the Mediterranean and Middle Eastern regions (peas (*Pisum*), broad (faba) beans (*Vicia*), lentils (*Lens*), chickpeas (*Cicer*), grass peas (*Lathyrus*)) originated from a subdivision of the *Fabaceae* plant family known as the *Fabeae* (*Vicieae*) tribe (Smartt, 1978). In European, African, Asian, and American regions, the *Phaseoleae* tribe (*Fabaceae* subdivision) is a major contributor of other common pulse varieties such as beans (*Phaseolus)* and pigeon peas (*Cajanus*) (Smartt, 1978).

### 2.1.2. Pulse Seed Structure

Pulse seeds are comprised of two cotyledons (endosperm) and the germ (embryo) surrounded by a protective outer layer called the seed coat (testa) (Tiwari & Singh, 2012). The cotyledon portion makes up approximately 80–95% of the entire seed, while the seed coat and germ account for approximately 5–16% and 1–3%, respectively (Chibbar, Ambigaipalan, & Hoover, 2010; Tiwari & Singh, 2012). A single pulse pod may yield anywhere from one to 12 seeds which vary in physical characteristics (size, shape, colour) (FAO, 1994; FAO, 2016). The main food portion and highest nutrient content are found in the cotyledons (Singh, Singh, & Sikka, 1968; Tiwari & Singh, 2012). Pulses are used as human food sources and animal feed (FAO 1994; FAO 2016).

### 2.1.3. Pulse Varieties

Pulse crops are harvested exclusively for their dry seed, which differentiates them from other leguminous plant crops such as vegetable crops which are harvested when the plants are green (e.g. green beans, green peas), as well as oilseed crops such as soybean (*Glycine max*) and groundnut (*Arachis hypogaea*) which are primarily used for oil extraction (FAO, 1994). Eleven main pulse varieties are identified by the Food and Agricultural Organization (FAO) of the United Nations, which are as follows: dry beans, dry broad beans, dry peas, chickpeas, dry cowpeas, dry pigeon peas, lentils, bambara beans, vetches, lupines, and minor pulses (FAO, 1994; FAO, 2016).

#### 2.1.4. Pulse Production in Canada

Canada is one of the highest producing and exporting countries of pulses in the world (Bekkering, 2014). Lentils (*Lens culinaris*), dry peas (*Pisum sativum*), dry beans (*Phaseolus vulgaris*), and chickpeas (*Cicer arietinum*) are the most commonly grown pulse commodities in Canada (Bekkering, 2014). The Census of Agriculture reported that the majority of Canadian lentils and chickpeas were produced in Saskatchewan in the 2016 growing season (Statistics Canada, 2021). Saskatchewan as well as Alberta, each produced approximately half of the nation's total amount of dry peas, while most of the dry beans were produced in Ontario and Manitoba, followed by Alberta (Statistics Canada, 2021).

### 2.2. Proximate Composition of Pulses

Pulses are a nutrient-dense food source, that supply the diet with high amounts of protein, complex carbohydrates, dietary fibre, essential vitamins and minerals, as well as low amounts of fat and sodium (Tiwari & Singh, 2012). As with all plant-based food sources, pulses are also cholesterol free (Tiwari & Singh, 2012). Worldwide, dry legumes are the second highest consumed food crop following cereals (Singh, 2017). Factors such as plant species, genotype, variety, level of maturity, and growing environment influence the chemical composition of pulses (Roy, Boye, & Simpson, 2010; Tiwari & Singh, 2012; Singh, 2017).

#### 2.2.1. Protein

Protein content gradually increases throughout the maturation process of dry legume seed development (Duranti and Gius, 1997; Roy et al., 2010; Oomah et al., 2011). Because these crops are typically high in protein and less expensive than animal-based proteins, they are often a staple food of many diets. Lentils, yellow peas, navy beans, and chickpeas have been reported to have 26.7% (Hsu et al., 1980), 25.3% (Hsu et al., 1980), 24.1% (U.S. Department of Agriculture, 2019), and 24.0% (Iqbal et al., 2006) protein content, respectively on a dry weight basis. There is nearly twice more protein in pulses compared to that in cereals (Singh, 2017).

#### 2.2.2. Carbohydrates

High proportions of carbohydrates are present in pulses, which range between 49–68% on a dry weight basis (Chibbar et al., 2010). Carbohydrate content in cereals is slightly higher, ranging between 70–80% (Oomah et al., 2011). Monosaccharides, disaccharides, oligosaccharides, and polysaccharides are the main carbohydrates found in pulses (Oomah et al., 2011). In most dry legume seeds, the highest fraction of the total carbohydrate content is starch, a storage carbohydrate (Reddy et al. 1984; Oomah et al., 2011; Singh, 2017). Pulses are also a source of total dietary fibre – insoluble (8–27.5%) and soluble (3.3–13.8%) fibre (Guillon & Champ, 2002).

#### 2.2.3. Lipids

The lipid (fat) content of dry legume seeds is lower compared to the carbohydrate and protein content. Fat content in the cotyledon and seed coat is very low, with most of the fat mainly present in the embryonic axis of pulse seeds (Tiwari & Singh, 2012). Total fat content in pulses can be between 2% and 21%, with the principal fatty acid fractions consisting of linoleic (21–53%) and linolenic (4–22%) acids (Campos-Vega, Loarca-Piña, & Oomah, 2010). Pure varieties of dry pea (Lencolen variety), lentil (Giza 9 variety), and mung bean (V.C 2010 variety) flours have been reported to have 2.40%, 1.15%, and 1.75% fat content, respectively (El-Adawy et al., 2003), while a variety of dry bean cultivars were found to have fat contents in the range of 0.8–2.0% (Campos-Vega et al., 2009). Higher total fat contents have been found in chickpea (5.2%) and cowpea (4.8%) (Iqbal et al., 2006).

#### 2.2.4. Total Ash

Total ash content is an indicator of how much micro- and macronutrients are present in foods (Hossain et al., 2016). Ash content is often a determining factor in the quality of flours and whole grains (Harris & Marshall, 2017). In wheat flour, lower ash content signifies the presence of lower quantity of outer wheat kernel layers (e.g. aleurone, bran) and more of the desirable endosperm portion in the flour, and therefore a more refined (pure) flour (Carson & Edwards, 2009). Unlike for some common cereal foods such as wheat flour and pearl millet flour, the government, regulatory authorities, food industries, and retailers do not recognize ash as a quality factor for pulses (Joint FAO/WHO Codex Alimentarius Commission, 2007). Ash content is influenced by plant variety, soil, and the growing environment (Carson & Edwards, 2009). A study that was done by Khattab, Arntfield, & Nyachoti (2009) found significant differences in ash contents between cowpeas, kidney beans, and peas grown in Canada (2.84%, 4.56%, and 2.94% ash content, respectively) and Egypt (3.27%, 4.29%, and 3.65% ash content, respectively). Ash content cannot be a quality parameter in pulse flour milling because of the high mineral concentration in the cotyledon fractions of pulse seeds (Watson, McEwen, &

Bushuk, 1975). Ash generally does not significantly influence flour properties, therefore it is sometimes disputed whether ash values should be considered a quality parameter for flour specifications in baking processes (Posner & Hibbs, 2005).

#### 2.2.5. Moisture

The amount of water present in foods is represented as moisture content. Moisture content is associated with seed quality, storage, and safety (Canadian Grain Commission, 2020). Many aspects of seeds and grains such as storage life, drying cost, mechanical damage, and infestation due to insects, pests, and microorganisms are influenced by moisture content (Tiwari & Singh, 2012). Specifications of moisture content for pulse seeds are dependent on climate conditions such as temperature and humidity, storage duration, and marketing practices (Joint FAO/WHO Codex Alimentarius Commission, 2007). Lower seed moisture contents (14–15%) are suggested for tropical climates or long-term storage times, while in more temperate climates or short-term storage times, seed moisture content is higher (16–19%) for whole lentils, peas, chickpeas, beans, cowpeas, and field beans (Joint FAO/WHO Codex Alimentarius Commission, 2007). Moisture content of pulses has been shown to have an influence on processing operations. For instance, increasing moisture content conditioning of pulses is associated with decreasing flour yields (Sakhare et al., 2014) and increasing energy requirements in flour milling operations (Dijkink & Langelaan, 2002).

#### 2.2.6. Vitamins and Minerals

With their rich source of micronutrients, pulses are beneficial foods that have the potential to prevent or alleviate common nutrient deficiencies and other health conditions (Robinson, Balk, & Domoney, 2019). These crops are an excellent source of zinc (Otten, Hellwig, & Meyers, 2006), many B-vitamins, potassium, iron, magnesium, and phytochemicals (Mayo Clinic, 2002; Rebello, Greenway, & Finley, 2014). A 100 g portion of chickpeas and lentils contain 557 μg and 479 μg of folate (a B-vitamin), respectively which is significantly higher in folate when compared to whole grain wheat flour (44 μg), brown rice (23 μg), and yellow corn (19 μg) (Singh, 2018). Adequate dietary intakes of folate before and during pregnancy reduces the risk of serious birth defects commonly referred to as neural tube defects (Otten et al., 2006). Pulses contain 2 to 16 times more iron compared to common cereal grains such as barley, corn, and rice, therefore even small substitutions of cereals grains with pulses in the diet may alleviate iron deficiency anemia (Marinangeli et al., 2017), a serious health condition affecting many people around the world, particularly children under the age of 5 and pregnant women (WHO, n.d.).

### 2.3. Flour Milling

"Milling" is a general term in food processing used to describe the mechanical processing of various grain crops that can be accomplished with different milling procedures. Flour milling is an ancient grain processing method that dates back to the prehistoric time period (Catterall & Cauvain, 2007; Owens, 2001). Ancient records revealed that primitive grain grinding (milling) involved the use of a mortar and pestle to pulverize grains (Cauvain, 2015; Owens, 2001), followed by a sieving step to recover ground grain material with higher purity (Owens, 2001). Baudelaire (2013) defined grinding as "a unit operation widely used in the food industry and designed to reduce the size of materials to give a usable form or to separate their components."

Common grinding equipment for flour milling includes roller mills, impact mills (e.g. hammer mills, pin mills), and attrition mills (e.g. ball mills, stone mills) (Posner & Hibbs, 2005; USA Pulses, n.d.). Grinding operations of flour mills use a combination of compression, shear, friction/abrasion, and impact forces (Posner & Hibbs, 2005). Flour particle size, starch damage, and end-product quality have been reported to be affected by mill type and settings (Deng & Manthey, 2017a; Gélinas, Dessureault, & Beauchemin, 2004). High energy expenditures during the milling process are used to separate the outer seed coat layers (bran in wheat kernels) from the cotyledons (endosperm in wheat kernels) and reduce the size of the cotyledons to flour particles, thereby producing heat which causes moisture losses in the ground product (Posner & Hibbs, 2005). Heat generation during flour milling will be higher with more intense grinding operations (Ross & Kongraksawech, 2018).

#### 2.3.1. Single-Stream Milling

Single-stream mills are described by Ross & Kongraksawech (2018) as mills that use one grinding setting to grind seeds into whole-seed flour which is not sieved, separated, or reground later. The milling operation of single-stream mills involves grinding the material using two basic elements – one that remains stationary and one that rotates during the milling process (Ross & Kongraksawech, 2018). The most frequently used single-stream flour milling systems are stone mills and hammer mills (Deng & Manthey, 2017a). Grinding action on hammer mills is performed by a series of swinging steel hammers (blades) equally spread out and attached to a rotating rotor positioned horizontally (Posner & Hibbs, 2005). After the material is fed through the hopper, the slow moving material makes contact with the hammers swinging at very high speed, resulting in size reduction induced by impact forces applied when the material collides with the fast moving hammers causing a transfer of kinetic energy from the hammers to the material (Koch, 2002; Posner & Hibbs, 2005). Size reduction by impact forces also happens in hammer milling when the material contacts the walls of the mill as well as other seed particles (Kaiser et al., 2019; Posner & Hibbs, 2005). The grinding process in the hammer mill continues until the material is a small enough particle size that it can be pushed through the screen openings by the velocity of the hammers, thereby producing friction and heat (Posner & Hibbs, 2005).

The Ferkar mill is another single-stream mill that is used for grinding a variety of foods, including grains, seeds, wheat, corn, oats, barley, buckwheat, rye, and rice (Ferkar, 2008). The Ferkar mill is a high-speed knife mill that operates similarly to the hammer mill. Both the Ferkar mill and hammer mill use impact grinding action as their method of size reduction. But instead of having a series of steel hammers, the Ferkar mill is designed with a series of knives and pins of differing shapes that are attached to a vertical rotor. High speed air currents are produced during Ferkar mill operations which acts to force the flour particles produced through the openings of two metal flour screens located at opposite sides of the grinding area. Flour screens with different aperture sizes can be used at the same time if two particle size ranges are desired.

**Figure 2.1. Ferkar mill (model: Ferkar 5)**

A drawback to single-stream milling systems is that sieving and separation of the different portions of the seeds (i.e. seed coat/bran, cotyledon/endosperm) is difficult to accomplish because the outer seed coat portions are ground to similar particle sizes as the cotyledon portions (Cauvain, 2015). Therefore, single-stream mills produce unrefined flours.

### 2.3.2. Gradual Reduction (Multi-Stream) Milling

Gradual reduction milling is a multi-stream flour milling process that is performed on roller milling machines. Roller milling is the most common milling method used to produce flours from cereal grains such as wheat, a long-established commodity. The roller milling process is generally divided into three separate systems – the break system, the sizing and purification system, and the reduction system (Owens, 2001; Pagani, Marti, & Bottega, 2014). In more basic terms, these separate gradual reduction milling systems may be described as "grinding, sifting, separation, and regrinding" (Haros & Wronkowska, 2017) stages of the milling process.

Size reduction is accomplished in the roller milling process by grinding the material between pairs of parallel iron cylinders (rolls) (Posner & Hibbs, 2005). Depending on the manufacturer and model of the roller milling machine, the rolls may be arranged vertically, horizontally, or diagonally (Kent & Evers, 1994). The rolls rotate in opposite directions, with one roll rotating faster than the other roll creating what is referred to as speed *differential* (Kent & Evers, 1994; Posner & Hibbs, 2005). The roll rotating faster is referred as the fast roll, while the roll rotating slower is referred to as the slow roll. Size reduction is more effective when one roll rotates faster than the other (Koch, 2002). Differentials for fast to slow roll ratio typically ranges from 1.2:1 to 2.0:1 (Koch, 2002).

When the material falls in between the two rolls it is said to be entering the grinding zone, as the material is crushed between the two rolls working together to perform size reduction (Posner & Hibbs, 2005). The magnitude of the grind is affected by the distance between the rolls which is referred to as the roll gap, as well as whether the surface of the rolls have a smooth or corrugated texture (Posner & Hibbs, 2005).


**Figure 2.2. Roller mill (model: Buhler MLU 202)**

**2.3.2.1. The break system** In the break system, the material is crushed between corrugated rolls which use a scissor-type action (Catterall & Cauvain, 2007) to tear apart the material into coarse particles through the application of compression and shear grinding actions, with minimal shattering of the seed coats (Jones, 1958). The main purpose of the break grinding stage is to remove the outer seed coat layers from the cotyledon portions of the seeds (Wood & Malcolmson, 2011). Scraping action is elicited by the corrugated surface of the break rolls in combination with the speed differential of the rolls (Rosentrater & Evers, 2018) which works to separate the seed coat from the cotyledons. Most of the material processed with break grinding resembles large, coarse fragments, however small amounts of flour are also produced at this stage (Rosentrater & Evers, 2018). This operation is typically performed using a series of three to five pairs of corrugated rolls (Catterall & Cauvain, 2007), with the roll gap decreasing with each successive break roll pair (Jones, 1958; Wood & Malcolmson, 2011). After the material exits the grinding zone of each break roll pair, it passes through a sifter composed of a series of stacked sieves moving in an oscillating motion (Cauvain, 2015) to separate and collect the break flour streams into separate flour containers corresponding with each of the break roll pairs. The break material that does not pass through the sieves will continue to be processed within the roller milling system, while the break flours (break flour streams) that pass through the sieves and enter the containers are not further processed (Cauvain, 2015).

**2.3.2.2. The sizing and purification system** The main objective of the sizing and purification system is to separate and classify the particles produced after break grinding based on how much seed coat is attached to the cotyledon (Pagani et al., 2014). The break material that does not pass through the oscillating sieves in the break system are separated into three particle fractions – pure cotyledon particles, particles comprised of both cotyledon and seed coat, and pure seed coat particles (Posner & Hibbs, 2005). Air flow passes through the particles laying on sieves (Jones, 1958) to separate them into different fractions based on specific gravity and size of the particles (Pagani et al., 2014); the seed coat particles by-pass the remainder of the milling process and are collected separately from the flour streams as milling by-product (Jones, 1958). The cotyledon particles with seed coat attached are passed through sizing rolls which have finely corrugated or smooth surfaces to remove the seed coat from the cotyledon portion of these particles (Pagani et al., 2014; Posner & Hibbs, 2005). These seed coat and cotyledon particles along with the pure cotyledon particles are sent to the reduction system for further processing (Pagani et al., 2014). The ground material sent to the reduction system is often referred to as middlings.

**2.3.2.3. The reduction system** The reduction system is the stage of the roller milling process when the middling particles are transformed into flour. Middlings are reduced to smaller particle sizes when they pass through the grinding zone of a sequence of reduction rolls. There can be up to 8–12 reduction rolls accompanied by the same number of sifters within the reduction system (Pagani et al., 2014; Rosentrater & Evers, 2018). Smooth rolls are used in the reduction system because they can reduce the size of the more fragile cotyledon fractions while also keeping the seed coat fractions in larger particle sizes so they can be more easily separated from the flours when they enter the sifters (Posner & Hibbs, 2005) operating at the end of each pair of reduction rolls. The fast roll in the break and reduction systems operate at 500–550 rpm (Kent & Evers, 1994); however, the speed differential is lower in the rolls of the reduction system compared to the break system (Catterall & Cauvain, 2007; Kent & Evers, 1994).

The reduction milling process begins with grinding the largest middling particles during the early stages of reduction grinding. These ground middlings are then passed through the reduction rolls in the later stages to be further reduced in particle size (Rosentrater & Evers, 2018).

The sifting stage after each reduction grinding is similar to that in the break system. A series of 3–5 sieves are used to collect and remove the middling flour streams produced after each reduction grinding stage, as well as recover the remaining material for further size reduction in the reduction rolls operating in the series (Rosentrater & Evers, 2018).

### 2.3.3. Roller Milled Flours

Break and middling flour streams from each of the break and reduction grinding stages of the roller milling process can be blended at ratios chosen by the miller, food manufacturer, researcher, etc. Seed coat particles are recovered from the top of the sieves of the last break and last reduction passages and are collected separately from the break and middling flour streams. These are considered milling by-products but may be incorporated into the flour blend if a less refined, whole seed flour is desired.

### 2.3.4. Laboratory-Scale Milling

Flour milling research is commonly performed on laboratory-scale mills. Their use is ideal at the beginning phases of flour milling research. Canadian wheat breeding programs performed at the Canadian Grain Commission in Winnipeg, MB, Canada use laboratory-scale mills (model: Buhler MLU 202) to evaluate the milling, compositional, and functional qualities of new wheat cultivars (Izydorczyk & Kletke, 2019). The small sample size requirements for laboratory-scale milling make it practical to examine and compare milled flours produced with different mill types. The milling performance of grain commodities is often evaluated in the research field using different models of laboratory-scale mills (Deng & Manthey, 2017a; Baasandorj et al., 2018; Xu et al., 2018; Fernando & Manthey, 2021). Adequate amounts of flour can be produced with laboratory mills to evaluate flour properties (Wheat Marketing Center, 2008) such as moisture content, protein content, ash content, lipid content, particle size distribution, colour, water-holding capacity, and pasting properties. Also, flour extraction observed with laboratory mills are good estimates for flour processing using commercial-scale mills. Information gained from small-scale milling trials can also be used to estimate optimal mill settings (e.g. mill speed, roll gap size, speed differential, feed rate, screen aperture sizes), as well as optimize flour extraction for flour milling research at the commercial level using pilot-scale mills (Wheat Marketing Center, 2008). Optimal mill configurations and seed conditioning studied with laboratory-scale milling have been reported (Khalid, Manthey, & Simsek, 2017; Deng & Manthey, 2017b).

### 2.3.5. Fractionation of Pulse Components

The major pulse fractions – protein, starch, and dietary fibre can be isolated and utilized as basic ingredients, functional ingredients, or additives in food processing (Guillon & Champ, 2002), influencing functional characteristics such as end-product quality, nutritional content, appearance, and taste (Spink, Zabik, & Uebersax, 1984; Silaula et al., 1989; Rangira et al., 2020).

Recognition of the added value of pulse fraction utilization in processed food applications has motivated steady investigation of the pulse fractionation process and pulse protein, starch, and fibre utilization over many decades (Vose et al., 1976; Tyler & Panchuk, 1982; Wright et al., 1984; Cloutt, Walker, & Pike, 1987; van der Poel, Aarts, & Stolp, 1989; Maaroufi et al., 2000; Wu & Nichols, 2005; Dalgetty & Baik, 2006; Pelgrom et al., 2014; Chan et al., 2019).

The process of separating and isolating seed fractions is commonly referred to as fractionation. In the dry fractionation process, whole or dehulled pulse seeds are milled into flour particles which get separated based on size, mass, and density using air classification (Reichert, 1982; Pelgrom et al., 2014). The finer and less dense particles (protein fractions) are separated from the coarser and denser particles (starch fractions) in an air classifier by means of spiral air current (Vose et al. 1976; Reichert, 1982), while the dietary fibre fraction is isolated as a by-product of the fractionation process (Guillon & Champ, 2002). The distinct size difference between the protein and starch particles in pulses makes air classification the ideal fractionation method (Wright et al. 1984).

Impact grinding is the ideal method of size reduction for protein and starch fractionation because it can separate the starch granules from the matrix of proteins without causing damage to the starch granules by excessive crushing (Jones, Halton, & Stevens, 1959). Numerous research scientists with specializations in the disciplinary fields of biology, chemistry, engineering, food science, plant science, and nutritional science have published works over the past several decades about fractionated pulse flours. Flours in pulse fractionation studies are produced mainly using pin mills or other types of impact mills capable of grinding down the seed material to fine particle size. Efficient separation of the protein and starch fractions is attributed to how well the impact milling process can disturb the cell structure of the seed material to the extent that the protein and starch bodies disengage, resulting in a greater proportion of the total protein flour fraction of the pin-milled flours to move into the fine flour fraction during air classification

(Tyler, 1984). Multiple repeats of the process of impact milling and subsequent air classification on the coarse starch flour fractions cause further disentanglement of the protein from the starch, therefore recovering starch fractions with increasingly higher purity (Reichert & Youngs, 1978; Tyler, Youngs, & Sosulski, 1981; Tyler, 1984; van der Poel, Aarts, & Kik, 1990). Chickpeas are less suitable for pin-milling and air-classification. The high lipid content of chickpeas is a contributing factor to their poorer protein and starch separation efficiency during dry fractionation (Sosulski & Youngs, 1979; Han & Khan, 1990) compared to other pulse types such as lentils, field peas, faba beans, mung beans, and dry beans (Sosulski & Youngs, 1979; Tyler et al., 1981; van der Poel et al., 1990). Average protein recovered in the fine fraction of pin-milled lentil, field pea, navy bean, and chickpea flours fractionated using three different air-classifiers were 66%, 65%, 61%, and 35%, respectively (Sosulski et al., 1987).

Dry fractionated pulse protein and starch fractions have been evaluated for their compositional (Tyler et al., 1981; Elkowicz & Sosulski, 1982; Reichert, 1982; Sosulski et al., 1987), functional (Sosulski & McCurdy, 1987; Han & Khan, 1990), and physical (Tyler, 1984) properties. In an air-classification study, Sosulski et al. (1987) analyzed the composition of seven different pulse types and observed lower starch content and higher protein, lipid, fibre, and ash contents in the fine fractions compared to the coarse fractions.

**2.3.5.1. Effects of grinding speed and air classification** Application of different grinding speeds for milling pulse flour has been found to influence air-classified fractions. In van der Poel et al. (1990), similar crude protein contents were observed between fine fractions of fractionated dry beans produced with different impact mills and grinding speeds (Pallmann-mill (5000 rpm), Alpine 160Z pin mill (11,000 rpm, 14,000 rpm)) and within the same air-classifier settings. This trend was also reported for peas milled with two different pin mills (one rotating disc versus two counter-rotating discs) at the same air-classifier speeds in Wright et al. (1984). Use of higher grinding speeds to process air-classified whole and dehulled field peas were associated with higher starch contents in air-classified coarse fractions (Wu & Nichols, 2005).

Similar particle size distributions of dry bean flours were observed using two different types of pin mills (Pallmann-mill, Alpine 160Z pin mill), however, there was approximately 5% more volume of dry bean flour particles no larger than 28 μm in diameter produced with the Pallmann-mill operating at 5000 rpm compared to the other model of pin mill that operated at 11,000 rpm (van der Poel et al., 1990). In a different fractionation study, the particle size of milled lupine seeds got increasingly smaller with increasing grinding speeds of an impact mill (Pelgrom et al., 2014).

Yields of air-classified fine and coarse flour fractions can vary depending on pulse variety, however the coarse, starch-rich fractions will generally have higher yields than the fine, protein-rich fractions (Tyler & Panchuk, 1982; Sosulski et al., 1987). On a C–E Bauer Centri-Sonic 751 commercial scale air-classifier, lentil, field pea, navy bean, and chickpea pin-milled flours yielded between 66.3% and 77.0% of the coarse fraction and between 23.0% and 33.7% of the fine fraction on a dry weight basis (Sosulski et al., 1987).

Change in air-classifier speeds has been found to influence the compositional and physical properties of fine fractions. At increasingly higher air-classifier speeds, the protein contents on a dry weight basis of the fine fractions of pea (Wright et al. 1984), cowpea, faba bean, and pigeon pea (Cloutt et al., 1987) were observed. Lower yields of the fine fraction and higher yields of the coarse fraction, as well as a greater volume of fine fractions with particle sizes 15 μm or less have been reported (Wright et al., 1984).

**2.4. Pulse Flour**

Most published papers written on pulse flours are concerned with the determination of the compositional, physical, and functional properties of ground pulses. This has often involved converting whole or split pulses into pulse flours using laboratory-scale batch grinders that are commonly used in research facilities to prepare material into a ground or powdered form for analysis (Kosson, Czuchajowska, & Pomeranz, 1994a; Kerr et al., 2000; Ettoumi & Chibane, 2015; Patrascu et al., 2017). The added benefits, quality changes, and consumer acceptability of traditionally wheat-based foods re-formulated with ground pulses such as breads (Shehata et al., 1988; Miñarro et al., 2012; Wani et al., 2016), pastas (Zhao et al., 2005; Petitot et al., 2010; Teterycz et al., 2020), baked goods (Singh, Byars, & Liu, 2015; Thongram et al., 2016; Jeong & Chung, 2019), and snack products (Han, Janz, & Gerlat, 2010; Saint-Eve et al., 2019) are largely studied areas within pulse flour research.

A key drawback to developing a full and complete understanding of pulse flour and its processing requirements, utilization, and evaluation is the lack of clearly defined criteria for "pulse flour" (Thakur et al., 2019) as well as globally recognized analytical test methods for evaluating these flour commodities. This is not the case for wheat flour, a widely utilized cereal commodity. Definitions for wheat flours are separated by wheat variety. For instance, in order to meet internationally-based food standards, common wheat flour must meet the criteria for particle size which is that at least 98% of the flour must pass a 212 μm (No. 70 sieve); whereas for durum wheat flour, a minimum of 80% of flour must pass through a 315 μm silk gauze or manufactured sieve (Joint FAO/WHO Codex Alimentarius Commission, 2007). There are also standardized testing methods established to analyze wheat flour quality. Reliable and valid analysis of pulse flour is hindered by a lack of similar criteria and standardized test methods specifically developed for dry legumes (Thakur et al., 2019).

**2.5. Pulse Flour Milling**

Pulse flour milling research, thus far has primarily focused on the fractionation of pulse flours to separate and isolate pulse seed components such as protein and starch. At this time, a small segment of pulse flour research has concentrated on understanding the quality of whole seed pulse flour as it relates to the pulse flour milling process.

Many studies published to date that investigate flour milling technology for pulse flour processing have been done by using a single type of flour milling method such as roller milling and hammer milling to produce a pulse flour product, often from one pulse type. Production of pulse flour with high purity was demonstrated by Watson et al. (1975) who studied the use of the roller milling method to produce faba bean (*Vicia faba*) flour. In their faba bean milling study, it was determined that prior to flour milling, whole pulse seeds should be broken down to the size of wheat kernels. This early study also observed that faba bean seeds tempered to moisture levels greater than about 9% was associated with increased adhesion between the seed coat and cotyledons, making seed coat removal, reduction milling, and sifting less efficient in the roller milling process of faba beans (Watson et al., 1975). In another pulse roller milling study (Sakhare et al., 2014), green gram (*Vigna radiata*) seeds tempered to different moisture content levels (8%, 10%, 12%, 14%, 16%), displayed differences in efficiency of seed coat separation and flour yield. The highest flour yield along with the cleanest separation of the seed coat from the cotyledons was achieved with green gram seeds roller milled at 10% seed moisture content (Sakhare et al., 2014).

There are also published flour milling studies that evaluate and compare the roller milled flour streams of pulses to determine their distribution of nutritional and chemical components. In Kosson, Czuchajowska, & Pomeranz (1994b), it was observed that the flour stream fractions produced from the outer and intermediate layers (shorts and reduction flour streams, respectively) of different cultivars of smooth and wrinkled peas had higher lipid and protein contents compared to the flours stream fractions made from the inner pea layers (break flour streams). The principal fatty acid was linoleic acid (C18:2) in the roller milled flour streams of these pea cultivars (Kosson et al., 1994b). Higher protein content in reduction flours compared to break flours was also reported for roller milled green gram flours in Sakhare et al. (2014).

Different combinations of roller mill configurations (number of grinding roll passes and sieve sizes) were examined for producing pea and lentil pulse flours in Motte et al. (2021). Among the roller milled flour streams of these pulse flours, moderate differences were reported for protein, ash, and starch content. Also, yield, damaged starch, and particle size distribution of the flour streams that were produced from each of the roller mill configurations in that study were different from one another, demonstrating the flour milling process influences yield and physical properties of pulse flours. However, chemical composition (protein, ash, and starch content) of the pea and lentil flours when the flour streams were combined showed little difference between roller mill configurations (Motte et al., 2021).

Kaiser et al. (2019) found that physical flour properties (particle size, bulk density, L*a*b* colour, starch damage) and pasting properties were significantly influenced by the interaction between hammer milling speed (34 m/s and 102 m/s) and screen aperture size (9 different sizes; 0.84 to 9.53 mm) in their split yellow pea milling study. Particle size and peak and final viscosities were lowest (98 μm) at higher hammer milling speed (102 m/s) and smallest screen aperture size (0.84 mm). Higher milling speed and smaller screen aperture sizes were associated with brighter flour (L* colour). In another pulse milling study that used the hammer milling method (Indira & Bhattacharya, 2006), increase in surface area and number of particles were found to be different between pulse types (highest for lentil, lowest for Bengal gram, and similar among cowpea, black gram, and green gram). The authors of this study attributed higher surface area and particle size to the pulses being more amenable to grinding (Indira & Bhattacharya, 2006).

The pulse flour milling research that is summarized above demonstrates that knowledge and understanding about the flour milling process in relation to pulse flour processing is largely based on studies that use one type of flour milling method, often to produce flour from one pulse type. Also, most pulse flour milling studies published to date overlook the relationship between the quality of pulse flour properties and the flour milling method by employing more than one milling system and evaluating and comparing the quality of the pulse flours produced from each. Maskus et al. (2016) is one of a few studies that examined the quality differences in the properties of pulse flours (whole and split yellow pea) produced from five different milling methods. Particle size distribution results reported in this study were a strong indicator that yellow peas were physically influenced by milling method. Particle sizes and volume weighted means were larger in the stone milled compared to the hammer, roller, coarse pin, and fine pin milled flours. Whereas the smallest particle sizes were observed in the fine pin milled flours. These differences in particle sizes between the milling methods were also apparent in the particle size distribution curves (Maskus et al., 2016).

Physical and flow properties of black bean flours were influenced by a variety of mills designed with screens (cyclone mill, centrifugal mill, hammer mill) and mills designed without screens (disk mill, stone mill) in Fernando & Manthey (2021). Geometric mean particle size, particle size distribution, and range were generally larger for the disc and stone milled flours. Disc and stone milling methods also produced flours with higher b* colour. As well, a higher angle of slide was reported for cyclone, centrifugal, and hammer milled flours (Fernando & Manthey, 2021). Both Maskus et al. (2016) and Fernando & Manthey (2021) are novel pulse flour milling studies because pulse flours were produced using different milling methods and the properties of these different flour products were evaluated; however, both only used one pulse type in their investigation. Yellow pea, navy bean, and red lentil flours were produced using a Ferkar mill and a proprietary impact milling method in Bourré et al. (2019). Flour and baking properties of the flours produced using the two different milling methods in that study were evaluated within milling methods, but not between them.

## 2.6. Research Gap

This literature review establishes that most pulse flour milling research is based on flours processed from one type of mill and quite often with only one pulse type. There is currently little published research that evaluates the differences between flour milling technology and pulse flour quality. Hence, additional pulse flour milling experiments that examine the differences between flour milling methods and the corresponding pulse flours that are produced are strongly needed. The present thesis examined the flour quality of different pulses produced (1) from two different flour milling methods (Ferkar milling and roller milling) and (2) from pre-treated (short-time seed tempering and mechanical seed scouring) whole pulses prior to roller milling.  The objective of this work is to determine whether there are differences in pulse flour quality using different milling methods and pre-milling treatments.  This work will add to the currently small collection of pulse flour milling studies and assist in our understanding about the production of high-quality pulse flours for food processing end-uses.

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## 3. Evaluation of Milling Methods on Pulse Flour Characterization

This chapter is based on a manuscript that was submitted for peer-review to the journal *Journal of the Science of Food and Agriculture*, titled "Evaluation of milling methods on pulse flour characterization".

### 3.1. Abstract

BACKGROUND: Popularity of roller milling is contributed by the production of multiple flour streams that can be used to create customized flours that are refined and bright in colour. Increasing demands for nutritionally balanced and functional flour ingredients in processed food products has raised the idea of full or partial replacement of starch rich cereal flours with protein rich pulse flours. The present study evaluates the effects of a single-stream mill (Ferkar mill) and a gradual reduction mill (roller mill) on the flour characteristics of four pulse cultivars. Pulses were milled with the objective of determining the effect of the two mill types on the quality of pulse flour properties (compositional (moisture, ash, protein), functional (water-holding capacity (WHC)), and physical (colour, particle size distribution)).

RESULTS: Ash, protein, and WHC were similar between the two milling methods. L*, a*, b* colour values were often significantly different ($P<0.05$) between the Ferkar milled and roller milled flours, with the strongest differences observed in the green lentil flours. Particle size distribution properties were often significantly different ($P<0.05$) between the milling methods as well.

CONCLUSION: Pulse flour quality is influenced by flour milling method and varietal characteristics of pulses. The single-stream Ferkar mill may be a viable milling method for pulses with minimal nutritional loss and comparable functional properties to roller milled pulse flours. Further study of the relationship between the flour milling process and pulse flour quality is required to help establish standardized milling methods for different pulse varieties and to improve end-product quality.

**Keywords:** pulses, milling, flour quality, nutritional compositions, functional properties

### 3.2. Introduction

Pulses are mature, dried seeds that grow within pods of the legume (*Fabaceae*) family of plants used for human and animal consumption.[1] The largest pulse-producing countries in the world are India, Myanmar, Canada, China, Brazil, and Australia.[2] Common pulse varieties grown in Canada are lentils (*Lens culinaris*), dry peas (*Pisum sativum*), chickpeas (*Cicer arietinum*), and dry beans (*Phaseolus vulgaris*). Research has shown that increased consumption of pulses is associated with a better quality diet that is richer in carbohydrates, protein, fiber, potassium, folate, magnesium, iron, and zinc.[3] The high fiber and protein content of pulses have the additional benefit of increasing satiety.[4] Pulses are also low in fat, gluten-free, and have a low glycemic index, making them suitable for special diets (weight management, gluten-free, vegetarian, diabetic).[5] Frequent pulse consumption is associated with lowered risk of cardiovascular disease, diabetes, cancer, and obesity.[6]

Utilization of processed pulse ingredients in innovative and higher market value food products is a growing segment in the food industry.[7] Pulse flours have been shown to be valuable in food processing because they enhance nutritional content[8–10]; have numerous functional properties[11–13]; and can be used to develop gluten-free food products.[14–16] Most of the research done on pulse milling to date has focused on dehulling, fractionation, and air-classification of their fractions such as protein and starch.[17] Pulse flour milling with a focus on utilizing different varieties of pulses to produce staple food ingredients such as flour for applications in processed food products is a relatively new area of study. At this time, pulse flour research has primarily demonstrated the potential of pulse flours as functional food ingredients with value added benefits such as high nutritional content linked to improved health. Pulse flour milling technology on the other hand, is a subdivision of pulse-related research that is much less understood.[18] More pulse flour milling studies are required at this time to gain a better understanding about the link between the flour milling process and pulse flour quality. This would greatly benefit the flour milling industry by helping them develop optimal pulse flour milling processes to produce pulse flours with quality characteristics desired by the food processing industry.

Pulse flour milling is the process of reducing the size of whole seeds or split cotyledons by grinding them into flour particles. Pulse flours can be produced from whole seed, dehulled whole seed, or dehulled split seeds.[19] More uniform flour particle size can be achieved by passing the ground flour through one or a series of sieves, which can be done as a separate process or by using an automated mill (e.g. roller or impact mill) to perform the grinding and screening processes simultaneously.[19] Few pulse milling studies have investigated quality differences in pulse flours produced by different types of mills and milling methods. In a milling study that evaluated and compared the compositional, physical, and functional properties of yellow pea flours processed by pin milling, stone milling, hammer milling, and roller milling, differences in pulse flour quality were reported between the milling methods.[20] In that study, particle size was most affected by milling method, (for example, coarser particles were produced with stone milling and hammer milling), which was concluded to have influenced the functionality of the pea flour properties. The pea flours produced with roller milling were reported to have the most uniform particle size distribution but higher starch damage compared to the other pea flours. In a different study, the compositional, functional, and baking properties of commercially milled and laboratory milled pulse flours were assessed.[21] However, the authors of that study did not make direct comparisons between the properties of the commercially milled and laboratory milled flours.[21] Commercial pulse flour milling is proprietary, which poses challenges in developing a well understood milling process for pulse flour production. As there is no standard definition for "pulse flour", the ability to make comparisons of pulse flour properties reported in different milling studies, produced with different pulse samples, and analyzed in different laboratories becomes challenging.[18] The effect of milling method on the quality of pulse flour properties is a knowledge gap that needs to be addressed through research to increase our understanding of pulse flour production and develop a standard definition for pulse flours enabling their utilization in various consumer level end-products. Therefore, the objective of the present study was to determine whether single-stream (such as Ferkar mill) versus multi-stream gradual reduction milling (such as roller mill) has an effect on the quality of compositional, functional, and physical properties of different varieties of pulse flours.

## 3.3. Materials and Methods

### 3.3.1. Materials

Cultivars of whole green lentil (*CDC Greeenstar*), chickpea (*CDC Orion*), yellow pea (*CDC Spectrum*), and navy bean (*Nautica*) used in this study were from the 2018 growing season. The green lentils, chickpeas, and yellow peas were grown in Limerick, SK, Canada and the navy beans were grown in Hensall, ON, Canada. The acquired samples were stored at ambient temperature (22 ± 2°C) until use. Initial seed moisture content was measured using a Perten Inframatic 9500 Grain Analyzer (Perten Instruments NA, Inc., Springfield, IL) prior to flour milling. The initial seed moisture contents for the green lentils, yellow peas, chickpeas, and navy beans were 9.9%, 12.4%, 12.2%, and 13.3%, respectively.

### 3.3.2. Flour Milling

**3.3.2.1. Pre-break** Whole pulse seeds were pre-broken in a Jacobson 120-B hammer mill (Jacobson Machine Works Inc., Minneapolis, MN) using a 3.18 mm screen. All four pulse varieties were pre-broken prior to flour milling to prevent breaking the finer screens (Ferkar mill) and to allow passage through the gaps of the break rolls (roller mill).

**3.3.2.2. Ferkar milling** Pre-broken pulses (3 kg) were milled using a Ferkar multipurpose knife mill (KFM, Velenje, Slovenia) using a 0.140 mm screen. The Ferkar mill is a vertical single-stream mill designed with a series of knife-shaped cutting blades configured horizontally on the rotor which enable ground material to be forced through the screen apertures. The Ferkar mill motor was operated at 50 Hz and 2917 rpm with the feeding motor screw at 8 Hz and 19 rpm. Pulse flours were kept in plastic storage bags (0.12 mm thickness), sealed with a twist tie (without headspace), and stored at room temperature until testing. Milling replicates were performed on all pulse varieties. Milling yields for the green lentil, yellow pea, chickpea, and navy bean Ferkar milled flours are presented in Table 3.1..

**3.3.2.3. Roller milling** Pre-broken pulses (5 kg) were roller milled using a Buhler MLU 202 laboratory mill (Buhler Group, Uzwil, Switzerland) operating at 1400 rpm. The roller milling process involved gradual particle size reduction by passing the pulses through a series of three break rolls (1Bk, 2Bk, 3Bk) and three reduction rolls (1R, 2R, 3R), with each roll accompanied by a series of sieving stages, to produce six flour streams. The corrugated break rolls are designed to break open the pulse seeds, while the smooth-surfaced reduction rolls are meant to further reduce the pulses processed with the break rolls into a finer particle size.[22] The laboratory mill was operated at a 5 kg/h feed rate. The break roll gap sizes were 0.1 mm for 1Bk and 0.01 mm for 2Bk and 3Bk, and reduction roll gap sizes were 0.01 mm for 1R, 2R, and 3R. Screen sizes for the upper/lower levels of 1Bk, 2Bk, and 3Bk flour streams were 475 μm/132 μm, 475 μm/132 μm, and 375 μm/132 μm, respectively. All the screen sizes for the upper and lower levels of 1R, 2R, and 3R fractions were 150 μm. Three break flour streams (B1, B2, B3), three reduction flour streams (often referred to as middling flour streams (1M, 2M, 3M)), and two milling by-products (bran from the break system and shorts from the reduction system) were produced using the laboratory mill. Replicate millings were performed for each pulse type.

Yields of the roller milled green lentil, yellow pea, chickpea, and navy bean flour streams and milling by-products are presented in Table 3.1..

**Table 3.1. Flour milling yields for Ferkar milled and roller milled pulse flours**

| Mill type | Flour product | | Flour milling yield[α], % | | | |
|---|---|---|---|---|---|---|
| | | | Green lentil | Yellow pea | Chickpea | Navy bean |
| Ferkar | Whole/unrefined | | 75.08 | 72.92 | 74.74 | 75.58 |
| Roller | First break | B1 | 5.93 | 7.44 | 11.40 | 7.47 |
| | Second break | B2 | 6.45 | 6.80 | 6.93 | 6.85 |
| | Third break | B3 | 3.00 | 3.16 | 3.01 | 4.38 |
| | First reduction | 1M | 67.91 | 66.34 | 49.54 | 43.40 |
| | Second reduction | 2M | 4.93 | 5.14 | 15.67 | 20.46 |
| | Third reduction | 3M | 0.73 | 0.87 | 4.48 | 5.54 |
| | Break by-product | Bran | 5.80 | 6.86 | 4.27 | 7.18 |
| | Reduction by-product | Shorts | 2.39 | 0.60 | 1.12 | 1.30 |

[α]Average flour milling yields from two milling replicates.

### 3.3.3. Preparation of Roller Milled Flour Blends

Roller milled flour blends were prepared from the roller milled flour streams (B1, B2, B3, 1M, 2M, 3M) produced during the roller milling process. The B1, B2, and B3 flour streams were combined to make a break flour blend (B1+B2+B3). Middling flour blends were made using 1M, 2M, and 3M flour streams. Due to insufficient yields of the green lentil and yellow pea 1M and 2M flour streams in proportion to the 3M flour streams, green lentil and yellow pea middling flour blends were composed of all three middling flour streams (1M+2M+3M). For the chickpea and navy bean middling flours, two types of middling flours/blends were prepared for analysis ((1M) and (2M+3M)). Straight grade (SG) flours were made from a representative blend of B1, B2, B3, 1M, 2M, and 3M flour streams, proportional to the total yield of the milled flour streams and by-products. Break, middling, and SG flour blends were prepared by placing proportional amounts of B1, B2, B3, 1M, 2M, and 3M flour streams into a plastic storage bag, twisting the bag closed allowing enough headspace in the bag for adequate blending, and manually shaking the bag of flour for 2 minutes. Flour blends were then sealed with a twist tie (without headspace) and stored at room temperature. Break, middling, and SG flour blends for each pulse type were prepared from both flour milling replicates.

### 3.3.4. Pulse Flour Analysis

**3.3.4.1. Determination of moisture content** Moisture content was measured in duplicate using AACC International Method 44-15.02 (one-stage air-oven method).[23] Well mixed pulse flours (2-3 g per duplicate) were weighed into pre-weighed and tared moisture dishes. Measurements were repeated twice for each milling replicate and thereby an average was calculated from a total of four moisture content values which were used as a representative moisture content for each flour type (Ferkar milled, break, middling, SG).

**3.3.4.2. Determination of ash content** Total ash content was determined using AACC Approved Method 08-01.01.[24] Crucible dishes were dried for 1 h in a Fisher Scientific 550-58 Isotemp muffle furnace (Fisher Scientific Co., Pittsburgh, PA) at 600°C followed by being placed into a desiccator to cool completely before adding flour sample. About 3 g of pulse flour was carefully pressed and weighed into one side of each crucible dish. Pulse flours were incinerated in a muffle furnace at 600°C, for a minimum of 16 hours. Total ash content values were calculated on a dry weight basis. Ash content of each milling replicate was measured twice, yielding a total of four ash content values for each flour type (Ferkar milled, break, middling, SG), and used to calculate an average (representative) ash content.

**3.3.4.3. Determination of protein content** Nitrogen (N) content was determined by the Dumas (nitrogen combustion) method using a LECO FP-628 nitrogen/protein analyzer (LECO Corp., St. Joseph, MI) according to AACC International Method 46-30.01.[25] A nitrogen-to-protein conversion factor of 6.25 was used to calculate crude protein content of the pulse flours (% crude protein = % N $\times$ 6.25).[26] Crude protein values were calculated on a dry weight basis. Pulse flours of each milling replicate were analyzed for crude protein content. The four crude protein content values for each flour (Ferkar milled, break, middling, SG) of each pulse type were used to calculate an average value to represent crude protein content of the flour.

**3.3.4.4. Determination of water-holding capacity (WHC)** WHC was determined in duplicate from each milling replicate using AACC Approved Method 57-13.01,[27] for a total of four WHC values which were used to calculate an average or representative WHC value for each flour type. WHC is a physicochemical test method that measures the WHC of 1 g of pulse material (flour, concentrate, isolate) after being centrifuged at low speed. The only modification made from this method was the use of 50.8 $\times$ 101.6 mm pieces of filter cloth instead of 50.8 $\times$ 50.8 mm pieces.

**3.3.4.5. Measurement of flour colour** Flour colour was measured using a Minolta CR-410 chroma meter with CR-A501 cell holder attachment and two CR-A502 glass cells (Konica Minolta Inc., Osaka, Japan). The chroma meter was set to D65 illuminant with 2° standard observer angle and CIELAB colour parameters – L* (degree of darkness (0)/ lightness (100)); a* (degree of greenness (-)/ redness (+)); and b* (degree of blueness (-)/ yellowness (+)) were measured. The chroma meter was calibrated using a white ceramic calibration tile (L* = 93.97, a* = -0.60, b* = 3.95). After thoroughly mixing, 15 g of pulse flour (corrected at a dry moisture basis) was weighed into a clean and dry glass cell. Flour colour measurement with respect to volume of distilled water added (25 ml), along with mixing time (2 minutes) and waiting time (5 minutes) was performed according to AACC International Method 14-30.01.[28] The glass cell containing the wet flour sample was placed into the cell holder and left to rest for exactly 5 minutes before taking two consecutive colour measurements of L*a*b* colour values with the chroma meter. Consecutive L*, a*, b* colour values were used to calculate respective L*, a*, and b* average colour values (later used to calculate representative L*, a*, b* colour values). Colour measurements of the pulse flours were performed in duplicate for each milling replicate to obtain four of each L*, a*, b* colour values. These colour values were used to calculate the average representative L*, a*, b* values for each of the pulse flours.

**3.3.4.6. Measurement of particle size distributions** Particle size distribution was determined with laser diffraction using a Malvern Mastersizer 2000 optical bench instrument (Malvern Instruments, Malvern, UK) and Scirocco 2000 dry powder dispersion unit (Malvern Instruments, Malvern, UK). Mean particle size (μm) at the $10^{th}$ (d(0.1)), $50^{th}$ (d(0.5)), and $90^{th}$ (d(0.9)) percentile of the particle size distribution curve, volume weighted mean (μm; VWM), span, and uniformity were recorded. The 0.8 mm fine sieve basket was filled with eight stainless steel ball bearings and placed in the sample cone of the Scirocco 2000 dry powder feeder. A macro sample tray attachment was used for all pulse samples analyzed. For each particle size determination, approximately 2 g of well mixed pulse flour sample was carefully added (not packed) into the securely fastened macro sample tray using a lab spatula. The sample cone, sieve basket with ball bearings, and sample tray were cleaned between measurements using a ½ inch wide paint brush and canned compressed air duster. The pulse flours were analyzed in duplicate for each milling replicate to obtain a total of four values for each particle size distribution parameter, which were then used to calculate average values to represent each particle size distribution parameter.

### 3.3.5. Statistical Analysis

Statistical analysis was performed using SAS 9.4 (SAS Institute Inc., Cary, NC). Within pulse type, the Ferkar milled flours and roller milled flour streams/blends were analyzed using one-way Welch's analysis of variance (ANOVA) and Tukey HSD tests to determine if there were differences in the quality of the Ferkar milled and roller milled flour properties at 5% significance level ($P<0.05$). Data were reported as mean ± standard deviation. Statistical data assessment was performed using the Welch ANOVA test because of its compatibility with non-normality and heterogeneous variances, as well as very good control of both Type I error and statistical power.[29]

## 3.4. Results and Discussion

### 3.4.1. Moisture, Ash, and Protein Contents

The Ferkar milled flours had lower moisture content than the roller milled flours (Table 3.2.). Moisture contents of the roller milled break flours were higher than the roller milled middling flours (Table 3.2.), a similar observation that was reported in a study on green gram (*Vigna radiata*) flours milled using the same model of laboratory roller mill used in the present study.[30] Greater moisture losses in the reduction flours may be attributed to the pressure exerted by the rolls to grind the cotyledons into flour as well as to the greater degree of pneumatic lift used to transport milled flours in reduction passages.[30]

Small differences in ash and protein content were observed between the Ferkar milled and roller milled flours (Table 3.2.). In wheat flour milling, ash content is used to determine how much of the outer bran layer is present in the flour, with a lower ash content indicating a more refined flour (less bran and more endosperm). The effects of ash content in pulse flour quality has not been thoroughly investigated and documented in the literature, therefore it is uncertain if ash content analysis as it relates to wheat flour milling can also be applied in studying pulse flour milling. Ash and protein contents of the break flours were generally the lowest in this study (Table 3.2.). Similarly, ash contents of the three break flour streams were found to be lower than the three middling flour streams of smooth pea cultivars.[31] Similar differences in protein content between break and middling flours in addition to observations of gradual increases in protein content from first break to third reduction have been reported.[30–32]

These reports are consistent with the protein content results observed in the present study and demonstrates that pulse protein is distributed unequally in pulse seeds; protein content is lowest in the inner layers of the cotyledons (used to produce break flours) and increases at the outer cotyledon layers (used to produce middling flours). Protein contents of the unrefined Ferkar milled flours (produced from hulls and cotyledons) were slightly lower compared to the refined SG flours (produced mostly from cotyledons) (Table 3.2.). These findings in the present study contradict what was reported for unrefined split yellow pea flours (produced by hammer milling, stone milling, and pin milling) and refined split yellow pea flours (produced from pilot-scale roller milling), where the protein content for the unrefined flours was slightly higher than the refined roller milled flours.[20]

**Table 3.2. Compositional properties$^{\alpha}$ of Ferkar milled and roller milled pulse flours**

| Pulse | Flour$^{\beta}$ | Moisture, %$^{\alpha}$ | Protein, %$^{\alpha}$ | Ash, %$^{\alpha}$ |
|---|---|---|---|---|
| Green Lentil | Ferkar | $8.30 \pm 0.05^{d}$ | $24.81 \pm 0.08^{b}$ | $2.79 \pm 0.04^{a}$ |
| | B1+B2+B3 | $9.08 \pm 0.05^{a}$ | $24.84 \pm 0.10^{b}$ | $2.63 \pm 0.02^{b}$ |
| | 1M+2M+3M | $8.83 \pm 0.04^{b}$ | $26.54 \pm 0.18^{a}$ | $2.80 \pm 0.01^{a}$ |
| | SG | $8.64 \pm 0.04^{c}$ | $26.34 \pm 0.15^{a}$ | $2.78 \pm 0.01^{a}$ |
| Yellow Pea | Ferkar | $9.04 \pm 0.02^{b}$ | $24.97 \pm 0.27^{b}$ | $2.87 \pm 0.03^{a}$ |
| | B1+B2+B3 | $10.00 \pm 0.11^{a}$ | $22.42 \pm 0.03^{c}$ | $2.49 \pm 0.02^{b}$ |
| | 1M+2M+3M | $9.83 \pm 0.25^{a}$ | $26.20 \pm 0.09^{a}$ | $2.87 \pm 0.01^{a}$ |
| | SG | $9.61 \pm 0.22^{a}$ | $25.48 \pm 0.14^{b}$ | $2.84 \pm 0.03^{a}$ |
| Chickpea | Ferkar | $8.88 \pm 0.08^{b}$ | $20.50 \pm 0.06^{c}$ | $2.87 \pm 0.04^{b}$ |
| | B1+B2+B3 | $10.24 \pm 0.40^{a}$ | $18.87 \pm 0.12^{d}$ | $2.56 \pm 0.01^{d}$ |
| | 1M | $9.85 \pm 0.43^{a}$ | $20.81 \pm 0.07^{b}$ | $2.74 \pm 0.02^{c}$ |
| | 2M+3M | $9.66 \pm 0.53^{ab}$ | $22.90 \pm 0.11^{a}$ | $3.07 \pm 0.01^{a}$ |
| | SG | $9.94 \pm 0.51^{a}$ | $20.81 \pm 0.09^{b}$ | $2.79 \pm 0.02^{bc}$ |
| Navy Bean | Ferkar | $9.87 \pm 0.26^{d}$ | $26.27 \pm 0.18^{c}$ | $4.39 \pm 0.02^{b}$ |
| | B1+B2+B3 | $11.48 \pm 0.11^{a}$ | $22.48 \pm 0.06^{d}$ | $3.64 \pm 0.01^{d}$ |
| | 1M | $11.34 \pm 0.14^{ab}$ | $26.99 \pm 0.17^{b}$ | $4.31 \pm 0.07^{bc}$ |
| | 2M+3M | $10.56 \pm 0.29^{c}$ | $30.53 \pm 0.12^{a}$ | $4.56 \pm 0.01^{a}$ |
| | SG | $11.09 \pm 0.13^{bc}$ | $27.05 \pm 0.04^{b}$ | $4.23 \pm 0.05^{c}$ |

$^{\alpha}$Mean and standard deviations of two milling duplicates analyzed in duplicate; means with a different letter in a column within the same pulse type are significantly different ($P<0.05$); results reported on a dry basis.
$^{\beta}$Roller mill: B1+B2+B3 = break flours; 1M+2M+3M, 1M, and 2M+3M = middling flours; SG = straight grade flours.

### 3.4.2. Water-Holding Capacity (WHC)

WHC is an important property in food processing because it can be used to determine how well the flour will interact and bind with liquid ingredients and influence the rheological properties of the finished product.[33] Differences in WHC between the Ferkar milled and roller milled flours were generally very small (Table 3.3.). Although the present study found a significant difference ($P<0.05$) in the WHC in the green lentil Ferkar milled flours (0.77 ± 0.02 g/g) compared to the break, middling, and SG green lentil roller milled flours (0.72 ± 0.01 g/g, 0.72 ± 0.02 g/g, 0.71 ± 0.01 g/g, respectively), it is not certain if this small increase in WHC would have significant bearing in practical applications.

**Table 3.3. Water-holding capacity$^{\alpha}$ of Ferkar milled and roller milled pulse flours**

| Flour$^{\beta}$ | Water-holding capacity$^{\alpha}$, g/g | |
|---|---|---|
| | **Green Lentil** | **Yellow Pea** |
| Ferkar | 0.77 ± 0.02$^{a}$ | 0.75 ± 0.02$^{a}$ |
| B1+B2+B3 | 0.72 ± 0.01$^{b}$ | 0.70 ± 0.01$^{a}$ |
| 1M+2M+3M | 0.72 ± 0.02$^{b}$ | 0.69 ± 0.03$^{a}$ |
| SG | 0.71 ± 0.01$^{b}$ | 0.74 ± 0.03$^{a}$ |
| | **Chickpea** | **Navy Bean** |
| Ferkar | 0.65 ± 0.01$^{b}$ | 1.08 ± 0.02$^{b}$ |
| B1+B2+B3 | 0.60 ± 0.02$^{d}$ | 0.79 ± 0.02$^{c}$ |
| 1M | 0.62 ± 0.01$^{cd}$ | 1.07 ± 0.07$^{b}$ |
| 2M+3M | 0.78 ± 0.03$^{a}$ | 1.25 ± 0.01$^{a}$ |
| SG | 0.65 ± 0.02$^{bd}$ | 1.12 ± 0.02$^{b}$ |

$^{\alpha}$Mean and standard deviations of two milling duplicates analyzed in duplicate; means with a different letter in a column within the same pulse type are significantly different ($P<0.05$); results reported on a dry basis.
$^{\beta}$Roller mill: B1+B2+B3 = break flours; 1M+2M+3M, 1M, and 2M+3M = middling flours; SG = straight grade flours.

### 3.4.3. Pulse Flour Colour

Colour is an important physical property because it can influence consumer acceptability.[34] In previous milling studies, milling method was found to have an effect on the colour of pulse flours.[20,35] The differences in L*, a*, b* colour values between the Ferkar milled and roller milled yellow pea, chickpea, and navy bean flours in this study were relatively minor (Table 3.4.). In the case of the green lentil, there were considerably larger differences in the L*, a*, b* colour values between the Ferkar milled and roller milled green lentil flours (Table 3.4.). *CDC Greenstar* as well as other varieties of large green lentils have a characteristic green seed coat (hull) colour and a yellow cotyledon colour.[36] Removal of the green lentil hulls from the green lentil flours in the roller milling process resulted in a refined flour product that was brighter with a more uniform colour compared to the unrefined Ferkar milled green lentil flours which contained both the green hulls and yellow cotyledons, resulting in the production of a darker pigmented green lentil flour.  Colour differences between the hulls and cotyledons of the yellow pea, chickpea, and navy bean varieties used in this study were less significant, resulting in much smaller L*, a*, b* differences between the Ferkar milled and roller milled flours of these pulse varieties (Table 3.4.).

**Table 3.4. Colour results$^{\alpha}$ of Ferkar milled and roller milled pulse flours**

| Pulse | Flour$^{\beta}$ | Colour values$^{\alpha,\delta}$ | | |
|---|---|---|---|---|
| | | ***L**** | ***a**** | ***b**** |
| Green lentil | Ferkar | 66.94 ± 0.10$^{c}$ | -0.47 ± 0.04$^{c}$ | 25.99 ± 0.16$^{c}$ |
| | B1+B2+B3 | 73.06 ± 0.22$^{b}$ | 0.94 ± 0.04$^{b}$ | 33.20 ± 0.12$^{b}$ |
| | 1M+2M+3M | 74.39 ± 0.08$^{a}$ | 1.30 ± 0.06$^{a}$ | 35.92 ± 0.16$^{a}$ |
| | SG | 74.52 ± 0.08$^{a}$ | 1.14 ± 0.07$^{a}$ | 35.66 ± 0.11$^{a}$ |
| Yellow pea | Ferkar | 73.83 ± 0.18$^{b}$ | 2.61 ± 0.11$^{b}$ | 36.28 ± 0.31$^{c}$ |
| | B1+B2+B3 | 74.52 ± 0.74$^{ab}$ | 2.87 ± 0.36$^{ab}$ | 36.77 ± 0.63$^{c}$ |
| | 1M+2M+3M | 74.54 ± 0.10$^{a}$ | 3.34 ± 0.11$^{a}$ | 40.03 ± 0.11$^{a}$ |
| | SG | 74.56 ± 0.26$^{a}$ | 3.31 ± 0.13$^{a}$ | 39.52 ± 0.24$^{b}$ |
| Chickpea | Ferkar | 76.22 ± 0.09$^{c}$ | 2.48 ± 0.07$^{c}$ | 35.00 ± 0.14$^{c}$ |
| | B1+B2+B3 | 76.86 ± 0.20$^{ab}$ | 1.87 ± 0.13$^{d}$ | 33.96 ± 0.16$^{d}$ |
| | 1M | 77.00 ± 0.01$^{a}$ | 2.84 ± 0.03$^{b}$ | 36.67 ± 0.11$^{b}$ |
| | 2M+3M | 75.23 ± 0.09$^{d}$ | 3.39 ± 0.04$^{a}$ | 37.73 ± 0.09$^{a}$ |
| | SG | 76.57 ± 0.03$^{b}$ | 2.77 ± 0.03$^{b}$ | 36.61 ± 0.18$^{b}$ |
| Navy bean | Ferkar | 73.80 ± 0.15$^{a}$ | 1.99 ± 0.03$^{d}$ | 14.41 ± 0.17$^{b}$ |
| | B1+B2+B3 | 73.96± 0.09$^{a}$ | 2.07 ± 0.03$^{cd}$ | 15.15 ± 0.16$^{a}$ |
| | 1M | 73.94 ± 0.30$^{a}$ | 2.38 ± 0.04$^{a}$ | 13.61 ± 0.24$^{c}$ |
| | 2M+3M | 72.17 ± 0.14$^{c}$ | 2.12 ± 0.05$^{c}$ | 14.50 ± 0.06$^{b}$ |
| | SG | 73.32 ± 0.15$^{b}$ | 2.30 ± 0.02$^{b}$ | 14.63 ± 0.10$^{b}$ |

$^{\alpha}$Mean and standard deviations of two milling duplicates analyzed in duplicate; means with a different letter in a column within the same pulse type are significantly different ($P<0.05$); results reported on a dry basis.
$^{\beta}$Roller mill: B1+B2+B3 = break flours; 1M+2M+3M, 1M, and 2M+3M = middling flours; SG = straight grade flours.
$^{\delta}$*L** is lightness, 0 = black, 100 = white; *a** = (-) greenness, (+) redness; *b** = (-) blueness, (+) yellowness.

### 3.4.4. Particle Size Distributions

Particle size distributions between the Ferkar milled and roller milled flours were different for all pulse varieties in the present study, which is evident in the particle size distribution curves of the unrefined Ferkar milled flours and refined SG roller milled flours (Figures 3.1.–3.4.).  The Ferkar milled flours of all pulse varieties had smaller particle size at the $10^{th}$/ d(0.1) and $50^{th}$/ d(0.5) percentile of the particle size distribution curve compared to the roller milled flours (Table 3.5.).  Depending on the pulse type, particle size of the Ferkar milled flours at the $90^{th}$/ d(0.9) percentile was larger (green lentil), approximately the same (yellow pea and navy bean), or smaller (chickpea) compared to the roller milled flours (Table 3.5.). The particle size distribution curves of the green lentil (Figure 3.1.), yellow pea (Figure 3.2.), and navy bean (Figure 3.4.) Ferkar milled flours all displayed trimodal distributions with one of the three peaks situated at approximately the 1000 μm particle size region, indicating that there are larger flour particles present in the Ferkar milled flours. Volume weighted mean (VWM) which represents the particle size of the majority of the flour sample was larger for the Ferkar milled green lentil and yellow pea flours and smaller for the Ferkar milled chickpea flours compared to the roller milled flours (Table 3.5.). Similar VWM results were found for the Ferkar milled and roller milled navy bean flours (Table 3.5.). Higher span and uniformity values were found in the Ferkar milled flours compared to the roller milled flours for green lentil, yellow pea, and navy bean; whereas span and uniformity for the Ferkar milled and roller milled chickpea flours were similar (Table 3.5.). Span is a measurement of the width of the particle size distribution and uniformity represents the absolute distance the data points (particle sizes) are from the median particle size of the distribution.[37] Wider particle size distributions and less homogeneous flour particle size are associated with higher span and uniformity values, respectively.

Particle size distribution was narrowest for the Ferkar milled chickpea flours which is evident in the display of a narrow unimodal distribution compared to the wider bimodal distribution of the chickpea SG roller milled flours (Figure 3.4.). Contrary to the green lentil (Figure 3.1.), yellow pea (Figure 3.2.), and navy bean (Figure 3.4.) Ferkar milled flours, the chickpea (Figure 3.3.) Ferkar milled flours did not display the presence of large flour particles (approximately 1000 μm) on their particle size distribution curve, suggesting that the chickpea hulls were more easily reduced to smaller particle size. Differences in the grinding behaviour of hulls and cotyledons of various pulse varieties observed in previous pulse flour studies suggested that the greater difficulty in grinding hulls was due to their higher elasticity/pliability or lack of brittleness.[38]

**Table 3.5. Particle size distribution[α] of Ferkar milled and roller milled pulse flours**

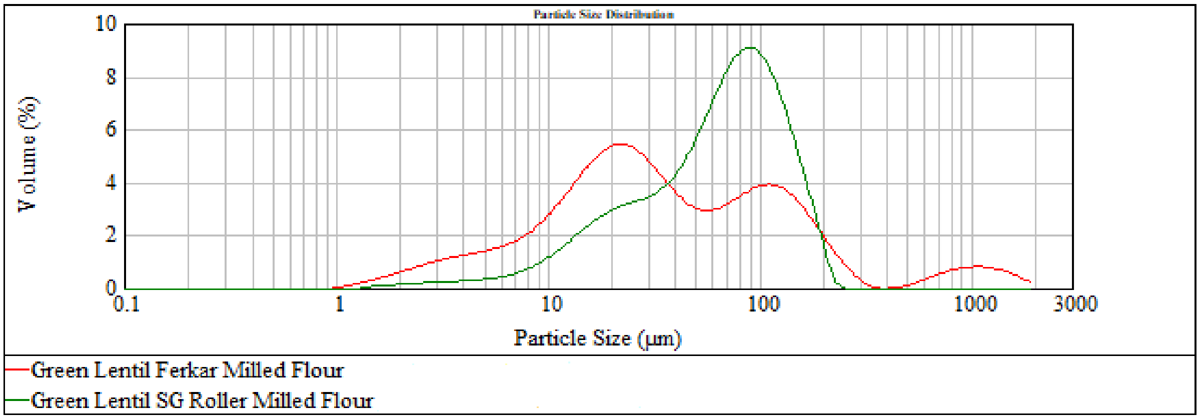
| | | Particle size distribution[α] | | | | | |
|---|---|---|---|---|---|---|---|
| **Pulse** | **Flour[β]** | **d(0.1), μm[γ]** | **d(0.5), μm[γ]** | **d(0.9), μm[γ]** | **Volume weighted mean, μm** | **Span** | **Uniformity** |
| Green lentil | Ferkar | 6.4 ± 0.2[d] | 31.0 ± 0.9[c] | 177.1 ± 3.2[a] | 106.7 ± 5.4[a] | 5.51 ± 0.22[a] | 2.97 ± 0.26[a] |
| | B1+B2+B3 | 17.0 ± 0.1[a] | 60.5 ± 0.2[b] | 149.6 ± 0.5[b] | 72.9 ± 0.2[b] | 2.19 ± 0.01[b] | 0.69 ± 0.00[b] |
| | 1M+2M+3M | 15.8 ± 0.1[c] | 68.8 ± 0.8[a] | 139.4 ± 1.6[c] | 73.7 ± 0.9[b] | 1.80 ± 0.00[c] | 0.56 ± 0.00[d] |
| | SG | 16.0 ± 0.0[b] | 67.6 ± 0.6[a] | 140.6 ± 1.5[c] | 73.4 ± 0.7[b] | 1.84 ± 0.01[d] | 0.57 ± 0.00[c] |
| Yellow pea | Ferkar | 6.6 ± 0.2[b] | 26.6 ± 0.2[c] | 144.0 ± 9.3[a] | 83.8 ± 7.4[a] | 5.17 ± 0.34[a] | 2.62 ± 0.27[a] |
| | B1+B2+B3 | 16.0 ± 0.1[a] | 46.9 ± 0.3[b] | 140.9 ± 1.6[a] | 64.6 ± 0.6[b] | 2.66 ± 0.02[b] | 0.83 ± 0.01[b] |
| | 1M+2M+3M | 15.4 ± 0.5[a] | 62.7 ± 3.8[a] | 136.1 ± 5.2[a] | 69.6 ± 3.3[ab] | 1.93 ± 0.04[c] | 0.60 ± 0.01[c] |
| | SG | 15.6 ± 0.4[a] | 59.6 ± 2.9[a] | 136.0 ± 4.7[a] | 68.3± 2.6[b] | 2.02 ± 0.03[c] | 0.64 ± 0.00[d] |
| Chickpea | Ferkar | 8.9 ± 0.1[c] | 21.0 ± 0.0[d] | 60.8 ± 1.4[c] | 30.3 ± 0.3[c] | 2.48 ± 0.07[b] | 0.82 ± 0.01[a] |
| | B1+B2+B3 | 14.8 ± 0.4[b] | 36.2 ± 0.3[c] | 117.7 ± 2.1[b] | 52.9 ± 0.3[b] | 2.84 ± 0.09[a] | 0.86 ± 0.03[a] |
| | 1M | 16.1 ± 0.3[a] | 55.7 ± 1.6[a] | 138.2 ± 3.8[a] | 67.3 ± 1.8[a] | 2.19 ± 0.00[c] | 0.70 ± 0.00[c] |
| | 2M+3M | 15.2 ± 0.9[ab] | 51.3 ± 3.3[ab] | 133.8 ± 3.2[a] | 64.1 ± 2.6[a] | 2.32 ± 0.11[bc] | 0.73 ± 0.03[bc] |
| | SG | 15.5 ± 0.4[ab] | 48.8 ± 2.0[b] | 131.7 ± 2.7[a] | 62.6 ± 1.7[a] | 2.38 ± 0.05[b] | 0.76 ± 0.02[b] |
| Navy bean | Ferkar | 6.3 ± 0.2[d] | 24.7 ± 0.1[d] | 138.8 ± 2.8[cd] | 69.7 ± 4.7[ab] | 5.37 ± 0.08[a] | 2.29 ± 0.17[a] |
| | B1+B2+B3 | 14.9 ± 0.0[a] | 35.2 ± 0.2[c] | 135.0 ± 0.7[d] | 56.9 ± 0.3[c] | 3.41 ± 0.01[b] | 1.01 ± 0.01[b] |
| | 1M | 14.9 ± 0.0[a] | 52.7 ± 1.0[a] | 153.2 ± 0.3[a] | 70.3 ± 0.2[a] | 2.62 ± 0.06[c] | 0.86 ± 0.02[c] |
| | 2M+3M | 13.9 ± 0.3[c] | 55.5 ± 2.3[a] | 141.3 ± 2.1[bc] | 67.4 ± 1.5[ab] | 2.30 ± 0.07[d] | 0.73 ± 0.02[d] |
| | SG | 14.6 ± 0.1[b] | 48.8 ± 1.1[b] | 146.0 ± 0.4[b] | 66.6 ± 0.5[b] | 2.70 ± 0.06[c] | 0.86 ± 0.02[c] |

[α]Mean and standard deviations of two milling duplicates analyzed in duplicate; means with a different letter in a column within the same pulse type are significantly different ($P<0.05$).

[β]Roller mill: B1+B2+B3 = break flours; 1M+2M+3M, 1M, and 2M+3M = middling flours; SG = straight grade flours.

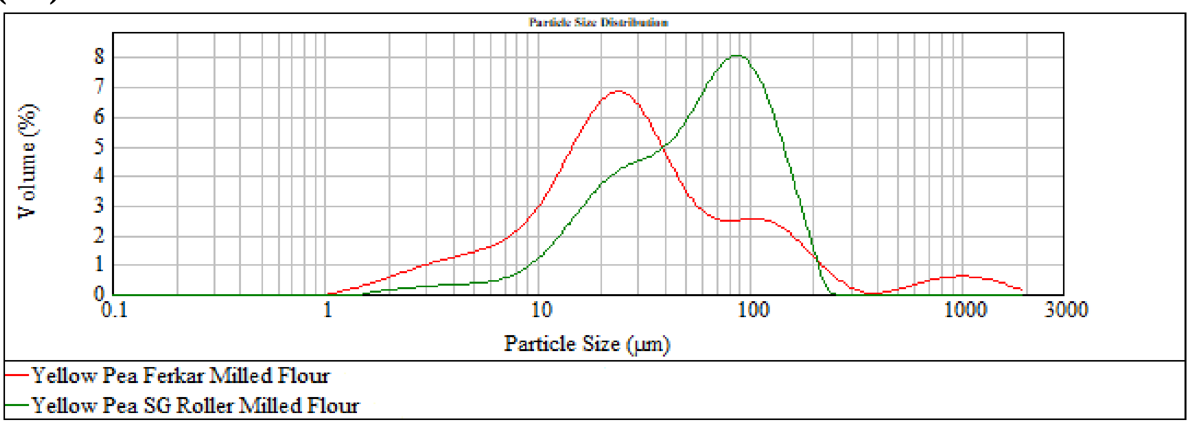
[γ]d(0.1), d(0.5), and d(0.9) = 10$^{th}$, 50$^{th}$, and 90$^{th}$ percentile, respectively, of the particle size distribution curve.

**Figure 3.1. Particle size distribution curves[α] of green lentil Ferkar milled and straight grade (SG) roller milled flours**



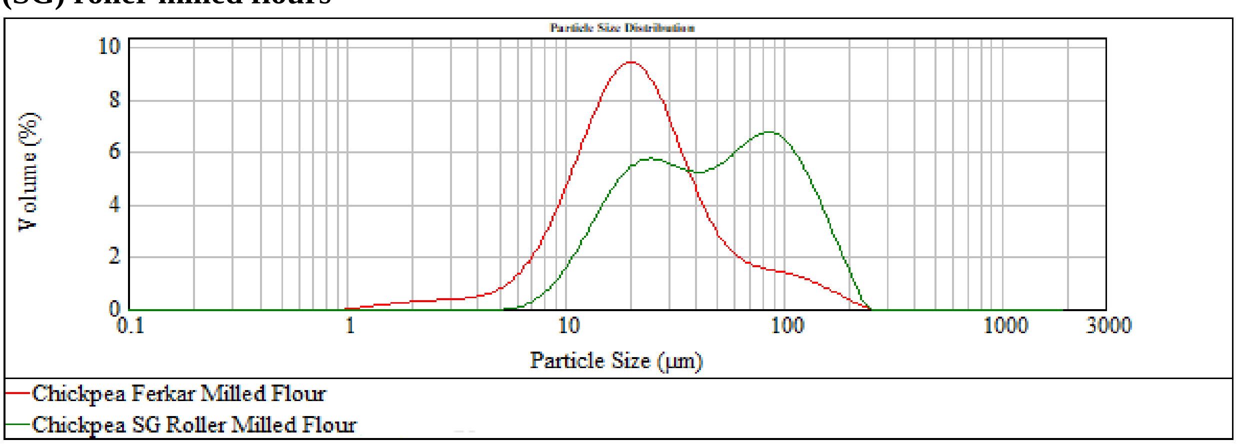

[α] Curves represent the average particle size distribution calculated from the average of two flour milling replicates.

**Figure 3.2. Particle size distribution curves[α] of yellow pea Ferkar milled and straight grade (SG) roller milled flours**



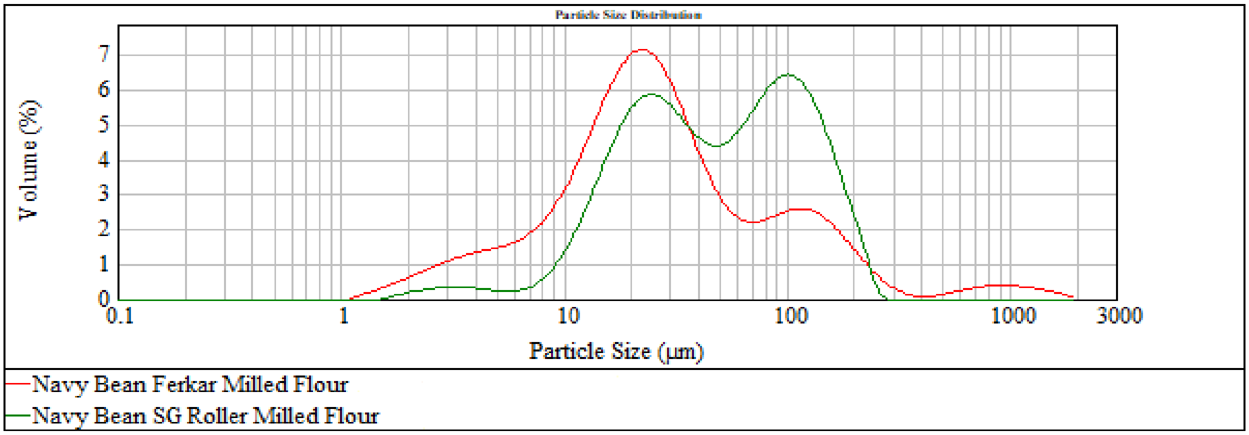

[α] Curves represent the average particle size distribution calculated from the average of two flour milling replicates.

**Figure 3.3. Particle size distribution curves[α] of chickpea Ferkar milled and straight grade (SG) roller milled flours**




[α] Curves represent the average particle size distribution calculated from the average of two flour milling replicates.

**Figure 3.4. Particle size distribution curves[α] of navy bean Ferkar milled and straight grade (SG) roller milled flours**




[α] Curves represent the average particle size distribution calculated from the average of two flour milling replicates.

## 3.5. Conclusion

Pulse flour qualities were affected by milling method. L*, a*, b* colour values were lower in the unrefined Ferkar milled flours, likely resulting from the Ferkar milled flours being produced from the darker coloured hulls and lighter coloured cotyledons. This was most particularly evident with the green lentil Ferkar milled flours which were produced from green hulls and yellow cotyledons. Most of the unrefined Ferkar milled flours (green lentil, yellow pea, navy bean) had wider particle size distributions and less homogeneous flours due to the presence of hulls that were insufficiently reduced in size during the milling process and resulting in flours comprised of heterogeneous particle sizes and wider particle size ranges. There were negligible differences between the Ferkar milled and roller milled pulse flours for moisture, ash, protein, and WHC. It is uncertain if the differences observed between the two milling methods in this study would be evident in food processing applications given that many of the differences were negligible. Analysis of these unrefined and refined pulse flours in ingredient functionality, food processing, and product development research should be undertaken to understand this aspect.

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# 4. Effects of Seed Moisture Conditioning and Mechanical Scouring Pre-Treatments on Roller Milled Green Lentil (*Lens culinaris*) and Chickpea (*Cicer arietinum*) Flours

This chapter is based on a manuscript that was submitted for peer-review to the journal *Food and Bioprocess Technology*, titled "Effects of seed moisture conditioning and mechanical scouring pre-treatments on roller milled green lentil (*Lens culinaris*) and chickpea (*Cicer arietinum*) flours".

## 4.1. Abstract

The study evaluates the effect of pulse milling pre-treatments such as moisture conditioning and mechanical scouring on the compositional (moisture, protein, ash), functional (water-holding capacity), and physical (L*a*b* colour, particle size distribution) properties of pulse flours. Two different varieties of pulse cultivars, lentil (*Lens culinaris*) and chickpea (*Cicer arietinum*) were milled into flour using a laboratory-scale roller mill. Prior to milling, pulse seeds were subjected to two types of seed pre-treatments – (1) moisture conditioning (0%, 0.5%, or 1% w/w) and (2) mechanical scouring. The green lentils and chickpeas showed distinctive differences in all of the studied properties with pre-treatments. Moisture contents were higher in the scoured green lentil flours, while in the scoured chickpea flours were often lower within moisture conditioning levels. For many of the scoured flours, protein content was lower compared to the unscoured flours within moisture conditioning levels. Scouring was associated with higher L*a*b* colour in the green lentil flours, however for the chickpea flours L*a*b* were less influenced by scouring. Green lentil middling and SG flours were more refined with scouring. Ash content and water-holding capacity values were not significantly different between the pre-treatment conditions for both pulse types. Differences in flour property results between pre-treatment conditions were significantly different ($P<0.05$) in the straight grade flours. These research findings could serve as a basis for the optimization and design of flour milling operations suitable for dry legumes and thereby improve the application of these high protein pulse flours in processed end-products to satisfy the desire for greater diversity in the food product market.

**Keywords:** Pulse milling, moisture conditioning, scouring, compositional and functional properties

### 4.2. Introduction

Pulses are the dry seeds harvested from the pods of legume (*Leguminosae*) plants which are a common food source around the world. Commonly produced pulses include lentils (*Lens culinaris*), chickpeas (*Cicer arietinum*), dry peas (*Pisum sativum*), and dry beans (*Phaseolus vulgaris*). There have been significant increases in pulse crop production since the 1980s (Bekkering, 2014). Pulse production is widespread throughout the world (Siddiq & Uebersax, 2013). Most pulses produced in North America are exported to countries where they are processed for consumption as a staple food source or utilized in food processing (Asif et al., 2013; Bekkering, 2014). In recent years, good health and nutrition has been a high priority for consumers, resulting in increased demand for nutritionally balanced plant-based foods in the diet (Siddiq & Uebersax, 2013), and is compatible with the dietary contribution pulses provide. Pulses are a highly nutritious food source, rich in plant-based protein, carbohydrates, dietary fibre, vitamins, and minerals. Pulses are low in fat and the absence of gluten makes them suitable for consumers allergic/sensitive to foods that contain it (e.g., wheat, rye, barley). Regular consumption of pulses is associated with improved human health (Anderson & Major, 2002; Becerra-Tomás et al., 2017; Venn et al., 2010).

For household consumption, pulses are commonly available in whole, split, canned, and flour form, among which the canned and flours are gaining more popularity as ready-to-use ingredients for many recipes and processed products. Grinding whole pulses into flour greatly reduces their size and increases surface area, producing a pulse ingredient which can be used in flour-based food applications such as baked goods (breads, cookies, cakes), pastas, and noodles. Studies have found that the inclusion of pulse ingredients in wheat-based food products enhances nutritional content and lowers the glycemic index, often without negatively influencing the sensory qualities (Fujiwara, Hall, & Jenkins, 2017; Marinangeli, Kassis, & Jones, 2009; Rizzello et al., 2014; Ringuette et al., 2018). This demonstrates that there is potential for producing good quality nutrient-rich food products that are high in plant-based protein, making pulse flours an excellent ingredient of choice for gluten-free products (Di-Cairano et al., 2021; Gularte, Gómez, & Rosell, 2012). Pulse seed dehulling (removal of the outer seed coat) and splitting (cleavage of the cotyledon) are pulse milling processes that have been widely studied for many years. Effects (e.g., seed properties, pre-treatments, genotype and location) of dehulling and splitting efficiency have been investigated (Black, Singh, & Meares, 1998; Brar et al., 2021; Erskine, Williams, &

Nakkoul, 1991a; Erskine, Williams, & Nakkoul, 1991b; Goyal, Vishwakarma, & Wanjari, 2009; Jerish Joyner & Yadav, 2015; Phirke, Bhole, & Adhaoo, 1995; Reichert, Oomah, & Youngs, 1984; Sunil et al., 2018; Wang, 2008). Pulse milling studies have also largely focused on dry fractionation, the process of grinding pulse seeds into flour, followed by separation and isolation of protein and starch fractions by air classification (Pelgrom, Boom, & Schutyser, 2015; Wood & Malcolmson, 2011). Milling of whole seed pulse flours on the other hand, has been studied less extensively. Limited research and understanding about pulse flour milling as compared to cereals hinders the development of benchmarking standards for pulse flour quality.

Wheat flour production at the commercial level is commonly performed using roller mills (Fang et al., 1997; Sakhare et al., 2015), primarily because of the versatility of roller milling (Pagani et al., 2020) than other flour milling methods. Roller mills are designed to gradually reduce the particle size of the material through a series of grinding stages, producing multiple flour streams. Each roller milled flour stream tends to vary in quality (e.g., moisture, protein, starch damage) (Sakhare et al., 2014). Unlike with single-stream flour mills (e.g., hammer mill, pin mill, stone mill) where only one type of flour is produced, roller milled flour streams can be combined in various proportions to create flours with desirable quality levels. Within the roller milling process, large portions of the outer seed coat are removed during milling and collected separately from the flour streams, enabling the production of more refined flours. If a less refined, whole-meal flour is desired, the seed coats may be milled and later incorporated with the roller milled flour streams. As was discussed in Cappelli, Oliva, & Cini (2020), roller milling is widely adopted for grain milling because of its greater efficiency and flexibility (Doblado-Maldonado et al., 2012; Posner & Hibbs, 2005) in final product particle size; lower heat generation during milling which limits the degradation of chemical components (Prabhasankar & Rao, 2001), and better dough rheology and baking performance (Kihlberg et al., 2004). But this common milling method and different pre-treatments of milling are yet to be explored extensively for pulse milling. Unlike with cereal grains, the hull and cotyledon layers of pulses strongly adhere to each other with a strong bond which is the result of the presence of gums, pectin, lignin, etc. (Vishwakarma et al., 2018). These characteristics make milling of pulses or legumes different than that of the starchy cereal grains. Therefore, the aim of the present study is to examine the effects of seed moisture conditioning and mechanical seed scouring on the compositional, functional, and physical properties of whole green lentil and chickpea flours milled using a roller mill.

## 4.3. Materials and Methods

### 4.3.1. Pulse Samples

Whole green lentil (*CDC Greeenstar*) and chickpea (*CDC Orion*) were obtained from the 2018 harvest season grown in Limerick, Saskatchewan, Canada. Pulses were stored at ambient temperature (22 ± 2°C) until use.

### 4.3.2. Pulse Seed Pre-Treatments

Prior to applying seed pre-treatments, initial whole seed moisture content was determined using a Perten Inframatic 9500 near infrared grain analyzer (Perten Instruments NA, Inc., Springfield, IL). Prior to milling, the whole green lentil and chickpea seeds were treated with one of the two pre-treatments each with three levels as shown in Table 4.1. and 4.2. (a combination of seed moisture conditioning and mechanical seed scouring) as discussed in detail in the following sections.

**Table 4.1. Pre-treatment conditions to determine moisture conditioning effects**

| Scouring effects | Pre-treatment conditions analyzed (% MC+ scouring level) |
|---|---|
| Unscoured flours | (0% + UnS), (0.5% + UnS), (1% + UnS) |
| Scoured flours | (0% + Sc), (0.5% + Sc), (1% + Sc) |

MC = moisture conditioning; UnS = unscoured; Sc = scoured

**Table 4.2. Pre-treatment conditions to determine scouring effects**

| MC effects | Pre-treatment conditions analyzed (% MC + scouring level) |
|---|---|
| 0% MC | (0% + UnS), (0% + Sc) |
| 0.5% MC | (0.5% + UnS), (0.5% + Sc) |
| 1% MC | (1% + UnS), (1% + Sc) |

MC = moisture conditioning; UnS = unscoured; Sc = scoured

**4.3.2.1. Moisture conditioning:** Three moisture conditioning (MC) levels chosen for the study were 0% (no MC), 0.5%, and 1% w/w. Initial seed moisture contents of the whole green lentil and chickpea seeds were determined using the Perten Inframatic grain analyzer. The amount of water to be added to the sample to obtain the desired seed MC level was calculated using the following formula:

$M_2 = \frac{(m_2 - m_1)}{(100 - m_2)} \times M_1$

where,

$M_1$ = mass (g) of pulse sample;

$M_2$ = mass (g) of water required for moisture tempering (g);

$m_1$ = initial moisture content (%) of whole pulse seeds;

$m_2$ = desired moisture content (%) after moisture tempering.

The calculated mass of water ($M_2$) (warm tap water; temperature not determined) was added to the sample in a clear plastic bag, and manually shaken continuously until excess water was no longer visible. The bag of moistened whole pulse seeds was left to rest for 20 minutes for equilibration before application of mechanical seed scouring (if applicable) and roller milling. The moisture conditioning procedure was performed by the same technician for all pulse samples to ensure consistency in MC to avoid any subjective errors.

**4.3.2.2. Mechanical seed scouring**: The whole pulse seeds were mechanically scoured with a Buhler MHXA 50/70 (Buhler, Uzwil, Switzerland), a spring-loaded vertical scourer that operated at 620 rpm. The screen size openings were 5 mm and made of wire mesh material. The clearance size between the screen and beater was set to 15 mm – 20 mm to ensure optimal seed scouring with minimal breakage of the cotyledons.

#### 4.3.3. Pre-Break

All pulses were pre-broken using the first break (B1) rolls of a Buhler MDDM 1000/250 pilot roller mill (Buhler, Uzwil, Switzerland) operating at 350 rpm, with a roll speed ratio of 2.5:1 (fast:slow).

#### 4.3.4. Flour Milling

Pre-broken pulses were milled using a Buhler MLU 202 laboratory mill (Buhler Group, Uzwil, Switzerland) operating at 1400 rpm at 5 kg/h feed rate. Break roll clearances were 0.1 mm for B1 and 0.01 mm for B2 and B3. Reduction roll clearances were set to 0.01 mm for 1M, 2M, and 3M. Screen sizes for the upper and lower levels of B1, B2, and B3 were 475 µm/132 µm, 475 µm/132 µm, and 375 µm/132 µm, respectively. All the screen sizes for the upper and lower levels of 1M, 2M, and 3M were 150 µm. Three break flour fractions (B1, B2, B3), three reduction (also known as middling) flour fractions (1M, 2M, 3M), and the milling by-products (bran and shorts) were produced for each milling trial of the roller mill. The milling by-products were not used or analyzed in this study. Duplicate milling trials were done for each pulse type and pre-treatment condition.

### 4.3.5. Preparation of Flour Blends for Analysis

Flour blends (break, middling, straight grade) were made of representative proportions of the milled flour fractions (B1, B2, B3, 1M, 2M, 3M), proportional to the total yield of the milled flour product. Break flour samples were a blend of B1, B2, and B3 (referred to as B1+B2+B3) for both green lentil and chickpea. Middling flour samples for green lentil were a blend of 1M, 2M, and 3M (referred to as 1M+2M+3M). For chickpea, there were two types of middling flours – 1M only flour stream (referred to as 1M) and a blend of 2M and 3M flour streams (referred to as 2M+3M). Straight grade (SG) flours for both roller-milled green lentil and chickpea were made from a representative blend of B1, B2, B3, 1M, 2M, and 3M flour streams. Break, middling, and SG flour blends were prepared by placing proportional amounts of break and middling flour fractions into a plastic storage bag, twisting the bag closed leaving enough headspace in the bag for adequate blending, and manually shaking the bag for 2 minutes. Flour blends were then sealed with a twist tie and stored at room temperature.

### 4.3.6. Pulse Flour Analysis

#### 4.3.6.1. Compositional properties:

**(a) Determination of moisture content** Moisture content was measured in duplicate using AACC International Method 44-15.02 (one-stage air-oven method) (AACCI, 1999a) for each milling replicate for each pre-treatment condition (Table 4.1. and 4.2.). Average moisture content was calculated from a total of four moisture content values.

**(b) Determination of protein content** Nitrogen (N) content of the pulse flours was determined in duplicate by the Dumas (nitrogen combustion) method using a LECO FP-628 nitrogen/protein analyzer (LECO Corp., St. Joseph, MI) according to the AACC International Method 46-30.01 (AACCI, 1999c) for each milling replicate and pre-treatment condition (Table 4.1. and 4.2.). A nitrogen-to-protein conversion factor of 6.25 was used to calculate crude protein content of the pulse flours (% crude protein = % N $\times$ 6.25). Crude protein was calculated on a dry weight basis. The four crude protein content values for each flour blend were used to calculate average crude protein content.

**(c) Determination of ash content** Total ash content of the pulse flours was also determined in duplicate for each milling replicate using AACC Approved Method 08-01.01

(AACCI, 1999b). Pulse flours were weighed into crucible dishes dried for 1 h in a Fisher Scientific Isotemp 550-58 muffle furnace (Fisher Scientific Co., Pittsburgh, PA) at 600°C, and then placed into a desiccator to cool before adding the flour sample. Pulse flour samples were incinerated in the muffle furnace at 600°C, for a minimum of 16 h. Total ash content was calculated on a dry weight basis. The duplicate ash content values of each milling replicate were used to calculate average ash content.

**4.3.6.2. Functional properties:**

**Determination of water-holding capacity** Water-holding capacity (WHC) of the pulse flours was determined in duplicate for each milling replicate using AACC Approved Method 57-13.01 (AACCI, 2017). One modification made from the standardized method was the use of a 50.8 × 101.6 mm piece of filter cloth instead of a 50.8 × 50.8 mm piece. Average WHC was calculated from the four WHC values determined.

**4.3.6.3. Physical properties:**

**(a) Flour colour measurement** Flour colour was measured in duplicate using a Minolta CR-410 chroma meter with CR-A501 cell holder attachment and two CR-A502 glass cells (Konica Minolta Inc., Osaka, Japan). The chroma meter was set to D65 (wavelength of light that simulates normal daylight) with 2° standard observer angle and calibrated using a white ceramic calibration tile (L* = 93.97, a* = -0.60, b* = 3.95). The CIELAB colour parameters measured were L* (degree of darkness (0)/ lightness (1)); a* (degree of greenness (-)/ redness (+)); and b* (degree of blueness (-)/ yellowness (+)). Flour colour measurement method with respect to volume of water added and mixing and waiting times were performed according to AACC International Method 14-30.01 (AACCI, 1999d). For each duplicate, uniform flour slurries were prepared using 15 g samples of pulse flour (corrected on a dry moisture basis (i.e. 0% moisture content)). Following the 5-minute resting time, two replicate colour measurements were taken, one consecutively after the other. Average L*a*b* was calculated from these two replicate colour measurements which represented one of the two duplicates for each pulse flour sample analyzed.

**(b) Determination of particle size distribution** Particle size was determined with laser diffraction spectroscopy using a Malvern Mastersizer 2000 optical bench instrument (Malvern Instruments, Malvern, UK) and Scirocco 2000 dry powder dispersion unit (Malvern Instruments, Malvern, UK). Air pressure of the compressed air tank was between 80 to 100 psi and feed rate was adjusted to 40%, 50%, or 60%, to ensure the fed flour samples would successfully pass through the optical bench instrument for measurement and ensure the obscuration range was less than 5%.

A fine sieve basket with 0.8 mm mesh size was filled with eight stainless steel ball bearings and placed in the sample cone of the Scirocco 2000 dry powder feeder. The macro sample tray attachment was used for all pulse samples analyzed. For each particle size determination, approximately 2 g of well mixed pulse flour sample was added using a lab spatula (without packing) to the securely fastened macro sample tray. The sample cone, sieve basket with ball bearings, and sample tray were cleaned between measurements using a ½ inch wide paint brush and compressed air duster. Particle size distribution was presented as three percentiles of a distribution curve (d), where d(0.1), d(0.5), and d(0.9) represent the flour particles in µm at the $10^{th}$, $50^{th}$, and $90^{th}$ percentile, respectively. Volume weighted mean (µm), span, and uniformity were additional parameters that were measured and evaluated. All pulse flours were analyzed in duplicate.

### 4.3.7. Statistical Analysis

Statistical analysis was performed using SAS, Version 9.4 (SAS Institute Inc., Cary, NC). The data was analyzed using one-way analysis of variance (Welch ANOVA) to test the differences between the different pre-treatments within break, middling, and SG flours; mean differences were calculated at the 5% significance level ($P<0.05$) using the Tukey HSD test. Significant effects of the pre-treatments were analyzed within break, middling, and SG flours of the appropriate pre-treatment conditions using Welch ANOVA (see Table 4.1. and Table 4.2.). Welch ANOVA statistical test procedure was selected for this study because it is appropriate for data with non-normal distributions and heterogeneous variances, while still having both very good control of Type I error and statistical power (Jan & Shieh, 2014).

## 4.4. Results and Discussion

### 4.4.1. Flour Yield

Green lentils and chickpeas subjected to scouring had lower flour yields compared to their unscoured counterparts (Table 4.3.). These are similar observations to a roller milling study on pearled barley flour, where lower flour yields were observed in the pearled barley flours compared to the unpearled barley flours (Izydorczyk et al., 2011). Conversely, higher flour yield was observed in roller milled wheat cultivars subjected to scouring using a commercial scourer by Nagi & Bains (1983).  However, the amount of difference in flour extraction between the scoured and control flours in that study varied between wheat cultivars.

**Table. 4.3. Flour yield for pre-treated green lentil and chickpea flours**

| Pre-treatments | | Flour yield, % | |
|---|---|---|---|
| **Seed scouring level** | **Moisture condition, %** | **Green lentil** | **Chickpea** |
| Unscoured | 0 | 88.68 ± 1.19 | 76.30 ± 0.87 |
| | 0.5 | 86.35 ± 0.16 | 84.56 ± 3.36 |
| | 1 | 87.31 ± 0.72 | 76.26 ± 0.46 |
| Scoured | 0 | 78.11 ± 0.64 | 69.00 ± 4.58 |
| | 0.5 | 72.48 ± 1.73 | 68.67 ± 0.86 |
| | 1 | 74.45 ± 1.15 | 69.68 ± 2.55 |

Mean ± standard deviation; % flour extraction based on the starting weight of pulse seed material.

### 4.4.2. Effects of Pre-Treatments

The results of compositional properties of green lentils and chickpeas with different levels of pre-treatments are given in Table 4.4. and 4.5.  MC had a significant effect ($P<0.05$) on all the compositional properties (ash, protein, moisture) for the green lentil break flours that were not subjected to scouring (Table 4.10.).  When subjected to scouring, the protein content of the green lentil break and SG flours showed significant pre-treatment effects ($P<0.05$) with MC (Table 4.10.).  Most of the green lentil flour fractions (mainly middling and SG) were significantly affected ($P<0.05$) by the scouring pre-treatment at the three MC levels.  Scouring is a processing step in flour milling that is performed to loosen and remove the dirt and hulls that are adhered on the outer surface of grains through abrasive action, which results in friction of the seed material when they make contact with each other or with the mesh screen (Willard & Swanson, 1911; Kent & Evers, 1994).  The scoured particles that pass through the mesh screen are considered to be a dust fraction and get discarded at the end of the scouring process (Kent & Evers, 1994).  The discarded dust fraction of the scoured green lentils in the present study was most likely comprised of a small proportion of protein, a factor that can explain the slightly lower protein contents in the scoured green lentil flours in comparison to the green lentil flours that did not undergo scouring.  A similar trend was reported in a spelt pearling study, where pearled spelt grain that was associated with higher yields of pearling fines (similar product to the dust fraction produced in the scouring process) during a pearling cycle and had lower protein contents (Winterová, Holasová, & Fiedlerová, 2016).

**Table 4.4. Compositional properties$^{\alpha}$ of pre-treated green lentil flours**

| Green lentil flour$^{\beta}$ | Pre-milling treatments: Moisture condition, % | Pre-milling treatments: Scouring level | Moisture, % db$^{\alpha}$ | Protein, % db$^{\alpha}$ | Ash, % db$^{\alpha}$ |
|---|---|---|---|---|---|
| B1+B2+B3 | 0 | Unscoured | 9.59 ± 0.09$^{c}$ | 24.71 ± 0.14$^{a}$ | 2.63 ± 0.02$^{a}$ |
| | | Scoured | 10.50 ± 0.23$^{a}$ | 24.40 ± 0.06$^{b}$ | 2.57 ± 0.02$^{b}$ |
| | 0.5 | Unscoured | 9.96 ± 0.05$^{b}$ | 24.49 ± 0.27$^{abc}$ | 2.58 ± 0.01$^{b}$ |
| | | Scoured | 10.37 ± 0.02$^{a}$ | 24.18 ± 0.06$^{c}$ | 2.57 ± 0.01$^{b}$ |
| | 1 | Unscoured | 10.20 ± 0.14$^{ab}$ | 24.37 ± 0.14$^{abc}$ | 2.56 ± 0.02$^{b}$ |
| | | Scoured | 10.41 ± 0.30$^{ab}$ | 24.16 ± 0.15$^{bc}$ | 2.55 ± 0.01$^{b}$ |
| 1M+2M+3M | 0 | Unscoured | 9.29 ± 0.09$^{c}$ | 26.75 ± 0.07$^{ab}$ | 2.81 ± 0.01$^{a}$ |
| | | Scoured | 10.26 ± 0.28$^{ab}$ | 26.57 ± 0.07$^{bc}$ | 2.76 ± 0.00$^{b}$ |
| | 0.5 | Unscoured | 9.78 ± 0.06$^{b}$ | 26.78 ± 0.19$^{ab}$ | 2.81 ± 0.01$^{a}$ |
| | | Scoured | 10.18 ± 0.07$^{a}$ | 26.46 ± 0.08$^{bc}$ | 2.76 ± 0.00$^{b}$ |
| | 1 | Unscoured | 10.02 ± 0.10$^{a}$ | 27.03 ± 0.24$^{a}$ | 2.80 ± 0.01$^{a}$ |
| | | Scoured | 10.27 ± 0.29$^{ab}$ | 26.40 ± 0.19$^{c}$ | 2.76 ± 0.01$^{b}$ |
| SG | 0 | Unscoured | 9.39 ± 0.07$^{e}$ | 26.37 ± 0.08$^{ab}$ | 2.76 ± 0.01$^{a}$ |
| | | Scoured | 10.27 ± 0.15$^{ab}$ | 26.21 ± 0.07$^{b}$ | 2.74 ± 0.03$^{a}$ |
| | 0.5 | Unscoured | 9.74 ± 0.05$^{cd}$ | 26.40 ± 0.07$^{a}$ | 2.76 ± 0.02$^{a}$ |
| | | Scoured | 10.24 ± 0.05$^{a}$ | 25.91 ± 0.10$^{c}$ | 2.75 ± 0.03$^{a}$ |
| | 1 | Unscoured | 10.01 ± 0.09$^{b}$ | 26.54 ± 0.11$^{a}$ | 2.76 ± 0.01$^{a}$ |
| | | Scoured | 10.28 ± 0.28$^{abc}$ | 26.01 ± 0.04$^{c}$ | 2.76 ± 0.02$^{a}$ |

$^{\alpha}$Mean and standard deviations of two milling duplicates analyzed in duplicate; means with a different letter in a column within the same flour type are significantly different ($P<0.05$); results reported on a dry basis.
$^{\beta}$B1+B2+B3 = break flours; 1M+2M+3M = middling flours; SG = straight grade flours.

**Table 4.5. Compositional properties$^{\alpha}$ of pre-treated chickpea flours**

| Chickpea flour$^{\beta}$ | Pre-milling treatments | | Moisture, % db$^{\alpha}$ | Protein, % db$^{\alpha}$ | Ash, % db$^{\alpha}$ |
|---|---|---|---|---|---|
| | Moisture conditioning, % | Scouring level | | | |
| B1+B2+B3 | 0 | Unscoured | 7.71 ± 0.09$^{b}$ | 19.90 ± 0.33$^{ab}$ | 2.68 ± 0.02$^{a}$ |
| | | Scoured | 6.66 ± 0.10$^{c}$ | 19.83 ± 0.06$^{a}$ | 2.63 ± 0.01$^{b}$ |
| | 0.5 | Unscoured | 8.05 ± 0.11$^{a}$ | 18.75 ± 0.11$^{c}$ | 2.55 ± 0.01$^{c}$ |
| | | Scoured | 7.07 ± 0.20$^{c}$ | 19.46 ± 0.55$^{abc}$ | 2.61 ± 0.08$^{abc}$ |
| | 1 | Unscoured | 7.57 ± 0.45$^{abc}$ | 18.69 ± 0.18$^{c}$ | 2.56 ± 0.03$^{c}$ |
| | | Scoured | 7.74 ± 0.20$^{ab}$ | 18.92 ± 0.47$^{bc}$ | 2.54 ± 0.04$^{c}$ |
| 1M | 0 | Unscoured | 7.74 ± 0.11$^{a}$ | 20.54 ± 0.14$^{b}$ | 2.73 ± 0.02$^{ab}$ |
| | | Scoured | 6.67 ± 0.05$^{c}$ | 20.58 ± 0.09$^{b}$ | 2.72 ± 0.02$^{b}$ |
| | 0.5 | Unscoured | 8.01 ± 0.08$^{a}$ | 21.10 ± 0.10$^{a}$ | 2.75 ± 0.00$^{a}$ |
| | | Scoured | 7.01 ± 0.14$^{b}$ | 20.77 ± 0.28$^{ab}$ | 2.72 ± 0.06$^{ab}$ |
| | 1 | Unscoured | 7.55 ± 0.45$^{abc}$ | 21.07 ± 0.06$^{a}$ | 2.76 ± 0.01$^{a}$ |
| | | Scoured | 7.76 ± 0.12$^{a}$ | 20.61 ± 0.09$^{b}$ | 2.73 ± 0.01$^{b}$ |
| 2M+3M | 0 | Unscoured | 7.38 ± 0.14$^{ab}$ | 21.46 ± 0.29$^{abc}$ | 2.82 ± 0.03$^{abc}$ |
| | | Scoured | 6.27 ± 0.04$^{d}$ | 21.01 ± 0.04$^{c}$ | 2.76 ± 0.01$^{bc}$ |
| | 0.5 | Unscoured | 7.57 ± 0.08$^{a}$ | 21.74 ± 0.03$^{a}$ | 2.85 ± 0.02$^{a}$ |
| | | Scoured | 6.68 ± 0.13$^{c}$ | 20.84 ± 0.09$^{c}$ | 2.75 ± 0.01$^{c}$ |
| | 1 | Unscoured | 7.20 ± 0.32$^{abc}$ | 21.46 ± 0.27$^{abc}$ | 2.81 ± 0.03$^{abc}$ |
| | | Scoured | 7.13 ± 0.10$^{b}$ | 21.27 ± 0.10$^{b}$ | 2.79 ± 0.01$^{b}$ |
| SG | 0 | Unscoured | 7.61 ± 0.17$^{ab}$ | 20.71 ± 0.11$^{a}$ | 2.76 ± 0.01$^{ab}$ |
| | | Scoured | 6.57 ± 0.04$^{d}$ | 20.37 ± 0.12$^{c}$ | 2.69 ± 0.00$^{d}$ |
| | 0.5 | Unscoured | 7.90 ± 0.04$^{a}$ | 20.70 ± 0.13$^{a}$ | 2.77 ± 0.01$^{a}$ |
| | | Scoured | 6.94 ± 0.07$^{c}$ | 20.43 ± 0.09$^{bc}$ | 2.71 ± 0.03$^{cd}$ |
| | 1 | Unscoured | 7.44 ± 0.44$^{abcd}$ | 20.62 ± 0.03$^{ab}$ | 2.73 ± 0.01$^{bc}$ |
| | | Scoured | 7.60 ± 0.07$^{b}$ | 20.36 ± 0.08$^{c}$ | 2.75 ± 0.01$^{ab}$ |

$^{\alpha}$Mean and standard deviations of two milling duplicates analyzed in duplicate; means with a different letter in a column within the same flour type are significantly different (P<0.05); reports reported on a dry basis.
$^{\beta}$B1+B2+B3 = break flours; 1M and 2M+3M = middling flours; SG = straight grade flours.

In the chickpea break flours, significant MC effects (P<0.05) were found for the majority of the compositional (Table 4.5.), physical (Table 4.7., 4.9A., and 4.9B.), and functional properties (Figure 4.4.) irrespective of scouring level (i.e. unscoured and scoured). Lower protein contents with scouring were observed in the chickpea flours (Table 4.5.), only less consistently than the green lentil flours (Table 4.4.). However, for both green lentil and chickpea flours, the differences in protein content between pre-treatments and their levels were infrequently significantly different. Ash contents of the green lentil and chickpea flours within flour blends were similar to one another (Table 4.4. and Table 4.5.).  This is consistent with the ash content results reported for control and scoured roller milled wheat flours in Nagi & Bains (1983).

**Table 4.6.  L*a*b* colour results$^{\alpha}$ of pre-treated green lentil flours**

| Green lentil flour$^{\beta}$ | Pre-milling treatments | | Colour value$^{\alpha\delta}$ | | |
|---|---|---|---|---|---|
| | **Moisture conditioning, %** | **Scouring level** | **L*** | **a*** | **b*** |
| B1+B2+B3 | 0 | Unscoured | 73.59 ± 0.15$^{e}$ | 0.65 ± 0.01$^{f}$ | 33.50 ± 0.22$^{c}$ |
| | | Scoured | 75.85 ± 0.17$^{c}$ | 1.08 ± 0.03$^{b}$ | 36.46 ± 0.35$^{a}$ |
| | 0.5 | Unscoured | 74.67 ± 0.09$^{d}$ | 0.84 ± 0.03$^{d}$ | 34.68 ± 0.08$^{b}$ |
| | | Scoured | 76.68 ± 0.07$^{a}$ | 1.01 ± 0.02$^{c}$ | 36.85 ± 0.14$^{a}$ |
| | 1 | Unscoured | 74.96 ± 0.12$^{d}$ | 0.73 ± 0.01$^{e}$ | 34.64 ± 0.02$^{b}$ |
| | | Scoured | 76.39 ± 0.04$^{b}$ | 1.14 ± 0.04$^{a}$ | 36.63 ± 0.09$^{a}$ |
| 1M+2M+3M | 0 | Unscoured | 74.62 ± 0.10$^{d}$ | 1.44 ± 0.01$^{ab}$ | 36.03 ± 0.10$^{d}$ |
| | | Scoured | 75.78 ± 0.19$^{b}$ | 1.46 ± 0.01$^{a}$ | 37.63 ± 0.37$^{ab}$ |
| | 0.5 | Unscoured | 75.01 ± 0.21$^{cd}$ | 1.42 ± 0.01$^{bc}$ | 36.71 ± 0.06$^{c}$ |
| | | Scoured | 76.24 ± 0.13$^{a}$ | 1.39 ± 0.02$^{cd}$ | 38.00 ± 0.18$^{a}$ |
| | 1 | Unscoured | 75.09 ± 0.06$^{c}$ | 1.34 ± 0.02$^{d}$ | 37.03 ± 0.12$^{b}$ |
| | | Scoured | 76.30 ± 0.04$^{a}$ | 1.41 ± 0.04$^{abcd}$ | 38.01 ± 0.22$^{a}$ |
| SG | 0 | Unscoured | 74.33 ± 0.31$^{c}$ | 1.16 ± 0.05$^{d}$ | 35.64 ± 0.25$^{c}$ |
| | | Scoured | 75.86 ± 0.04$^{b}$ | 1.40 ± 0.03$^{a}$ | 37.61 ± 0.36$^{a}$ |
| | 0.5 | Unscoured | 74.55 ± 0.34$^{c}$ | 1.26 ± 0.01$^{c}$ | 36.00 ± 0.47$^{bc}$ |
| | | Scoured | 76.25 ± 0.01$^{a}$ | 1.25 ± 0.04$^{bcd}$ | 37.58 ± 0.20$^{a}$ |
| | 1 | Unscoured | 74.93 ± 0.19$^{c}$ | 1.19 ± 0.03$^{d}$ | 36.39 ± 0.05$^{b}$ |
| | | Scoured | 76.24 ± 0.01$^{a}$ | 1.33 ± 0.03$^{ab}$ | 37.76 ± 0.18$^{a}$ |

$^{\alpha}$Mean and standard deviations of two milling duplicates analyzed in duplicate; means with a different letter in a column within the same flour type are significantly different (P<0.05); results reported on a dry basis.
$^{\beta}$B1+B2+B3 = break flours; 1M+2M+3M = middling flours; SG = straight grade flours.
$^{\delta}$*L** is lightness, 0 = black, 100 = white; *a** = (-) greenness, (+) redness; *b** = (-) blueness, (+) yellowness.

**Table 4.7. L*a*b* colour results[α] of pre-treated chickpea flours**

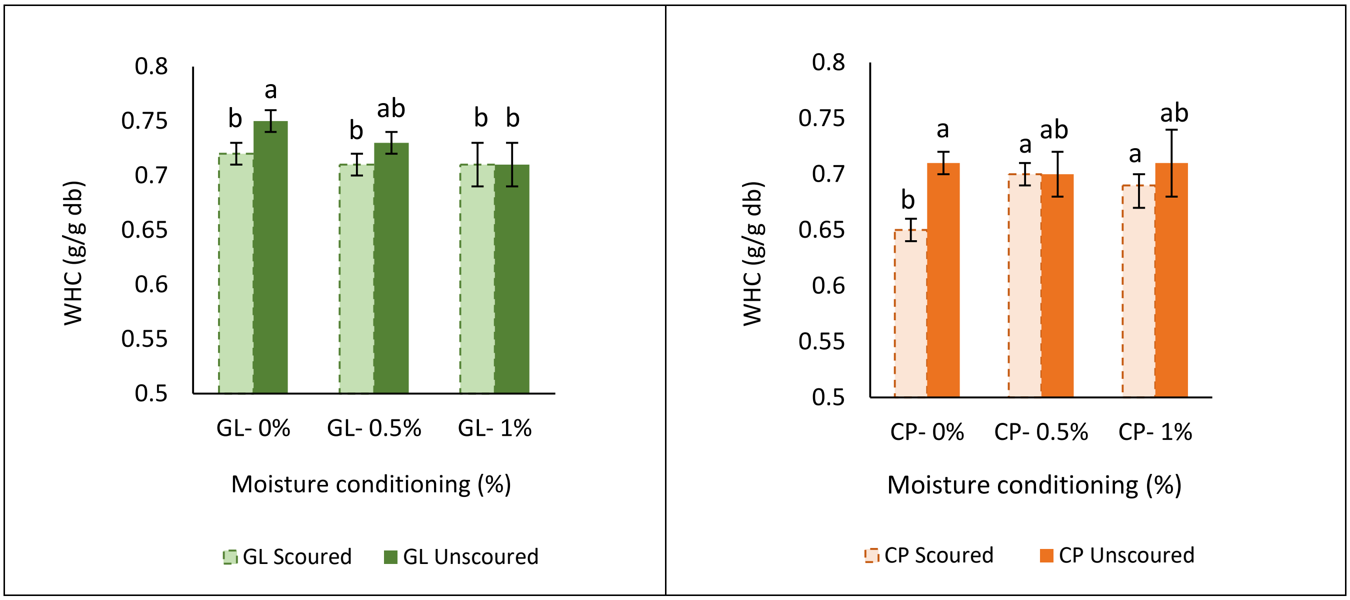
| Chickpea flour[β] | Pre-milling treatments | | Colour value[αδ] | | |
|---|---|---|---|---|---|
| | Moisture conditioning, % | Scouring level | L* | a* | b* |
| B1+B2+B3 | 0 | Unscoured | 77.03 ± 0.08[c] | 1.78 ± 0.04[a] | 34.21 ± 0.47[a] |
| | | Scoured | 77.30 ± 0.06[b] | 1.84 ± 0.08[a] | 33.79 ± 0.26[a] |
| | 0.5 | Unscoured | 77.73 ± 0.07[a] | 1.75 ± 0.02[a] | 33.56 ± 0.32[a] |
| | | Scoured | 77.23 ± 0.12[bc] | 1.75 ± 0.12[ab] | 33.78 ± 0.62[a] |
| | 1 | Unscoured | 77.72 ± 0.09[a] | 1.61 ± 0.03[b] | 33.11 ± 0.55[a] |
| | | Scoured | 77.72 ± 0.12[a] | 1.61 ± 0.12[ab] | 33.58 ± 0.37[a] |
| 1M | 0 | Unscoured | 77.43 ± 0.07[abc] | 2.47 ± 0.07[bc] | 35.87 ± 0.11[c] |
| | | Scoured | 77.50 ± 0.03[ab] | 2.25 ± 0.06[d] | 35.50 ± 0.13[d] |
| | 0.5 | Unscoured | 77.40 ± 0.05[bc] | 2.64 ± 0.03[a] | 36.36 ± 0.10[a] |
| | | Scoured | 77.34 ± 0.13[abc] | 2.40 ± 0.09[cd] | 35.84 ± 0.18[c] |
| | 1 | Unscoured | 77.32 ± 0.06[c] | 2.62 ± 0.02[ab] | 36.25 ± 0.14[ab] |
| | | Scoured | 77.56 ± 0.03[a] | 2.48 ± 0.04[c] | 36.00 ± 0.18[bc] |
| 2M+3M | 0 | Unscoured | 76.36 ± 0.12[c] | 2.46 ± 0.08[abc] | 35.36 ± 0.14[ab] |
| | | Scoured | 76.38 ± 0.06[bc] | 2.13 ± 0.02[d] | 34.13 ± 0.21[c] |
| | 0.5 | Unscoured | 76.47 ± 0.11[bc] | 2.62 ± 0.04[a] | 35.86 ± 0.26[a] |
| | | Scoured | 76.59 ± 0.09[ab] | 2.31 ± 0.06[c] | 34.89 ± 0.18[b] |
| | 1 | Unscoured | 76.52 ± 0.08[bc] | 2.56 ±0.08[ab] | 35.38 ± 0.51[ab] |
| | | Scoured | 76.76 ± 0.08[a] | 2.40 ± 0.09[bc] | 35.55 ± 0.34[ab] |
| SG | 0 | Unscoured | 76.95 ± 0.05[b] | 2.25 ± 0.06[bc] | 35.39 ± 0.09[ab] |
| | | Scoured | 77.17 ± 0.05[a] | 2.13 ± 0.04[c] | 34.70 ± 0.17[c] |
| | 0.5 | Unscoured | 77.15 ± 0.06[a] | 2.43 ± 0.01[a] | 35.66 ± 0.18[a] |
| | | Scoured | 77.12 ± 0.04[a] | 2.22 ± 0.04[c] | 35.16± 0.10[b] |
| | 1 | Unscoured | 77.14 ± 0.03[a] | 2.37 ± 0.03[b] | 35.45 ± 0.26[ab] |
| | | Scoured | 77.20 ± 0.04[a] | 2.21 ± 0.04[c] | 35.33 ± 0.19[ab] |

[α]Mean and standard deviations of two milling duplicates analyzed in duplicate; means with a different letter in a column within the same flour type are significantly different (P<0.05); results reported on a dry basis.
[β]B1+B2+B3 = break flours; 1M, and 2M+3M = middling flours; SG = straight grade flours.
[δ]*L** is lightness, 0 = black, 100 = white; *a** = (-) greenness, (+) redness; *b** = (-) blueness, (+) yellowness.

MC had a significant effect (P<0.05) on the WHC of the unscoured green lentil SG flours (Table 4.10.). Significant effects (P<0.05) of scouring on WHC of the green lentil SG flours was also observed at 0% MC (Table 4.11.). The unscoured green lentil SG flours that were subjected to 0% MC had the highest mean WHC (0.75 ± 0.01 g/g) and was also significantly different (P<0.05) than all other pre-treated green lentil SG flours, except for the 0.5% MC/unscoured condition (Figure 4.4.).

MC had a significant effect (P<0.05) on the WHC of the scoured chickpea SG flours (Table 4.12.), and like the green lentil SG flours, was significantly affected (P<0.05) by scouring at 0% MC level only (Table 4.13B.). WHC of the chickpea SG flours were also very similar between the pre-treatment conditions, with values ranging from 0.65 g/g to 0.71 g/g (Figure 4.4.). The differences in WHC observed in the green lentil and chickpea SG flours may be too small to have any practical or observable effect in food processing applications.

**Figure 4.4. Water-holding capacity of pre-treated green lentil (GL) and chickpea (CP) SG flours**




L*a*b* colour values of the green lentil flours showed the most significant differences with scouring, irrespective of the MC levels for all three flour fractions. In most instances, higher L*a*b* colour values were observed in the scoured green lentil flours compared to the unscoured green lentil flours (Table 4.6.). Similarly, Izydorczyk et al. (2011) reported greater flour brightness (L* colour) in pearled barley flours compared to unpearled barley flours produced at different grinding settings of a roller mill. Scouring in the present study may have aided in better removal of the outer seed coat layer which is darker in colour than the cotyledon portion of green lentil seeds. It is uncertain if these differences in L*a*b* colour values between the unscoured and scoured green lentil flours observed would be evident if these flours were used in end-products such as noodles, pasta, and bread. Therefore, food processing application studies utilizing green lentils pre-treated with MC and scouring used in the present study should be performed. Higher rates of pearling of roller milled barley flours that are associated with increasing L* colour were reported by Zhao et al. (2020). In that study, the barley flours were used to prepare barley-wheat flour noodles in a 1:1 proportion. From their sensory analysis it was concluded that the noodles produced from barley flours pearled at higher rates were most acceptable for all factors assessed (colour, flavour, surface smoothness, firmness, elasticity, overall acceptability).

Generally, L*a*b* colour values were similar between the unscoured and scoured chickpea flours at the three different MC levels (Table 4.7.). But, unlike the green lentil flours, the significant differences ($P<0.05$) observed in L*a*b* colour values within the chickpea break, middling, and SG flours did not follow a clear trend between pre-treatment conditions and their levels. The seed coat and cotyledon of the chickpea cultivar used in this study are a similar colour to one another which would likely result in small L*a*b* colour differences between these flours pre-treated at different MC and scouring levels.

There are currently no regulated standards for pulse flour particle size. Statistical analysis of the effects of MC and scouring concluded that green lentil flour particle size distribution was more affected by scouring than MC (Table 4.10. and Table 4.11.). However, the significant differences ($P<0.05$) in the green lentil flour particle size distribution properties that were observed between the pre-treatment conditions (within MC and scouring levels) were very minor (Table 4.8A. and 4.8B.).

**Table 4.8A. Particle size distribution properties (10th, 50th, 90th percentile) [α] of pre-treated green lentil flours**

| Green lentil flour[β] | Pre-milling treatments | | Particle size property[αγ] | | |
|---|---|---|---|---|---|
| | Moisture conditioning, % | Scouring level | d(0.1), µm | d(0.5), µm | d(0.9), µm |
| B1+B2+B3 | 0 | Unscoured | 15.2 ± 0.1[bc] | 52.9 ± 2.0[ab] | 155.0 ± 13.2[a] |
| | | Scoured | 15.8 ± 0.1[a] | 51.0 ± 0.1[a] | 142.4 ± 0.4[a] |
| | 0.5 | Unscoured | 15.1 ± 0.1[c] | 50.2 ± 0.6[ab] | 142.3 ± 0.5[a] |
| | | Scoured | 15.4 ± 0.1[b] | 49.6 ± 0.5[b] | 141.4 ± 0.7[a] |
| | 1 | Unscoured | 15.1 ± 0.1[c] | 48.7 ± 0.8[b] | 140.4 ± 1.9[a] |
| | | Scoured | 15.5 ± 0.2[abc] | 50.2 ± 0.5[ab] | 141.9 ± 0.3[a] |
| 1M+2M+3M | 0 | Unscoured | 13.9 ± 0.3[b] | 60.9 ± 3.0[ab] | 129.5 ± 4.9[ab] |
| | | Scoured | 15.0 ± 0.4[a] | 58.9 ± 3.6[ab] | 123.7 ± 6.7[ab] |
| | 0.5 | Unscoured | 14.4 ± 0.3[ab] | 62.3 ± 1.9[a] | 130.0 ± 2.4[a] |
| | | Scoured | 14.4 ± 0.1[ab] | 56.8 ± 0.1[b] | 122.3 ± 0.2[b] |
| | 1 | Unscoured | 14.4 ± 0.2[ab] | 61.4 ± 0.7[a] | 129.5 ± 1.6[a] |
| | | Scoured | 14.4 ± 0.5[ab] | 58.4 ± 1.5[ab] | 124.1 ± 2.6[ab] |
| SG | 0 | Unscoured | 14.3 ± 0.4[ab] | 58.9 ± 3.0[ab] | 131.1 ± 5.1[ab] |
| | | Scoured | 15.1 ± 0.2[a] | 57.3 ± 3.1[ab] | 125.5 ± 5.4[ab] |
| | 0.5 | Unscoured | 14.7 ± 0.0[a] | 58.9 ± 0.8[a] | 130.6 ± 1.7[a] |
| | | Scoured | 14.6 ± 0.0[b] | 55.0 ± 0.1[b] | 124.5 ± 0.2[b] |
| | 1 | Unscoured | 14.7 ± 0.1[ab] | 58.2 ± 0.4[a] | 130.2 ± 1.3[a] |
| | | Scoured | 14.6 ± 0.3[ab] | 56.3 ± 1.2[ab] | 125.9 ± 2.0[ab] |

[α]Mean and standard deviations of two milling duplicates analyzed in duplicate; means with a different letter in a column within the same flour type are significantly different ($P<0.05$).
[β]B1+B2+B3 = break flours; 1M+2M+3M = middling flours; SG = straight grade flours.
[γ]d(0.1), d(0.5), and d(0.9) = 10th, 50th, and 90th percentile, respectively, of the particle size distribution curve.

**Table 4.8B. Particle size distribution properties (VWM, span, uniformity) $^{\alpha}$ of pre-treated green lentil flours**

| Green lentil flour$^{\beta}$ | Pre-milling treatments | | Particle size property$^{\alpha}$ | | |
|---|---|---|---|---|---|
| | Moisture conditioning, % | Scouring level | VWM, µm$^{\gamma}$ | Span | Uniformity |
| B1+B2+B3 | 0 | Unscoured | 74.4 ± 8.8$^{ab}$ | 2.64 ± 0.15$^{ab}$ | 0.90 ± 0.12$^{ab}$ |
| | | Scoured | 66.6 ± 0.2$^{a}$ | 2.48 ± 0.01$^{a}$ | 0.78 ± 0.00$^{a}$ |
| | 0.5 | Unscoured | 66.0 ± 0.4$^{ab}$ | 2.54 ± 0.03$^{ab}$ | 0.80 ± 0.01$^{ab}$ |
| | | Scoured | 65.6 ± 0.0$^{b}$ | 2.54 ± 0.04$^{ab}$ | 0.80 ± 0.01$^{ab}$ |
| | 1 | Unscoured | 64.9 ± 0.9$^{ab}$ | 2.57 ± 0.00$^{b}$ | 0.81 ± 0.00$^{b}$ |
| | | Scoured | 66.1 ± 0.3$^{ab}$ | 2.52 ± 0.02$^{ab}$ | 0.79 ± 0.01$^{ab}$ |
| 1M+2M+3M | 0 | Unscoured | 66.7 ± 2.7$^{ab}$ | 1.90 ± 0.02$^{ab}$ | 0.59 ± 0.01$^{ab}$ |
| | | Scoured | 64.7 ± 3.6$^{ab}$ | 1.85 ± 0.01$^{c}$ | 0.57 ± 0.00$^{c}$ |
| | 0.5 | Unscoured | 67.8 ± 1.6$^{a}$ | 1.86 ± 0.02$^{abc}$ | 0.58 ± 0.01$^{abc}$ |
| | | Scoured | 63.1 ± 0.1$^{b}$ | 1.90 ± 0.00$^{a}$ | 0.59 ± 0.00$^{a}$ |
| | 1 | Unscoured | 67.1 ± 0.8$^{a}$ | 1.88 ± 0.00$^{b}$ | 0.58 ± 0.00$^{b}$ |
| | | Scoured | 64.3 ± 1.5$^{ab}$ | 1.88 ± 0.01$^{ab}$ | 0.58 ± 0.00$^{ab}$ |
| SG | 0 | Unscoured | 66.3 ± 2.8$^{ab}$ | 1.98 ± 0.02$^{abc}$ | 0.62 ± 0.00$^{ab}$ |
| | | Scoured | 64.4 ± 2.8$^{ab}$ | 1.93 ± 0.01$^{d}$ | 0.60 ± 0.00$^{c}$ |
| | 0.5 | Unscoured | 66.3 ± 0.8$^{a}$ | 1.97 ± 0.00$^{c}$ | 0.62 ± 0.00$^{b}$ |
| | | Scoured | 62.9 ± 0.1$^{b}$ | 2.00 ± 0.00$^{a}$ | 0.63 ± 0.00$^{a}$ |
| | 1 | Unscoured | 65.8 ± 0.5$^{a}$ | 1.99 ± 0.01$^{ab}$ | 0.62 ± 0.00$^{ab}$ |
| | | Scoured | 63.9 ± 1.1$^{ab}$ | 1.98 ± 0.01$^{bc}$ | 0.62 ± 0.00$^{ab}$ |

$^{\alpha}$Mean and standard deviations of two milling duplicates analyzed in duplicate; means with a different letter in a column within the same flour type are significantly different ($P<0.05$).

$^{\beta}$B1+B2+B3 = break flours; 1M+2M+3M = middling flours; SG = straight grade flours.

$^{\gamma}$VWM = volume weighted mean.

**Table 4.9A. Particle size distribution property (10$^{th}$, 50$^{th}$, 90$^{th}$ percentile) [α] of pre-treated chickpea flours**

| Chickpea flour[β] | Pre-milling treatments: Moisture conditioning, % | Pre-milling treatments: Scouring level | Particle size property[αγ]: d(0.1), µm | Particle size property[αγ]: d(0.5), µm | Particle size property[αγ]: d(0.9), µm |
|---|---|---|---|---|---|
| B1+B2+B3 | 0 | Unscoured | $11.8 \pm 0.2^{ab}$ | $36.7 \pm 2.7^{ab}$ | $170.0 \pm 12.0^{b}$ |
| | | Scoured | $12.1 \pm 0.1^{a}$ | $38.0 \pm 0.3^{a}$ | $485.8 \pm 58.1^{a}$ |
| | 0.5 | Unscoured | $11.3 \pm 0.2^{bc}$ | $30.2 \pm 1.7^{bc}$ | $151.7 \pm 43.0^{bc}$ |
| | | Scoured | $11.4 \pm 0.6^{abc}$ | $32.7 \pm 4.7^{abc}$ | $146.4 \pm 28.1^{bc}$ |
| | 1 | Unscoured | $11.2 \pm 0.1^{c}$ | $28.0 \pm 0.4^{c}$ | $97.4 \pm 2.6^{c}$ |
| | | Scoured | $11.8 \pm 0.1^{b}$ | $34.0 \pm 1.6^{ab}$ | $498.6 \pm 290.5^{abc}$ |
| 1M | 0 | Unscoured | $11.8 \pm 0.2^{abc}$ | $37.4 \pm 2.0^{abc}$ | $102.9 \pm 4.1^{abc}$ |
| | | Scoured | $11.4 \pm 0.1^{c}$ | $35.7 \pm 1.7^{bc}$ | $100.9 \pm 3.9^{abc}$ |
| | 0.5 | Unscoured | $12.1 \pm 0.1^{a}$ | $41.2 \pm 0.3^{a}$ | $109.1 \pm 0.6^{a}$ |
| | | Scoured | $11.5 \pm 0.1^{bc}$ | $36.1 \pm 1.7^{bc}$ | $100.9 \pm 3.2^{bc}$ |
| | 1 | Unscoured | $11.9 \pm 0.2^{ab}$ | $39.9 \pm 0.0^{b}$ | $107.5 \pm 0.8^{ab}$ |
| | | Scoured | $11.7 \pm 0.1^{b}$ | $35.9 \pm 0.5^{c}$ | $99.0 \pm 0.1^{c}$ |
| 2M+3M | 0 | Unscoured | $10.4 \pm 0.1^{b}$ | $29.4 \pm 1.1^{ab}$ | $92.2 \pm 5.3^{ab}$ |
| | | Scoured | $10.7 \pm 0.2^{ab}$ | $29.8 \pm 1.6^{ab}$ | $89.6 \pm 0.6^{a}$ |
| | 0.5 | Unscoured | $10.7 \pm 0.1^{a}$ | $31.3 \pm 0.3^{a}$ | $89.8 \pm 0.8^{a}$ |
| | | Scoured | $10.4 \pm 0.2^{ab}$ | $28.2 \pm 0.3^{b}$ | $87.3 \pm 0.8^{b}$ |
| | 1 | Unscoured | $10.7 \pm 0.3^{ab}$ | $30.8 \pm 0.4^{a}$ | $88.3 \pm 1.7^{ab}$ |
| | | Scoured | $10.4 \pm 0.2^{ab}$ | $28.9 \pm 0.5^{b}$ | $89.5 \pm 3.9^{ab}$ |
| SG | 0 | Unscoured | $11.5 \pm 0.2^{ab}$ | $34.2 \pm 0.1^{bc}$ | $105.7 \pm 4.2^{abc}$ |
| | | Scoured | $11.4 \pm 0.4^{abc}$ | $35.1 \pm 3.3^{abcde}$ | $113.4 \pm 10.6^{abcd}$ |
| | 0.5 | Unscoured | $11.9 \pm 0.1^{a}$ | $37.3 \pm 0.7^{a}$ | $117.4 \pm 3.3^{a}$ |
| | | Scoured | $11.0 \pm 0.1^{c}$ | $31.5 \pm 0.1^{e}$ | $97.8 \pm 1.3^{cd}$ |
| | 1 | Unscoured | $11.6 \pm 0.1^{b}$ | $34.4 \pm 0.3^{b}$ | $102.0 \pm 1.2^{b}$ |
| | | Scoured | $11.3 \pm 0.0^{b}$ | $32.0 \pm 0.2d^{e}$ | $95.3 \pm 1.3^{d}$ |

[α]Mean and standard deviations of two milling duplicates analyzed in duplicate; means with a different letter in a column within the same flour type are significantly different ($P<0.05$).

[β]B1+B2+B3 = break flours; 1M and 2M+3M = middling flours; SG = straight grade flours.

[γ]d(0.1), d(0.5), and d(0.9) = 10$^{th}$, 50$^{th}$, and 90$^{th}$ percentile, respectively, of the particle size distribution curve.

**Table 4.9B. Particle size distribution property (VWM, span, uniformity)$^{\alpha}$ of pre-treated chickpea flours**

| Chickpea flour$^{\beta}$ | Pre-milling treatments | | Particle size property$^{\alpha}$ | | |
|---|---|---|---|---|---|
| | Moisture conditioning, % | Scouring level | VWM, µm$^{\gamma}$ | Span | Uniformity |
| B1+B2+B3 | 0 | Unscoured | 117.5 ± 4.3$^{c}$ | 4.32 ± 0.14$^{c}$ | 2.68 ± 0.18$^{bc}$ |
| | | Scoured | 147.9 ± 8.7$^{ab}$ | 12.47 ± 1.44$^{a}$ | 3.37 ± 0.20$^{ab}$ |
| | 0.5 | Unscoured | 92.3 ± 19.6$^{bcd}$ | 4.35 ± 1.49$^{bcd}$ | 2.46 ± 0.49$^{abc}$ |
| | | Scoured | 95.9 ± 11.2$^{c}$ | 4.10 ± 0.26$^{c}$ | 2.38 ± 0.11$^{c}$ |
| | 1 | Unscoured | 42.3 ± 1.0$^{d}$ | 3.08 ± 0.05$^{d}$ | 0.91 ± 0.02$^{d}$ |
| | | Scoured | 166.9 ± 10.4$^{a}$ | 14.63 ± 9.22$^{abcd}$ | 4.37 ± 0.52$^{a}$ |
| 1M | 0 | Unscoured | 48.5 ± 2.1$^{abc}$ | 2.44 ± 0.03$^{bc}$ | 0.76 ± 0.00$^{bc}$ |
| | | Scoured | 47.2 ± 1.9$^{abc}$ | 2.51 ± 0.02$^{a}$ | 0.78 ± 0.0$^{0a}$ |
| | 0.5 | Unscoured | 52.0 ± 0.1$^{a}$ | 2.36 ± 0.03$^{d}$ | 0.74 ± 0.01$^{c}$ |
| | | Scoured | 47.3 ± 1.6$^{bc}$ | 2.48 ± 0.02$^{ab}$ | 0.77 ± 0.00$^{b}$ |
| | 1 | Unscoured | 50.9 ± 0.2$^{b}$ | 2.40 ± 0.02$^{cd}$ | 0.76 ± 0.01$^{bc}$ |
| | | Scoured | 46.8 ± 0.3$^{c}$ | 2.43 ± 0.04$^{abcd}$ | 0.76 ± 0.01$^{bc}$ |
| 2M+3M | 0 | Unscoured | 79.9 ± 7.9$^{a}$ | 2.78 ± 0.08$^{a}$ | 2.14 ± 0.19$^{a}$ |
| | | Scoured | 58.1 ± 18.3$^{ab}$ | 2.65 ± 0.13$^{ab}$ | 1.40 ± 0.71$^{ab}$ |
| | 0.5 | Unscoured | 42.2 ± 0.3$^{b}$ | 2.52 ± 0.01$^{b}$ | 0.78 ± 0.00$^{b}$ |
| | | Scoured | 72.5 ± 7.7$^{a}$ | 2.72 ± 0.02$^{a}$ | 1.98 ± 0.28$^{a}$ |
| | 1 | Unscoured | 41.2 ± 0.7$^{b}$ | 2.52 ± 0.03$^{b}$ | 0.77 ± 0.01$^{b}$ |
| | | Scoured | 76.9 ± 14.7$^{ab}$ | 2.74 ± 0.08$^{a}$ | 2.07 ± 0.46$^{a}$ |
| SG | 0 | Unscoured | 55.1 ± 9.6$^{abc}$ | 2.75 ± 0.12$^{abc}$ | 1.06 ± 0.28$^{ab}$ |
| | | Scoured | 66.6 ± 16.2$^{abc}$ | 2.90 ± 0.02$^{a}$ | 1.34 ± 0.31$^{ab}$ |
| | 0.5 | Unscoured | 82.8 ± 10.2$^{a}$ | 2.83 ± 0.08$^{ab}$ | 1.69 ± 0.27$^{a}$ |
| | | Scoured | 44.4 ± 0.5$^{c}$ | 2.75 ± 0.04$^{b}$ | 0.84 ± 0.02$^{b}$ |
| | 1 | Unscoured | 47.0 ± 0.4$^{b}$ | 2.63 ± 0.02$^{c}$ | 0.81 ± 0.01$^{b}$ |
| | | Scoured | 43.9 ± 0.5$^{c}$ | 2.62 ± 0.03$^{c}$ | 0.80 ± 0.01$^{b}$ |

$^{\alpha}$Mean and standard deviations of two milling duplicates analyzed in duplicate; means with a different letter in a column within the same flour type are significantly different (P<0.05).
$^{\beta}$B1+B2+B3 = break flours; 1M+2M+3M, 1M, and 2M+3M = middling flours; SG = straight grade flours.
$^{\gamma}$VWM = volume weighted mean.

The majority of the particle size distribution properties for the chickpea break and SG flours were significantly affected (P<0.05) by MC with and without scouring (Table 4.12.). In the middling chickpea flours, MC had significant effects (P<0.05) on mainly the unscoured flours (Table 4.12.). Scouring had a significant effect (P<0.05) on particle size distribution properties of primarily the chickpea break flours at 0% and 1% MC level, as well as the middling and SG flours at 0.5% and 1% MC (Table 4.13.). Particle sizes at d(0.1) and d(0.5) of the particle size distribution curves within the chickpea break, middling, and SG flours were similar between the different pre-treatment conditions and their levels (Table 4.9A.). Greater disparities were observed at d(0.9) of the particle size distribution curves, along with VWM, span, and uniformity in the chickpea break flours and SG flours (to a lesser degree than the break flours) (Table 4.9A. and 4.9B.). The values for these particle size distribution properties were the most different in the chickpea break flours pre-treated with 0% and 1% MC and scouring. Higher values were observed in these flours compared to the other pre-treatments; however, these differences were not always significantly different (Table 4.9A. and 4.9B.).

### 4.4.3. Responses to the Pre-Treatments Based on Pulse Type and their Milling Fractions

Compared to green lentil, the chickpea flours exhibited more frequency of significant pre-treatment effects in their compositional (ash, protein moisture) and particle size distribution properties with MC. Scouring more frequently affected ash and particle size distribution properties of the chickpea flours (Table 4.13.), and L*a*b* colour values of the green lentil flours (Table 4.10.). Due to the differences in physical properties (e.g., seed size, shape, colour) and processing characteristics (downstream processing properties) of different pulse varieties, the pulse flour milling process varies based on the particular pulse variety being milled, and therefore, requires the development of flour milling operations tailored to each pulse variety (Sarkar & Subramaniam, 2016). The differences in seed size, composition, thickness, and hardness of the seed coat between different pulse varieties may have attributed to the pre-treatment effects observed in the milled fractions (Scanlon et al., 2018). Particle size uniformity of the SG flours as well as their greenness or redness (a* colour value) of both green lentil and chickpea varieties showed significant differences with the MC levels with and without scouring.

For the chickpea break flours, MC had a significant effect on all of the compositional properties (ash, protein, moisture) and particle size distribution properties irrespective of the scouring level (Table 4.12.). L*a*b* colour values of the green lentil break and middling flours were significantly affected by scouring at all three MC levels, with exception to the green lentil middling flours pre-treated with 0% MC (Table 4.11.). These observations lead to the conclusion that the colour quality of the green lentil flours were primarily influenced by scouring. Both the green lentil and chickpea flours' responses to MC and scouring in this study were mixed, meaning that these pre-treatment effects did not result in a clear pattern or trend in the findings.

**Table 4.10. Effect of moisture conditioning of unscoured and scoured green lentil flours**

| Green lentil flour property | Welch ANOVA p-value$^{\alpha}$ | | | | | |
|---|---|---|---|---|---|---|
| | B1+B2+B3$^{\beta}$ | | 1M+2M+3M$^{\beta}$ | | SG$^{\beta}$ | |
| | Unscoured | Scoured | Unscoured | Scoured | Unscoured | Scoured |
| Ash | 0.0025* | 0.0855 | 0.1399 | 0.9795 | 0.9044 | 0.6574 |
| Protein | 0.0487* | 0.0062* | 0.2138 | 0.1708 | 0.1261 | 0.0063* |
| Moisture | 0.0015* | 0.5977 | 0.0002* | 0.7870 | 0.0002* | 0.8898 |
| WHC | – | – | – | – | 0.0217* | 0.9677 |
| L* | <.0001* | 0.0007* | 0.0012* | 0.0154* | 0.0512 | <.0001* |
| a* | <.0001* | 0.0041* | 0.0004* | 0.0045* | 0.0070* | 0.0041* |
| b* | 0.0013* | 0.0869 | <.0001* | 0.2776 | 0.0115* | 0.4795 |
| d(0.1) | 0.2802 | 0.0035* | 0.0534 | 0.1106 | 0.1960 | 0.0257* |
| d(0.5) | 0.0207* | 0.0055* | 0.6648 | 0.1922 | 0.3553 | 0.1466 |
| d(0.9) | 0.1396 | 0.1140 | 0.9321 | 0.4775 | 0.8886 | 0.4768 |
| VWM | 0.0965 | 0.0004* | 0.7480 | 0.3307 | 0.6500 | 0.2833 |
| Span | 0.1138 | 0.0399* | 0.1005 | 0.0001* | 0.0293* | 0.0011* |
| Uniformity | 0.1105 | 0.0463* | 0.1369 | <.0001* | 0.0277* | 0.0003* |

$^{\alpha}$Significant moisture conditioning effects (*P<0.05).
$^{\beta}$B1+B2+B3 = break flours; 1M+2M+3M = middling flours; SG = straight grade flours.

Table 4.11. Effect of seed scouring at 0%, 0.5%, and 1% moisture conditioning of green lentil flours

| Green lentil flour Property | Welch ANOVA p-value[α] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | B1+B2+B3[β] | | | 1M+2M+3M[β] | | | SG[β] | | |
| | 0% | 0.5% | 1% | 0% | 0.5% | 1% | 0% | 0.5% | 1% |
| Ash | 0.0021* | 0.1831 | 0.2070 | 0.0002* | 0.0029* | 0.0003* | 0.2321 | 0.5150 | 0.5269 |
| Protein | 0.0151* | 0.1042 | 0.0773 | 0.0076* | 0.0346* | 0.0067* | 0.0217* | 0.0004* | 0.0010* |
| Moisture | 0.0019* | <.0001* | 0.2577 | 0.0038* | <.0001* | 0.1766 | 0.0004* | <.0001* | 0.1471 |
| WHC | – | – | – | – | – | – | 0.0061* | 0.1241 | 0.6780 |
| L* | <.0001* | <.0001* | <.0001* | 0.0002* | 0.0001* | <.0001* | 0.0020* | 0.0022* | 0.0009* |
| a* | <.0001* | 0.0001* | 0.0002* | 0.1426 | 0.0342* | 0.0362* | 0.0003* | 0.5514 | 0.0004* |
| b* | <.0001* | <.0001* | <.0001* | 0.0021* | 0.0004* | 0.0007* | 0.0002* | 0.0033* | 0.0003* |
| d(0.1) | 0.0002* | 0.0029* | 0.0265* | 0.0052* | 0.7581 | 0.9579 | 0.0163* | 0.0011* | 0.6105 |
| d(0.5) | 0.1621 | 0.1782 | 0.0179* | 0.4369 | 0.0109* | 0.0185* | 0.5038 | 0.0019* | 0.0504 |
| d(0.9) | 0.1515 | 0.0855 | 0.2067 | 0.2157 | 0.0077* | 0.0176* | 0.1807 | 0.0055* | 0.0147* |
| VWM | 0.1750 | 0.1314 | 0.0670 | 0.4043 | 0.0109* | 0.0267* | 0.3758 | 0.0036* | 0.0359* |
| Span | 0.1213 | 0.8471 | 0.0124* | 0.0063* | 0.0331* | 0.5275 | 0.0032* | <.0001* | 0.2226 |
| Uniformity | 0.1546 | 1.0000 | 0.0130* | 0.0074* | 0.0503 | 0.4533 | 0.0001* | 0.0007* | 0.1204 |

[α]Significant seed scouring effects (*P<0.05).
[β]B1+B2+B3 = break flours; 1M+2M+3M = middling flours; SG = straight grade flours.

**Table 4.12. Effect of moisture conditioning of unscoured and scoured chickpea flours**

| Chickpea flour Property | Welch ANOVA p-value[α] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | B1+B2+B3[β] | | 1M[β] | | 2M+3M[β] | | SG[β] | |
| | Unscoured | Scoured | Unscoured | Scoured | Unscoured | Scoured | Unscoured | Scoured |
| Ash | 0.0004* | 0.0372* | 0.0800 | 0.7833 | 0.1004 | 0.0046* | 0.0020* | 0.0032* |
| Protein | 0.0031* | 0.0465* | 0.0026* | 0.5100 | 0.1330 | 0.0044* | 0.3349 | 0.5979 |
| Moisture | 0.0134* | 0.0006* | 0.0239* | <.0001* | 0.0784 | <.0001* | 0.0530 | <.0001* |
| WHC | – | – | – | – | – | – | 0.7703 | 0.0004* |
| L* | <.0001* | 0.0036* | 0.1049 | 0.0361* | 0.1973 | 0.0016* | 0.0031* | 0.0789 |
| a* | 0.0004* | 0.0675 | 0.0225* | 0.0050* | 0.0388* | 0.0029* | 0.0040* | 0.0397* |
| b* | 0.0696 | 0.6674 | 0.0026* | 0.0134* | 0.0617 | 0.0013* | 0.1187 | 0.0085* |
| d(0.1) | 0.0099* | 0.0111* | 0.0256* | 0.0117* | 0.0126* | 0.1353 | 0.0087* | 0.0133* |
| d(0.5) | 0.0073* | 0.0177* | 0.0038* | 0.9637 | 0.0343* | 0.0766 | 0.0017* | 0.0183* |
| d(0.9) | 0.0007* | 0.0006* | 0.0241* | 0.4452 | 0.3010 | 0.0225* | 0.0016* | 0.0268* |
| VWM | <.0001* | 0.0003* | 0.0007* | 0.7940 | 0.0010* | 0.3658 | 0.0067* | 0.0711 |
| Span | 0.0002* | 0.0009* | 0.0212* | 0.0288* | 0.0090* | 0.5974 | 0.0158* | <.0001* |
| Uniformity | 0.0001* | 0.0005* | 0.0530 | 0.0031* | 0.0002* | 0.3681 | 0.0091* | 0.0079* |

[α]Significant moisture conditioning effects (*P<0.05)

[β]B1+B2+B3 = break flours; 1M+2M+3M, 1M, and 2M+3M = middling flours; SG = straight grade flours.

**Table 4.13A. Effect of seed scouring at 0%, 0.5%, and 1% moisture conditioning of chickpea flours (B1+B2+B3, 1M)**

| Chickpea flour Property | Welch ANOVA p-value[α] | | | | | |
|---|---|---|---|---|---|---|
| | B1+B2+B3[β] | | | 1M[β] | | |
| | 0% | 0.5% | 1% | 0% | 0.5% | 1% |
| Ash | 0.0170* | 0.1954 | 0.6643 | 0.5393 | 0.2962 | 0.0012* |
| Protein | 0.6828 | 0.0792 | 0.4104 | 0.6778 | 0.0897 | 0.0003* |
| Moisture | <.0001* | 0.0005* | 0.5357 | <.0001* | 0.0001* | 0.4113 |
| WHC | – | – | – | – | – | – |
| L* | 0.0022* | 0.0007* | 1.0000 | 0.1128 | 0.3910 | 0.0011* |
| a* | 0.2457 | 0.9852 | 0.9561 | 0.0037* | 0.0094* | 0.0025* |
| b* | 0.1852 | 0.5667 | 0.2122 | 0.0057* | 0.0042* | 0.0772 |
| d(0.1) | 0.0629 | 0.9021 | 0.0001* | 0.0091* | <.0001* | 0.2991 |
| d(0.5) | 0.4137 | 0.3748 | 0.0033* | 0.2637 | 0.0074* | 0.0006* |
| d(0.9) | 0.0012* | 0.8441 | 0.0701 | 0.4947 | 0.0124* | 0.0002* |
| VWM | 0.0024* | 0.7676 | 0.0001* | 0.3810 | 0.0099* | <.0001* |
| Span | 0.0014* | 0.7645 | 0.0872 | 0.0093* | 0.0011* | 0.2207 |
| Uniformity | 0.0024* | 0.7751 | 0.0009* | <.0001* | 0.0093* | 0.8653 |

[α]Significant seed scouring effects (*P<0.05)
[β]B1+B2+B3 = break flours; 1M = middling flours.

**Table 4.13B. Effect of seed scouring at 0%, 0.5%, and 1% moisture conditioning of chickpea flours (2M+3M, SG)**

| Chickpea flour property | Welch ANOVA p-value[α] | | | | | |
|---|---|---|---|---|---|---|
| | 2M+3M[β] | | | SG[β] | | |
| | **0%** | **0.5%** | **1%** | **0%** | **0.5%** | **1%** |
| Ash | 0.0236* | <.0001* | 0.2913 | 0.0001* | 0.0193* | 0.1939 |
| Protein | 0.0514 | <.0001* | 0.2561 | 0.0055* | 0.0154* | 0.0030* |
| Moisture | 0.0003* | 0.0001* | 0.6855 | 0.0009* | <.0001* | 0.5362 |
| WHC | – | – | – | <.0001* | 0.7758 | 0.3105 |
| L* | 0.7774 | 0.1414 | 0.0076* | 0.0007* | 0.4341 | 0.0524 |
| a* | 0.0018* | 0.0004* | 0.0378* | 0.0195* | 0.0011* | 0.0006* |
| b* | 0.0001* | 0.0013* | 0.6118 | 0.0012* | 0.0049* | 0.5000 |
| d(0.1) | 0.0478* | 0.0799 | 0.1338 | 0.4295 | <.0001* | 0.0180* |
| d(0.5) | 0.6856 | <.0001* | 0.0011* | 0.6275 | 0.0004* | <.0001* |
| d(0.9) | 0.3859 | 0.0047* | 0.5965 | 0.2486 | 0.0005* | 0.0003* |
| VWM | 0.0923 | 0.0042* | 0.0167* | 0.2782 | 0.0048* | <.0001* |
| Span | 0.1411 | <.0001* | 0.0105* | 0.0882 | 0.1347 | 0.7576 |
| Uniformity | 0.1270 | 0.0034* | 0.0112* | 0.2270 | 0.0084* | 0.1022 |

[α]Significant seed scouring effects (*P<0.05).
[β]2M+3M = middling flours; SG = straight grade flours.

## 4.5. Conclusion

The green lentil and chickpea flours responded differently to the MC and scouring pre-treatments in this study. Significant effects ($P<0.05$) of the pre-treatments were frequently concluded for the pulse flours, however the differences between the data values of the flour properties were quite small. Although infrequently concluded to be significantly different ($P<0.05$), both the green lentil and chickpea flours were observed to have lower protein contents with scouring which was likely caused by some of the pulse material getting discarded during the scouring process. Scouring was also associated with higher L*a*b* colour values in the green lentil flours. Better removal of the dark seed coat of green lentils during the scouring process enabled the production of green lentil flours with higher L*a*b* colour values. The seed coat and cotyledon colours of chickpeas were similar, therefore L*a*b* colour values with and without scouring within the chickpea flour blends were similar to each other. The respective levels of MC and scouring did little to affect the particle size distribution properties of the green lentil flours. Differences in particle size properties between the pre-treatment conditions were more evident in the chickpea flours.

Significant differences between the MC and scouring pre-treatments in this study were marginal, suggesting that the quality of the roller milled green lentil and chickpea flours were not strongly influenced by seed MC and scouring. In order to draw stronger conclusions regarding the effects of pulse seed MC and scouring these pre-treated pulse flours should be utilized as food ingredients to determine if quality differences can be observed in processed food products. This pulse study contributes insight into the direction flour milling research should take to continue advancing the knowledge of pulse flour milling technology for the food processing industry.

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# 5. Summary and Overall Conclusions

The intent of this research project was to evaluate whether the quality of compositional, physical, and functional flour properties of a selection of different pulse types (green lentil, yellow pea, chickpea, navy bean) would be affected by different flour milling procedures; in this case, using a Ferkar mill (single-stream type) and a roller mill (gradual reduction, multi-stream type).

The use of different milling methods for pulse flour processing had the most influence on the physical flour properties L*a*b* colour and particle size distribution. Given the sharp colour contrast between the outer hull and inner cotyledon portions of green lentil, the observations for the green lentil flours supports this statement more than the other pulse types used in this study. The roller mill was able to remove much of the outer (hull) seed layers which tend to be darker in colour than the inner (cotyledon) seed portions, resulting in flours having a brighter colour than the legume flours produced using the Ferkar mill. The single-stream design of the Ferkar mill enables all portions of the seed material entering the grinding zone to be used for producing a single flour product. Particle size distribution curves show that grinding the hulls along with the cotyledons in single-stream milling will more likely result in flours having less homogeneous particle size as well as the presence of coarser particles. Due to the capability of producing refined flour streams and its ability to separate the coarse hull material during the grinding process, roller milling is the ideal flour milling method. Greater versatility in flour processing and flour formulation using the roller mill increases the ease of developing legume flours that meet specified flour quality standards for end-uses in commercial food production.

Seed moisture conditioning (MC) and scouring are pulse pre-treatments that have not been evaluated and discussed in any published pulse flour milling studies at this time. In the present study, MC and scouring pre-treatments had varying effects on the properties of the green lentil and chickpea roller milled flour blends (break, middling, and SG flours). Significant pre-treatment effects were found for many of the flour properties, however the differences in the flour property data results between pre-treatment conditions were not wide enough to conclude that MC and scouring have a strong influence on the quality of milled pulse flours.

## 6. Recommendations for Future Research

The primary objective of this thesis project was to determine if the quality of legume flour is affected by single-stream (Ferkar mill) and gradual reduction (roller mill) milling methods. Due to the enormity of experimental work, the scope of this project was limited to analyzing the quality of the pulse flours in their raw form. Valuable information would be gained through further studying these milled flours as ingredients in processed foods.

The small-batch roller milling performed in this project limited the yields of the break (B1, B2, B3) and middling (1M, 2M, 3M) flour streams, and didn't allow us to analyze the flour properties of both the break and middling streams *and* the break, middling, and straight grade blends. Legume flour property data of roller milled flour streams is essential information for the pulse research science sector as it provides a more comprehensive understanding of the roller milling process for pulse flour production. Such studies should be pursued in the future for a more comprehensive understanding of all flour streams and blends.

# 7. Appendices

**Appendix 1. % Moisture (db) (raw data) of Ferkar and roller milled green lentil and yellow pea flours**

| Dup | Green lentil | | | | Yellow pea | | | |
|---|---|---|---|---|---|---|---|---|
| | Ferkar | SG | B1+B2+B3 | 1M+2M+3M | Ferkar | SG | B1+B2+B3 | 1M+2M+3M |
| 1.1 | 8.35 | 8.67 | 9.06 | 8.77 | 9.05 | 9.43 | 9.96 | 9.58 |
| 1.2 | 8.28 | 8.66 | 9.10 | 8.86 | 9.05 | 9.41 | 9.87 | 9.65 |
| 2.1 | 8.23 | 8.59 | 9.13 | 8.82 | 9.05 | 9.80 | 10.07 | 10.01 |
| 2.2 | 8.32 | 8.66 | 9.02 | 8.85 | 9.01 | 9.80 | 10.10 | 10.07 |

**Appendix 2. % Moisture (db) (raw data) of Ferkar and roller milled chickpea and navy bean flours**

| Dup | Chickpea | | | | | Navy bean | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ferkar | SG | B1+B2+B3 | 1M | 2M+3M | Ferkar | SG | B1+B2+B3 | 1M | 2M+3M |
| 1.1 | 8.94 | 10.42 | 10.58 | 10.25 | 10.15 | 10.12 | 11.18 | 11.55 | 11.50 | 10.81 |
| 1.2 | 8.96 | 10.32 | 10.59 | 10.20 | 10.08 | 10.07 | 11.21 | 11.60 | 11.41 | 10.81 |
| 2.1 | 8.82 | 9.52 | 9.88 | 9.42 | 9.24 | 9.66 | 10.96 | 11.44 | 11.21 | 10.29 |
| 2.2 | 8.80 | 9.47 | 9.89 | 9.54 | 9.16 | 9.64 | 11.00 | 11.35 | 11.25 | 10.32 |

**Appendix 3. % Ash (db) (raw data) of Ferkar and roller milled green lentil and yellow pea flours**

| Dup | Green lentil | | | | Yellow pea | | | |
|---|---|---|---|---|---|---|---|---|
| | Ferkar | SG | B1+B2+B3 | 1M+2M+3M | Ferkar | SG | B1+B2+B3 | 1M+2M+3M |
| 1.1 | 2.76 | 2.78 | 2.62 | 2.81 | 2.85 | 2.83 | 2.51 | 2.87 |
| 1.2 | 2.76 | 2.76 | 2.64 | 2.80 | 2.84 | 2.80 | 2.46 | 2.86 |
| 2.1 | 2.82 | 2.78 | 2.65 | 2.80 | 2.87 | 2.86 | 2.48 | 2.89 |
| 2.2 | 2.83 | 2.79 | 2.60 | 2.79 | 2.90 | 2.87 | 2.50 | 2.88 |

**Appendix 4. % Ash (db) (raw data) of Ferkar and roller milled chickpea and navy bean flours**

| Dup | Chickpea | | | | | Navy bean | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ferkar | SG | B1+B2+B3 | 1M | 2M+3M | Ferkar | SG | B1+B2+B3 | 1M | 2M+3M |
| 1.1 | 2.90 | 2.76 | 2.57 | 2.73 | 3.06 | 4.38 | 4.26 | 3.65 | 4.36 | 4.57 |
| 1.2 | 2.89 | 2.77 | 2.56 | 2.74 | 3.07 | 4.37 | 4.28 | 3.64 | 4.39 | 4.56 |
| 2.1 | 2.85 | 2.81 | 2.56 | 2.76 | 3.09 | 4.41 | 4.21 | 3.63 | 4.24 | 4.56 |
| 2.2 | 2.82 | 2.81 | 2.57 | 2.71 | 3.06 | 4.40 | 4.18 | 3.65 | 4.26 | 4.55 |

**Appendix 5. % Protein (db) (raw data) of Ferkar and roller milled green lentil and yellow pea flours**

| Dup | Green lentil | | | | Yellow pea | | | |
|---|---|---|---|---|---|---|---|---|
| | Ferkar | SG | B1+B2+B3 | 1M+2M+3M | Ferkar | SG | B1+B2+B3 | 1M+2M+3M |
| 1.1 | 24.84 | 26.33 | 24.82 | 26.33 | 25.19 | 25.58 | 22.44 | 26.25 |
| 1.2 | 24.70 | 26.18 | 24.71 | 26.44 | 25.21 | 25.29 | 22.38 | 26.17 |
| 2.1 | 24.81 | 26.54 | 24.93 | 26.74 | 24.75 | 25.47 | 22.43 | 26.08 |
| 2.2 | 24.90 | 26.29 | 24.89 | 26.63 | 24.73 | 25.58 | 22.44 | 26.28 |

**Appendix 6. % Protein (db) (raw data) of Ferkar and roller milled chickpea and navy bean flours**

| Dup | Chickpea | | | | | Navy bean | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ferkar | SG | B1+B2+B3 | 1M | 2M+3M | Ferkar | SG | B1+B2+B3 | 1M | 2M+3M |
| 1.1 | 20.52 | 20.70 | 18.74 | 20.72 | 22.85 | 26.18 | 27.08 | 22.54 | 26.96 | 30.66 |
| 1.2 | 20.46 | 20.79 | 18.84 | 20.79 | 22.79 | 26.44 | 27.08 | 22.51 | 26.83 | 30.57 |
| 2.1 | 20.45 | 20.89 | 18.88 | 20.86 | 22.94 | 26.40 | 27.03 | 22.42 | 26.92 | 30.38 |
| 2.2 | 20.58 | 20.87 | 19.03 | 20.87 | 23.03 | 26.06 | 27.00 | 22.43 | 27.23 | 30.51 |

**Appendix 7. Water-holding capacity (g/g, db) (raw data) of Ferkar and roller milled green lentil and yellow pea flours**

| Dup | Green lentil | | | | Yellow pea | | | |
|---|---|---|---|---|---|---|---|---|
| | Ferkar | SG | B1+B2+B3 | 1M+2M+3M | Ferkar | SG | B1+B2+B3 | 1M+2M+3M |
| 1.1 | 0.75 | 0.71 | 0.72 | 0.70 | 0.72 | 0.77 | 0.70 | 0.67 |
| 1.2 | 0.76 | 0.70 | 0.71 | 0.71 | 0.73 | 0.76 | 0.71 | 0.66 |
| 2.1 | 0.80 | 0.71 | 0.71 | 0.71 | 0.77 | 0.73 | 0.71 | 0.72 |
| 2.2 | 0.79 | 0.73 | 0.73 | 0.74 | 0.77 | 0.70 | 0.69 | 0.70 |

**Appendix 8. Water-holding capacity (g/g, db) (raw data) of Ferkar and roller milled chickpea and navy bean flours**

| Dup | Chickpea | | | | | Navy bean | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ferkar | SG | B1+B2+B3 | 1M | 2M+3M | Ferkar | SG | B1+B2+B3 | 1M | 2M+3M |
| 1.1 | 0.64 | 0.64 | 0.58 | 0.61 | 0.76 | 1.05 | 1.12 | 0.82 | 1.01 | 1.26 |
| 1.2 | 0.64 | 0.63 | 0.61 | 0.62 | 0.75 | 1.06 | 1.11 | 0.80 | 1.01 | 1.26 |
| 2.1 | 0.64 | 0.66 | 0.60 | 0.61 | 0.80 | 1.08 | 1.13 | 0.78 | 1.13 | 1.26 |
| 2.2 | 0.66 | 0.66 | 0.63 | 0.63 | 0.81 | 1.10 | 1.10 | 0.77 | 1.13 | 1.23 |

**Appendix 9. L*a*b* colour (raw data) of Ferkar and roller milled green lentil and yellow pea flours**

| | Dup | Green lentil | | | | Yellow pea | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Ferkar | SG | B1+B2+B3 | 1M+2M+3M | Ferkar | SG | B1+B2+B3 | 1M+2M+3M |
| L* | 1.1 | 66.98 | 74.49 | 73.22 | 74.31 | 73.89 | 74.91 | 75.25 | 74.63 |
| | 1.2 | 67.07 | 74.43 | 73.27 | 74.41 | 73.91 | 74.58 | 75.08 | 74.58 |
| | 2.1 | 66.87 | 74.55 | 72.91 | 74.50 | 73.57 | 74.43 | 73.85 | 74.56 |
| | 2.2 | 66.84 | 74.61 | 72.83 | 74.34 | 73.98 | 74.32 | 73.92 | 74.41 |
| a* | 1.1 | -0.49 | 1.08 | 0.93 | 1.26 | 2.53 | 3.16 | 2.53 | 3.21 |
| | 1.2 | -0.47 | 1.09 | 0.92 | 1.24 | 2.55 | 3.25 | 2.58 | 3.31 |
| | 2.1 | -0.51 | 1.22 | 0.91 | 1.33 | 2.77 | 3.39 | 3.19 | 3.40 |
| | 2.2 | -0.41 | 1.17 | 1.00 | 1.37 | 2.58 | 3.43 | 3.18 | 3.45 |
| b* | 1.1 | 26.05 | 35.62 | 33.37 | 36.02 | 36.05 | 39.86 | 37.45 | 39.92 |
| | 1.2 | 26.17 | 35.54 | 33.10 | 35.70 | 36.06 | 39.34 | 37.17 | 39.97 |
| | 2.1 | 25.80 | 35.81 | 33.17 | 36.04 | 36.70 | 39.45 | 36.31 | 40.17 |
| | 2.2 | 25.94 | 35.69 | 33.17 | 35.91 | 36.31 | 39.42 | 36.16 | 40.05 |

**Appendix 10. L*a*b* colour (raw data) of Ferkar and roller milled chickpea and navy bean flours**

| | Dup | Chickpea | | | | | Navy bean | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ferkar | SG | B1+B2+B3 | 1M | 2M+3M | Ferkar | SG | B1+B2+B3 | 1M | 2M+3M |
| L* | 1.1 | 76.31 | 76.59 | 77.01 | 76.99 | 75.34 | 73.65 | 73.42 | 74.02 | 73.95 | 72.01 |
| | 1.2 | 76.11 | 76.57 | 77.07 | 77.02 | 75.23 | 73.74 | 73.41 | 73.83 | 74.30 | 72.09 |
| | 2.1 | 76.29 | 76.57 | 76.66 | 76.99 | 75.23 | 73.80 | 73.10 | 74.00 | 73.97 | 72.31 |
| | 2.2 | 76.20 | 76.53 | 76.73 | 77.00 | 75.12 | 74.01 | 73.37 | 74.01 | 73.56 | 72.28 |
| a* | 1.1 | 2.39 | 2.76 | 1.76 | 2.82 | 3.33 | 1.96 | 2.32 | 2.09 | 2.43 | 2.18 |
| | 1.2 | 2.48 | 2.74 | 1.75 | 2.81 | 3.40 | 1.99 | 2.31 | 2.11 | 2.36 | 2.14 |
| | 2.1 | 2.49 | 2.79 | 1.97 | 2.86 | 3.42 | 2.01 | 2.30 | 2.06 | 2.35 | 2.08 |
| | 2.2 | 2.56 | 2.79 | 2.00 | 2.87 | 3.42 | 2.02 | 2.28 | 2.03 | 2.39 | 2.08 |
| b* | 1.1 | 34.88 | 36.86 | 34.09 | 36.81 | 37.75 | 14.49 | 14.56 | 15.26 | 13.55 | 14.52 |
| | 1.2 | 35.16 | 36.62 | 34.08 | 36.69 | 37.85 | 14.60 | 14.55 | 15.30 | 13.31 | 14.42 |
| | 2.1 | 34.87 | 36.54 | 33.90 | 36.55 | 37.67 | 14.30 | 14.76 | 15.07 | 13.70 | 14.54 |
| | 2.2 | 35.09 | 36.43 | 33.76 | 36.63 | 37.65 | 14.25 | 14.68 | 14.97 | 13.87 | 14.52 |

**Appendix 11. Particle size distribution (raw data) of Ferkar and roller milled green lentil flours**

| Dup | Green lentil | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Ferkar | SG | B1+B2+B3 | 1M+2M+3M | Ferkar | SG | B1+B2+B3 | 1M+2M+3M |
| | d(0.1), µm | | | | VWM, µm | | | |
| 1.1 | 6.2 | 16.0 | 17.1 | 15.6 | 108.0 | 72.7 | 72.8 | 72.8 |
| 1.2 | 6.3 | 16.0 | 17.1 | 15.7 | 113.8 | 72.9 | 72.9 | 73.1 |
| 2.1 | 6.5 | 16.1 | 16.9 | 15.9 | 103.2 | 74.0 | 72.7 | 74.3 |
| 2.2 | 6.6 | 16.1 | 17.0 | 15.9 | 101.8 | 74.1 | 73.2 | 74.5 |
| | d(0.5), µm | | | | Span | | | |
| 1.1 | 30.0 | 67.1 | 60.5 | 67.9 | 5.65 | 1.84 | 2.19 | 1.80 |
| 1.2 | 30.5 | 67.0 | 60.6 | 68.3 | 5.74 | 1.85 | 2.18 | 1.79 |
| 2.1 | 31.7 | 68.1 | 60.3 | 69.5 | 5.38 | 1.85 | 2.20 | 1.80 |
| 2.2 | 31.8 | 68.2 | 60.7 | 69.6 | 5.27 | 1.85 | 2.20 | 1.80 |
| | d(0.9), µm | | | | Uniformity | | | |
| 1.1 | 175.5 | 139.1 | 149.2 | 137.9 | 3.12 | 0.57 | 0.69 | 0.56 |
| 1.2 | 181.4 | 139.6 | 149.3 | 138.2 | 3.25 | 0.57 | 0.69 | 0.55 |
| 2.1 | 177.4 | 141.9 | 149.5 | 140.7 | 2.77 | 0.58 | 0.70 | 0.56 |
| 2.2 | 174.1 | 142.0 | 150.3 | 140.9 | 2.72 | 0.57 | 0.69 | 0.56 |

**Appendix 12. Particle size distribution (raw data) of Ferkar and roller milled yellow pea flours**

| Dup | Yellow pea | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Ferkar | SG | B1+B2+B3 | 1M+2M+3M | Ferkar | SG | B1+B2+B3 | 1M+2M+3M |
| | d(0.1), µm | | | | VWM, µm | | | |
| 1.1 | 6.3 | 15.2 | 15.9 | 14.9 | 82.4 | 65.9 | 64.0 | 66.8 |
| 1.2 | 6.5 | 15.2 | 15.9 | 14.9 | 94.5 | 66.0 | 64.1 | 66.7 |
| 2.1 | 6.7 | 15.9 | 16.0 | 15.8 | 81.2 | 70.6 | 65.3 | 72.5 |
| 2.2 | 6.8 | 15.9 | 16.0 | 15.9 | 77.2 | 70.5 | 64.9 | 72.4 |
| | d(0.5), µm | | | | Span | | | |
| 1.1 | 26.3 | 57.1 | 46.6 | 59.4 | 5.19 | 2.04 | 2.65 | 1.97 |
| 1.2 | 26.8 | 57.1 | 46.8 | 59.5 | 5.63 | 2.05 | 2.64 | 1.96 |
| 2.1 | 26.7 | 62.0 | 47.4 | 66.0 | 4.96 | 2.00 | 2.67 | 1.89 |
| 2.2 | 26.6 | 62.1 | 46.9 | 65.9 | 4.88 | 2.00 | 2.69 | 1.89 |
| | d(0.9), µm | | | | Uniformity | | | |
| 1.1 | 143.0 | 131.8 | 139.6 | 131.7 | 2.61 | 0.64 | 0.83 | 0.62 |
| 1.2 | 157.3 | 132.1 | 139.4 | 131.4 | 3.00 | 0.64 | 0.82 | 0.62 |
| 2.1 | 139.3 | 140.2 | 142.4 | 140.6 | 2.50 | 0.63 | 0.83 | 0.59 |
| 2.2 | 136.4 | 140.0 | 142.0 | 140.6 | 2.37 | 0.63 | 0.84 | 0.59 |

**Appendix 13. Particle size distribution (raw data) of Ferkar and roller milled chickpea flours**

| Dup | Chickpea | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ferkar | SG | B1+B2+B3 | 1M | 2M+3M | Ferkar | SG | B1+B2+B3 | 1M | 2M+3M |
| | d(0.1), µm | | | | | VWM, µm | | | | |
| 1.1 | 8.9 | 15.9 | 15.1 | 16.3 | 16.0 | 30.2 | 64.1 | 52.7 | 69.0 | 66.4 |
| 1.2 | 8.9 | 15.9 | 15.2 | 16.3 | 16.0 | 30.0 | 64.1 | 52.6 | 68.7 | 66.2 |
| 2.1 | 8.8 | 15.1 | 14.5 | 15.9 | 14.4 | 30.4 | 61.1 | 53.3 | 65.8 | 61.9 |
| 2.2 | 8.8 | 15.1 | 14.4 | 15.8 | 14.3 | 30.6 | 61.2 | 53.1 | 65.7 | 61.8 |
| | d(0.5), µm | | | | | Span | | | | |
| 1.1 | 20.9 | 50.6 | 36.4 | 57.2 | 54.1 | 2.43 | 2.34 | 2.77 | 2.19 | 2.23 |
| 1.2 | 20.9 | 50.5 | 36.5 | 56.9 | 54.1 | 2.42 | 2.34 | 2.75 | 2.20 | 2.22 |
| 2.1 | 21.0 | 46.9 | 36.2 | 54.3 | 48.4 | 2.52 | 2.44 | 2.91 | 2.19 | 2.41 |
| 2.2 | 21.0 | 47.2 | 35.8 | 54.3 | 48.3 | 2.55 | 2.42 | 2.94 | 2.19 | 2.41 |
| | d(0.9), µm | | | | | Uniformity | | | | |
| 1.1 | 59.8 | 134.0 | 116.2 | 141.8 | 136.8 | 0.81 | 0.74 | 0.84 | 0.70 | 0.70 |
| 1.2 | 59.6 | 134.2 | 115.6 | 141.2 | 136.3 | 0.81 | 0.74 | 0.83 | 0.70 | 0.70 |
| 2.1 | 61.7 | 129.6 | 119.6 | 135.1 | 131.2 | 0.82 | 0.77 | 0.88 | 0.70 | 0.76 |
| 2.2 | 62.3 | 129.3 | 119.5 | 134.8 | 130.9 | 0.84 | 0.77 | 0.89 | 0.70 | 0.76 |

**Appendix 14. Particle size distribution (raw data) of Ferkar and roller milled navy bean flours**

| Dup | Navy bean | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ferkar | SG | B1+B2+B3 | 1M | 2M+3M | Ferkar | SG | B1+B2+B3 | 1M | 2M+3M |
| | d(0.1), µm | | | | | VWM, µm | | | | |
| 1.1 | 6.4 | 14.7 | 14.9 | 14.9 | 14.1 | 73.8 | 67.0 | 57.4 | 70.5 | 68.3 |
| 1.2 | 6.4 | 14.7 | 14.8 | 14.9 | 14.2 | 71.1 | 66.9 | 56.8 | 70.6 | 69.1 |
| 2.1 | 6.2 | 14.5 | 14.9 | 14.8 | 13.7 | 71.0 | 66.4 | 56.8 | 70.1 | 66.5 |
| 2.2 | 6.0 | 14.5 | 14.9 | 14.8 | 13.6 | 63.0 | 66.0 | 56.7 | 70.2 | 65.7 |
| | d(0.5), µm | | | | | Span | | | | |
| 1.1 | 24.8 | 49.9 | 35.5 | 53.6 | 57.3 | 5.41 | 2.63 | 3.41 | 2.57 | 2.23 |
| 1.2 | 24.7 | 49.5 | 35.1 | 53.6 | 57.5 | 5.33 | 2.66 | 3.41 | 2.58 | 2.26 |
| 2.1 | 24.8 | 48.1 | 35.2 | 51.8 | 53.7 | 5.45 | 2.74 | 3.40 | 2.67 | 2.37 |
| 2.2 | 24.5 | 47.6 | 35.1 | 52.0 | 53.3 | 5.28 | 2.75 | 3.41 | 2.67 | 2.35 |
| | d(0.9), µm | | | | | Uniformity | | | | |
| 1.1 | 140.5 | 146.1 | 136.1 | 152.8 | 141.7 | 2.44 | 0.85 | 1.01 | 0.84 | 0.71 |
| 1.2 | 138.1 | 146.1 | 134.8 | 153.1 | 143.8 | 2.34 | 0.85 | 1.01 | 0.84 | 0.72 |
| 2.1 | 141.5 | 146.2 | 134.6 | 153.3 | 140.7 | 2.32 | 0.88 | 1.00 | 0.87 | 0.76 |
| 2.2 | 135.2 | 145.4 | 134.5 | 153.5 | 138.8 | 2.04 | 0.88 | 1.00 | 0.87 | 0.75 |

**Appendix 15. % Moisture (db) (raw data) of pre-treated green lentil and chickpea flours**

| Moisture conditioning level | Scour level | Dup | Green lentil | | | Chickpea | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | SG | B1+B2+B3 | 1M+2M+3M | SG | B1+B2+B3 | 1M | 2M+3M |
| 0% | Unscoured | 1.1 | 9.43 | 9.63 | 9.38 | 7.75 | 7.77 | 7.86 | 7.52 |
| | | 1.2 | 9.47 | 9.70 | 9.35 | 7.77 | 7.81 | 7.79 | 7.49 |
| | | 2.1 | 9.33 | 9.50 | 9.23 | 7.46 | 7.64 | 7.61 | 7.25 |
| | | 2.2 | 9.34 | 9.52 | 9.19 | 7.46 | 7.64 | 7.69 | 7.27 |
| | Scoured | 1.1 | 10.41 | 10.69 | 10.50 | 6.54 | 6.59 | 6.63 | 6.31 |
| | | 1.2 | 10.39 | 10.71 | 10.50 | 6.54 | 6.57 | 6.62 | 6.29 |
| | | 2.1 | 10.18 | 10.29 | 10.01 | 6.61 | 6.76 | 6.73 | 6.22 |
| | | 2.2 | 10.11 | 10.31 | 10.03 | 6.60 | 6.73 | 6.68 | 6.28 |
| 0.5% | Unscoured | 1.1 | 9.73 | 10.00 | 9.85 | 7.86 | 8.00 | 7.95 | 7.51 |
| | | 1.2 | 9.77 | 9.98 | 9.79 | 7.86 | 7.92 | 7.93 | 7.51 |
| | | 2.1 | 9.78 | 9.90 | 9.72 | 7.94 | 8.16 | 8.09 | 7.66 |
| | | 2.2 | 9.67 | 9.94 | 9.74 | 7.93 | 8.12 | 8.05 | 7.62 |
| | Scoured | 1.1 | 10.27 | 10.37 | 10.12 | 6.91 | 6.89 | 6.85 | 6.55 |
| | | 1.2 | 10.28 | 10.36 | 10.14 | 6.87 | 6.90 | 6.93 | 6.58 |
| | | 2.1 | 10.20 | 10.36 | 10.21 | 6.97 | 7.24 | 7.16 | 6.79 |
| | | 2.2 | 10.20 | 10.40 | 10.26 | 7.02 | 7.24 | 7.09 | 6.80 |
| 1% | Unscoured | 1.1 | 10.09 | 10.32 | 10.11 | 7.04 | 7.15 | 7.13 | 6.93 |
| | | 1.2 | 10.08 | 10.31 | 10.09 | 7.10 | 7.22 | 7.18 | 6.93 |
| | | 2.1 | 9.91 | 10.09 | 9.94 | 7.86 | 7.97 | 7.93 | 7.46 |
| | | 2.2 | 9.95 | 10.07 | 9.93 | 7.79 | 7.96 | 7.94 | 7.48 |
| | Scoured | 1.1 | 10.55 | 10.70 | 10.53 | 7.50 | 7.57 | 7.67 | 7.05 |
| | | 1.2 | 10.48 | 10.64 | 10.50 | 7.57 | 7.57 | 7.65 | 7.03 |
| | | 2.1 | 10.03 | 10.15 | 10.04 | 7.65 | 7.96 | 7.87 | 7.22 |
| | | 2.2 | 10.04 | 10.16 | 10.01 | 7.66 | 7.86 | 7.86 | 7.22 |

**Appendix 16.  % Protein (db) (raw data) of pre-treated green lentil and chickpea flours**

| Moisture conditioning level | Scour level | Dup | Green lentil | | | Chickpea | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | SG | B1+B2+B3 | 1M+2M+3M | SG | B1+B2+B3 | 1M | 2M+3M |
| 0% | Unscoured | 1.1 | 26.32 | 24.83 | 26.74 | 20.76 | 19.67 | 20.67 | 21.67 |
| | | 1.2 | 26.31 | 24.84 | 26.72 | 20.82 | 19.57 | 20.65 | 21.75 |
| | | 2.1 | 26.37 | 24.58 | 26.70 | 20.57 | 20.20 | 20.47 | 21.21 |
| | | 2.2 | 26.48 | 24.60 | 26.85 | 20.67 | 20.17 | 20.37 | 21.21 |
| | Scoured | 1.1 | 26.25 | 24.47 | 26.65 | 20.50 | 19.90 | 20.66 | 21.04 |
| | | 1.2 | 26.18 | 24.41 | 26.58 | 20.43 | 19.81 | 20.65 | 21.04 |
| | | 2.1 | 26.13 | 24.34 | 26.49 | 20.26 | 19.75 | 20.50 | 20.97 |
| | | 2.2 | 26.28 | 24.37 | 26.54 | 20.28 | 19.85 | 20.50 | 20.98 |
| 0.5% | Unscoured | 1.1 | 26.48 | 24.82 | 26.62 | 20.73 | 18.83 | 21.21 | 21.75 |
| | | 1.2 | 26.44 | 24.53 | 26.66 | 20.86 | 18.84 | 21.13 | 21.77 |
| | | 2.1 | 26.32 | 24.17 | 26.81 | 20.57 | 18.70 | 21.09 | 21.70 |
| | | 2.2 | 26.37 | 24.42 | 27.04 | 20.63 | 18.61 | 20.97 | 21.74 |
| | Scoured | 1.1 | 25.86 | 24.11 | 26.57 | 20.54 | 18.99 | 21.02 | 20.76 |
| | | 1.2 | 25.83 | 24.24 | 26.48 | 20.45 | 18.97 | 20.99 | 20.78 |
| | | 2.1 | 25.89 | 24.15 | 26.40 | 20.39 | 19.90 | 20.52 | 20.96 |
| | | 2.2 | 26.06 | 24.21 | 26.39 | 20.32 | 19.97 | 20.53 | 20.85 |
| 1% | Unscoured | 1.1 | 26.63 | 24.29 | 27.12 | 20.65 | 18.83 | 21.09 | 21.18 |
| | | 1.2 | 26.38 | 24.23 | 27.31 | 20.64 | 18.86 | 21.13 | 21.28 |
| | | 2.1 | 26.57 | 24.53 | 26.74 | 20.58 | 18.52 | 20.99 | 21.65 |
| | | 2.2 | 26.59 | 24.44 | 26.96 | 20.62 | 18.56 | 21.08 | 21.72 |
| | Scoured | 1.1 | 26.00 | 24.05 | 26.42 | 20.42 | 19.34 | 20.51 | 21.14 |
| | | 1.2 | 26.04 | 24.33 | 26.65 | 20.43 | 19.31 | 20.56 | 21.29 |
| | | 2.1 | 26.04 | 24.01 | 26.24 | 20.29 | 18.56 | 20.71 | 21.27 |
| | | 2.2 | 25.95 | 24.23 | 26.27 | 20.30 | 18.48 | 20.66 | 21.37 |

**Appendix 17. % Ash (db) (raw data) of pre-treated green lentil and chickpea flours**

| Moisture conditioning level | Scour level | Dup | Green lentil | | | Chickpea | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | SG | B1+B2+B3 | 1M+2M+3M | SG | B1+B2+B3 | 1M | 2M+3M |
| 0% | Unscoured | 1.1 | 2.77 | 2.64 | 2.82 | 2.77 | 2.66 | 2.74 | 2.83 |
| | | 1.2 | 2.76 | 2.64 | 2.81 | 2.76 | 2.67 | 2.75 | 2.85 |
| | | 2.1 | 2.76 | 2.61 | 2.80 | 2.77 | 2.70 | 2.71 | 2.79 |
| | | 2.2 | 2.75 | 2.64 | 2.80 | 2.75 | 2.71 | 2.72 | 2.79 |
| | Scoured | 1.1 | 2.75 | 2.58 | 2.76 | 2.70 | 2.64 | 2.73 | 2.75 |
| | | 1.2 | 2.70 | 2.56 | 2.77 | 2.69 | 2.64 | 2.70 | 2.78 |
| | | 2.1 | 2.76 | 2.59 | 2.76 | 2.69 | 2.63 | 2.74 | 2.75 |
| | | 2.2 | 2.76 | 2.57 | 2.76 | 2.69 | 2.63 | 2.71 | 2.77 |
| 0.5% | Unscoured | 1.1 | 2.73 | 2.60 | 2.82 | 2.76 | 2.56 | 2.76 | 2.87 |
| | | 1.2 | 2.76 | 2.58 | 2.80 | 2.77 | 2.55 | 2.75 | 2.86 |
| | | 2.1 | 2.78 | 2.57 | 2.81 | 2.78 | 2.54 | 2.75 | 2.83 |
| | | 2.2 | 2.78 | 2.57 | 2.79 | 2.77 | 2.54 | 2.76 | 2.84 |
| | Scoured | 1.1 | 2.74 | 2.57 | 2.76 | 2.70 | 2.54 | 2.77 | 2.75 |
| | | 1.2 | 2.71 | 2.57 | 2.76 | 2.69 | 2.55 | 2.76 | 2.74 |
| | | 2.1 | 2.77 | 2.56 | 2.76 | 2.75 | 2.68 | 2.67 | 2.75 |
| | | 2.2 | 2.77 | 2.56 | 2.77 | 2.72 | 2.69 | 2.66 | 2.77 |
| 1% | Unscoured | 1.1 | 2.76 | 2.55 | 2.79 | 2.74 | 2.59 | 2.77 | 2.79 |
| | | 1.2 | 2.78 | 2.56 | 2.80 | 2.74 | 2.57 | 2.76 | 2.78 |
| | | 2.1 | 2.75 | 2.57 | 2.80 | 2.73 | 2.53 | 2.75 | 2.84 |
| | | 2.2 | 2.76 | 2.58 | 2.80 | 2.73 | 2.54 | 2.76 | 2.84 |
| | Scoured | 1.1 | 2.74 | 2.55 | 2.77 | 2.75 | 2.58 | 2.73 | 2.79 |
| | | 1.2 | 2.78 | 2.55 | 2.76 | 2.76 | 2.58 | 2.71 | 2.78 |
| | | 2.1 | 2.75 | 2.56 | 2.76 | 2.74 | 2.50 | 2.73 | 2.80 |
| | | 2.2 | 2.75 | 2.54 | 2.75 | 2.73 | 2.52 | 2.73 | 2.80 |

**Appendix 18. Water-holding capacity (WHC) (raw data) for pre-treated green lentil and chickpea SG flours**

| Moisture conditioning level | Scour level | Dup | WHC (g/g, db) | |
|---|---|---|---|---|
| | | | Green lentil SG | Chickpea SG |
| 0% | Unscoured | 1.1 | 0.75 | 0.70 |
| | | 1.2 | 0.76 | 0.71 |
| | | 2.1 | 0.74 | 0.70 |
| | | 2.2 | 0.75 | 0.72 |
| | Scoured | 1.1 | 0.73 | 0.64 |
| | | 1.2 | 0.71 | 0.65 |
| | | 2.1 | 0.72 | 0.64 |
| | | 2.2 | 0.70 | 0.66 |
| 0.5% | Unscoured | 1.1 | 0.73 | 0.67 |
| | | 1.2 | 0.71 | 0.69 |
| | | 2.1 | 0.73 | 0.72 |
| | | 2.2 | 0.74 | 0.71 |
| | Scoured | 1.1 | 0.71 | 0.69 |
| | | 1.2 | 0.70 | 0.70 |
| | | 2.1 | 0.73 | 0.71 |
| | | 2.2 | 0.72 | 0.71 |
| 1% | Unscoured | 1.1 | 0.72 | 0.72 |
| | | 1.2 | 0.73 | 0.74 |
| | | 2.1 | 0.69 | 0.69 |
| | | 2.2 | 0.69 | 0.67 |
| | Scoured | 1.1 | 0.69 | 0.68 |
| | | 1.2 | 0.71 | 0.69 |
| | | 2.1 | 0.71 | 0.69 |
| | | 2.2 | 0.74 | 0.69 |

**Appendix 19. L*a*b* colour (raw data) for pre-treated green lentil flours**

| Moisture conditioning level | Scour level | Dup | SG | | | B1+B2+B3 | | | 1M+2M+3M | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | L* | a* | b* | L* | a* | b* | L* | a* | b* |
| 0% | Unscoured | 1.1 | 74.61 | 1.11 | 35.86 | 73.73 | 0.64 | 33.70 | 74.71 | 1.45 | 36.12 |
| | | 1.2 | 74.60 | 1.12 | 35.85 | 73.71 | 0.66 | 33.69 | 74.70 | 1.46 | 36.12 |
| | | 2.1 | 74.07 | 1.20 | 35.42 | 73.47 | 0.66 | 33.32 | 74.54 | 1.43 | 35.94 |
| | | 2.2 | 74.06 | 1.20 | 35.41 | 73.46 | 0.65 | 33.31 | 74.53 | 1.43 | 35.94 |
| | Scoured | 1.1 | 75.90 | 1.42 | 37.92 | 76.00 | 1.10 | 36.77 | 75.95 | 1.46 | 37.95 |
| | | 1.2 | 75.89 | 1.43 | 37.93 | 75.99 | 1.10 | 36.76 | 75.95 | 1.45 | 37.95 |
| | | 2.1 | 75.83 | 1.37 | 37.31 | 75.72 | 1.03 | 36.17 | 75.62 | 1.45 | 37.31 |
| | | 2.2 | 75.82 | 1.39 | 37.29 | 75.70 | 1.09 | 36.15 | 75.61 | 1.47 | 37.31 |
| 0.5% | Unscoured | 1.1 | 74.26 | 1.28 | 35.59 | 74.75 | 0.86 | 34.75 | 75.20 | 1.41 | 36.78 |
| | | 1.2 | 74.26 | 1.26 | 35.59 | 74.75 | 0.85 | 34.74 | 75.18 | 1.42 | 36.75 |
| | | 2.1 | 74.85 | 1.27 | 36.41 | 74.61 | 0.80 | 34.62 | 74.83 | 1.44 | 36.67 |
| | | 2.2 | 74.85 | 1.26 | 36.40 | 74.59 | 0.84 | 34.61 | 74.83 | 1.43 | 36.66 |
| | Scoured | 1.1 | 76.25 | 1.24 | 37.40 | 76.61 | 1.03 | 36.73 | 76.13 | 1.37 | 37.85 |
| | | 1.2 | 76.25 | 1.20 | 37.41 | 76.62 | 1.00 | 36.74 | 76.12 | 1.38 | 37.84 |
| | | 2.1 | 76.26 | 1.28 | 37.76 | 76.74 | 1.02 | 36.97 | 76.36 | 1.41 | 38.17 |
| | | 2.2 | 76.26 | 1.29 | 37.75 | 76.74 | 0.99 | 36.97 | 76.36 | 1.41 | 38.16 |
| 1% | Unscoured | 1.1 | 74.76 | 1.22 | 36.34 | 74.86 | 0.72 | 34.65 | 75.15 | 1.36 | 37.13 |
| | | 1.2 | 74.77 | 1.19 | 36.35 | 74.85 | 0.74 | 34.65 | 75.15 | 1.32 | 37.14 |
| | | 2.1 | 75.10 | 1.21 | 36.43 | 75.07 | 0.74 | 34.63 | 75.05 | 1.35 | 36.93 |
| | | 2.2 | 75.10 | 1.15 | 36.44 | 75.06 | 0.72 | 34.62 | 75.04 | 1.35 | 36.93 |
| | Scoured | 1.1 | 76.24 | 1.30 | 37.92 | 76.44 | 1.10 | 36.72 | 76.33 | 1.39 | 38.20 |
| | | 1.2 | 76.23 | 1.32 | 37.92 | 76.42 | 1.12 | 36.70 | 76.34 | 1.37 | 38.21 |
| | | 2.1 | 76.24 | 1.36 | 37.61 | 76.35 | 1.19 | 36.55 | 76.27 | 1.45 | 37.83 |
| | | 2.2 | 76.24 | 1.36 | 37.60 | 76.37 | 1.14 | 36.56 | 76.27 | 1.45 | 37.82 |

**Appendix 20. L*a*b* colour (raw data) for pre-treated chickpea flours**

| Moisture conditioning level | Scour level | Dup | SG | | | B1+B2+B3 | | | 1M | | | 2M+3M | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | L* | a* | b* | L* | a* | b* | L* | a* | b* | L* | a* | b* |
| 0% | Unscoured | 1.1 | 76.92 | 2.31 | 35.46 | 77.03 | 1.74 | 33.83 | 77.42 | 2.51 | 35.90 | 76.25 | 2.52 | 35.30 |
| | | 1.2 | 76.90 | 2.29 | 35.26 | 76.92 | 1.78 | 33.79 | 77.34 | 2.55 | 35.82 | 76.28 | 2.54 | 35.21 |
| | | 2.1 | 77.01 | 2.19 | 35.46 | 77.10 | 1.79 | 34.70 | 77.50 | 2.45 | 36.02 | 76.44 | 2.38 | 35.53 |
| | | 2.2 | 76.97 | 2.21 | 35.38 | 77.08 | 1.82 | 34.54 | 77.46 | 2.38 | 35.76 | 76.49 | 2.42 | 35.42 |
| | Scoured | 1.1 | 77.24 | 2.07 | 34.70 | 77.30 | 1.76 | 33.62 | 77.53 | 2.17 | 35.41 | 76.46 | 2.13 | 33.98 |
| | | 1.2 | 77.18 | 2.14 | 34.46 | 77.22 | 1.80 | 33.53 | 77.46 | 2.22 | 35.37 | 76.41 | 2.15 | 33.95 |
| | | 2.1 | 77.17 | 2.17 | 34.86 | 77.35 | 1.92 | 34.00 | 77.53 | 2.31 | 35.65 | 76.33 | 2.13 | 34.39 |
| | | 2.2 | 77.12 | 2.14 | 34.78 | 77.35 | 1.88 | 34.03 | 77.50 | 2.29 | 35.58 | 76.34 | 2.10 | 34.21 |
| 0.5% | Unscoured | 1.1 | 77.10 | 2.42 | 35.59 | 77.70 | 1.73 | 33.26 | 77.41 | 2.68 | 36.45 | 76.35 | 2.62 | 35.77 |
| | | 1.2 | 77.12 | 2.44 | 35.45 | 77.64 | 1.78 | 33.31 | 77.33 | 2.67 | 36.37 | 76.40 | 2.57 | 35.56 |
| | | 2.1 | 77.23 | 2.43 | 35.78 | 77.81 | 1.75 | 33.82 | 77.45 | 2.63 | 36.40 | 76.57 | 2.66 | 36.17 |
| | | 2.2 | 77.15 | 2.45 | 35.83 | 77.77 | 1.76 | 33.87 | 77.43 | 2.61 | 36.22 | 76.56 | 2.65 | 35.96 |
| | Scoured | 1.1 | 77.16 | 2.26 | 35.11 | 77.36 | 1.61 | 33.30 | 77.22 | 2.49 | 36.01 | 76.66 | 2.39 | 35.13 |
| | | 1.2 | 77.15 | 2.26 | 35.05 | 77.29 | 1.69 | 33.20 | 77.24 | 2.48 | 35.96 | 76.68 | 2.34 | 34.92 |
| | | 2.1 | 77.08 | 2.20 | 35.26 | 77.12 | 1.85 | 34.38 | 77.43 | 2.32 | 35.74 | 76.47 | 2.28 | 34.81 |
| | | 2.2 | 77.11 | 2.18 | 35.21 | 77.15 | 1.86 | 34.25 | 77.47 | 2.33 | 35.64 | 76.57 | 2.24 | 34.71 |
| 1% | Unscoured | 1.1 | 77.11 | 2.37 | 35.32 | 77.63 | 1.59 | 32.57 | 77.27 | 2.65 | 36.12 | 76.57 | 2.50 | 34.91 |
| | | 1.2 | 77.14 | 2.34 | 35.15 | 77.69 | 1.63 | 32.70 | 77.28 | 2.61 | 36.16 | 76.62 | 2.50 | 34.98 |
| | | 2.1 | 77.16 | 2.41 | 35.74 | 77.83 | 1.58 | 33.63 | 77.40 | 2.60 | 36.43 | 76.44 | 2.62 | 35.87 |
| | | 2.2 | 77.16 | 2.38 | 35.59 | 77.75 | 1.63 | 33.53 | 77.32 | 2.63 | 36.31 | 76.47 | 2.64 | 35.77 |
| | Scoured | 1.1 | 77.20 | 2.18 | 35.25 | 77.64 | 1.71 | 34.02 | 77.59 | 2.44 | 35.84 | 76.71 | 2.31 | 35.39 |
| | | 1.2 | 77.19 | 2.17 | 35.11 | 77.60 | 1.73 | 33.73 | 77.58 | 2.45 | 35.96 | 76.70 | 2.36 | 35.14 |
| | | 2.1 | 77.27 | 2.24 | 35.54 | 77.82 | 1.49 | 33.36 | 77.53 | 2.52 | 36.27 | 76.88 | 2.45 | 35.80 |
| | | 2.2 | 77.17 | 2.24 | 35.43 | 77.85 | 1.52 | 33.20 | 77.53 | 2.52 | 35.95 | 76.74 | 2.51 | 35.86 |

**Appendix 21. Particle size distribution (raw data) for pre-treated green lentil straight grade (SG) flours**

| Moisture conditioning level | Scour level | Dup | Green lentil flours (SG) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | d(0.1), µm | d(0.5), µm | d(0.9), µm | VWM, µm | Span | Uniformity |
| 0% | Unscoured | 1.1 | 14.6 | 61.3 | 135.4 | 68.6 | 1.97 | 0.62 |
| | | 1.2 | 14.7 | 61.5 | 135.7 | 68.8 | 1.97 | 0.62 |
| | | 2.1 | 14.0 | 56.2 | 126.6 | 63.8 | 2.00 | 0.63 |
| | | 2.2 | 14.0 | 56.3 | 126.7 | 63.9 | 2.00 | 0.63 |
| | Scoured | 1.1 | 15.3 | 59.9 | 130.1 | 66.8 | 1.92 | 0.60 |
| | | 1.2 | 15.3 | 60.2 | 130.1 | 66.9 | 1.91 | 0.60 |
| | | 2.1 | 15.0 | 54.7 | 120.9 | 62.0 | 1.94 | 0.60 |
| | | 2.2 | 14.8 | 54.5 | 120.7 | 61.8 | 1.94 | 0.61 |
| 0.5% | Unscoured | 1.1 | 14.8 | 59.6 | 132.2 | 67.0 | 1.97 | 0.62 |
| | | 1.2 | 14.7 | 59.5 | 132.0 | 66.9 | 1.97 | 0.62 |
| | | 2.1 | 14.7 | 58.3 | 129.2 | 65.6 | 1.96 | 0.61 |
| | | 2.2 | 14.7 | 58.1 | 129.1 | 65.5 | 1.97 | 0.62 |
| | Scoured | 1.1 | 14.6 | 55.0 | 124.6 | 62.9 | 2.00 | 0.63 |
| | | 1.2 | 14.6 | 54.8 | 124.4 | 62.8 | 2.00 | 0.63 |
| | | 2.1 | 14.5 | 55.0 | 124.3 | 62.8 | 2.00 | 0.63 |
| | | 2.2 | 14.5 | 55.0 | 124.7 | 62.9 | 2.00 | 0.63 |
| 1% | Unscoured | 1.1 | 14.8 | 58.5 | 131.2 | 66.2 | 1.99 | 0.63 |
| | | 1.2 | 14.8 | 58.5 | 131.3 | 66.2 | 1.99 | 0.63 |
| | | 2.1 | 14.7 | 57.9 | 129.0 | 65.3 | 1.98 | 0.62 |
| | | 2.2 | 14.6 | 57.8 | 129.2 | 65.3 | 1.98 | 0.62 |
| | Scoured | 1.1 | 14.9 | 57.3 | 127.5 | 64.8 | 1.97 | 0.61 |
| | | 1.2 | 14.9 | 57.4 | 127.7 | 64.9 | 1.96 | 0.61 |
| | | 2.1 | 14.3 | 55.3 | 124.1 | 62.8 | 1.99 | 0.62 |
| | | 2.2 | 14.3 | 55.3 | 124.2 | 62.9 | 1.99 | 0.62 |

**Appendix 22. Particle size distribution (raw data) for pre-treated green lentil break (B1+B2+B3) flours**

| Moisture conditioning level | Scour level | Dup | Green lentil flours (B1+B2+B3) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | d(0.1), µm | d(0.5), µm | d(0.9), µm | VWM, µm | Span | Uniformity |
| 0% | Unscoured | 1.1 | 15.3 | 54.8 | 167.3 | 83.4 | 2.77 | 1.02 |
| | | 1.2 | 15.3 | 54.4 | 165.6 | 80.7 | 2.76 | 0.98 |
| | | 2.1 | 15.1 | 51.1 | 143.7 | 66.8 | 2.52 | 0.79 |
| | | 2.2 | 15.1 | 51.2 | 143.6 | 66.9 | 2.51 | 0.79 |
| | Scoured | 1.1 | 15.8 | 50.9 | 142.8 | 66.7 | 2.49 | 0.78 |
| | | 1.2 | 15.8 | 51.0 | 142.7 | 66.7 | 2.49 | 0.78 |
| | | 2.1 | 15.7 | 51.2 | 142.4 | 66.7 | 2.47 | 0.78 |
| | | 2.2 | 15.7 | 51.0 | 141.8 | 66.4 | 2.47 | 0.78 |
| 0.5% | Unscoured | 1.1 | 15.2 | 50.6 | 142.6 | 66.3 | 2.52 | 0.79 |
| | | 1.2 | 15.1 | 50.7 | 142.6 | 66.3 | 2.51 | 0.79 |
| | | 2.1 | 14.9 | 49.6 | 141.6 | 65.6 | 2.55 | 0.80 |
| | | 2.2 | 15.0 | 49.7 | 142.3 | 65.8 | 2.56 | 0.80 |
| | Scoured | 1.1 | 15.3 | 49.2 | 142.1 | 65.7 | 2.58 | 0.81 |
| | | 1.2 | 15.3 | 49.2 | 141.9 | 65.6 | 2.57 | 0.81 |
| | | 2.1 | 15.5 | 49.9 | 141.0 | 65.7 | 2.52 | 0.79 |
| | | 2.2 | 15.5 | 50.0 | 140.6 | 65.6 | 2.50 | 0.79 |
| 1% | Unscoured | 1.1 | 15.1 | 48.1 | 139.0 | 64.2 | 2.58 | 0.81 |
| | | 1.2 | 15.0 | 48.0 | 138.6 | 64.0 | 2.57 | 0.81 |
| | | 2.1 | 15.1 | 49.2 | 141.7 | 65.5 | 2.57 | 0.81 |
| | | 2.2 | 15.1 | 49.5 | 142.3 | 65.8 | 2.57 | 0.81 |
| | Scoured | 1.1 | 15.7 | 50.6 | 142.2 | 66.4 | 2.50 | 0.78 |
| | | 1.2 | 15.8 | 50.6 | 142.2 | 66.4 | 2.50 | 0.78 |
| | | 2.1 | 15.3 | 49.7 | 141.5 | 65.7 | 2.54 | 0.80 |
| | | 2.2 | 15.4 | 49.9 | 141.8 | 65.9 | 2.53 | 0.80 |

**Appendix 23. Particle size distribution (raw data) for pre-treated green lentil middling (1M+2M+3M) flours**

| Moisture conditioning level | Scour level | Dup | Green lentil flours (1M+2M+3M) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | d(0.1), µm | d(0.5), µm | d(0.9), µm | VWM, µm | Span | Uniformity |
| 0% | Unscoured | 1.1 | 14.0 | 63.5 | 133.8 | 69.1 | 1.89 | 0.59 |
| | | 1.2 | 14.2 | 63.5 | 133.7 | 69.1 | 1.88 | 0.59 |
| | | 2.1 | 13.6 | 58.3 | 125.3 | 64.4 | 1.92 | 0.60 |
| | | 2.2 | 13.6 | 58.2 | 125.3 | 64.3 | 1.92 | 0.60 |
| | Scoured | 1.1 | 15.4 | 62.1 | 129.5 | 67.8 | 1.84 | 0.57 |
| | | 1.2 | 15.4 | 62.0 | 129.6 | 67.8 | 1.84 | 0.57 |
| | | 2.1 | 14.6 | 55.7 | 117.9 | 61.6 | 1.85 | 0.57 |
| | | 2.2 | 14.6 | 55.8 | 117.9 | 61.6 | 1.85 | 0.57 |
| 0.5% | Unscoured | 1.1 | 14.6 | 63.9 | 132.3 | 69.2 | 1.84 | 0.57 |
| | | 1.2 | 14.7 | 64.1 | 132.1 | 69.2 | 1.83 | 0.57 |
| | | 2.1 | 14.2 | 60.7 | 127.9 | 66.3 | 1.87 | 0.58 |
| | | 2.2 | 14.2 | 60.6 | 128.0 | 66.4 | 1.88 | 0.58 |
| | Scoured | 1.1 | 14.4 | 56.9 | 122.2 | 63.2 | 1.90 | 0.59 |
| | | 1.2 | 14.4 | 56.7 | 122.1 | 63.0 | 1.90 | 0.59 |
| | | 2.1 | 14.4 | 56.8 | 122.5 | 63.2 | 1.90 | 0.59 |
| | | 2.2 | 14.3 | 56.9 | 122.4 | 63.1 | 1.90 | 0.59 |
| 1% | Unscoured | 1.1 | 14.5 | 62.0 | 130.8 | 67.7 | 1.88 | 0.59 |
| | | 1.2 | 14.5 | 62.0 | 131.0 | 67.8 | 1.88 | 0.59 |
| | | 2.1 | 14.2 | 60.7 | 128.0 | 66.3 | 1.87 | 0.58 |
| | | 2.2 | 14.3 | 60.8 | 128.1 | 66.5 | 1.87 | 0.58 |
| | Scoured | 1.1 | 14.8 | 59.6 | 126.5 | 65.7 | 1.87 | 0.58 |
| | | 1.2 | 14.8 | 59.7 | 126.2 | 65.6 | 1.87 | 0.58 |
| | | 2.1 | 14.0 | 57.1 | 121.9 | 63.0 | 1.89 | 0.59 |
| | | 2.2 | 14.0 | 57.2 | 121.9 | 63.1 | 1.89 | 0.59 |

**Appendix 24. Particle size distribution (raw data) for pre-treated chickpea straight grade (SG) flours**

| Moisture conditioning level | Scour level | Dup | Chickpea flours (SG) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | d(0.1), µm | d(0.5), µm | d(0.9), µm | VWM, µm | Span | Uniformity |
| 0% | Unscoured | 1.1 | 11.4 | 34.4 | 102.6 | 47.0 | 2.65 | 0.82 |
| | | 1.2 | 11.4 | 34.2 | 101.6 | 46.7 | 2.64 | 0.82 |
| | | 2.1 | 11.7 | 34.1 | 109.7 | 64.8 | 2.87 | 1.34 |
| | | 2.2 | 11.7 | 34.2 | 108.9 | 61.8 | 2.84 | 1.25 |
| | Scoured | 1.1 | 11.7 | 38.2 | 122.5 | 80.2 | 2.90 | 1.58 |
| | | 1.2 | 11.6 | 37.9 | 122.6 | 81.0 | 2.93 | 1.62 |
| | | 2.1 | 11.1 | 32.3 | 104.7 | 52.7 | 2.90 | 1.07 |
| | | 2.2 | 11.0 | 32.1 | 103.7 | 52.4 | 2.89 | 1.07 |
| 0.5% | Unscoured | 1.1 | 12.0 | 38.2 | 121.3 | 88.8 | 2.86 | 1.79 |
| | | 1.2 | 11.8 | 37.3 | 113.6 | 67.9 | 2.73 | 1.29 |
| | | 2.1 | 12.0 | 36.9 | 116.1 | 84.4 | 2.82 | 1.75 |
| | | 2.2 | 11.9 | 36.6 | 118.6 | 89.9 | 2.91 | 1.91 |
| | Scoured | 1.1 | 11.0 | 31.5 | 96.9 | 44.0 | 2.73 | 0.83 |
| | | 1.2 | 11.0 | 31.6 | 96.5 | 43.9 | 2.71 | 0.83 |
| | | 2.1 | 11.2 | 31.6 | 98.8 | 44.9 | 2.77 | 0.85 |
| | | 2.2 | 11.0 | 31.4 | 99.0 | 44.8 | 2.80 | 0.86 |
| 1% | Unscoured | 1.1 | 11.5 | 34.6 | 103.0 | 47.3 | 2.64 | 0.82 |
| | | 1.2 | 11.5 | 34.7 | 103.1 | 47.4 | 2.64 | 0.82 |
| | | 2.1 | 11.7 | 34.1 | 100.8 | 46.5 | 2.61 | 0.81 |
| | | 2.2 | 11.7 | 34.3 | 101.2 | 46.7 | 2.61 | 0.81 |
| | Scoured | 1.1 | 11.3 | 32.2 | 96.4 | 44.3 | 2.64 | 0.81 |
| | | 1.2 | 11.3 | 32.2 | 96.5 | 44.3 | 2.65 | 0.81 |
| | | 2.1 | 11.3 | 31.9 | 94.3 | 43.5 | 2.60 | 0.79 |
| | | 2.2 | 11.4 | 31.9 | 94.1 | 43.4 | 2.60 | 0.79 |

**Appendix 25. Particle size distribution (raw data) for pre-treated chickpea break (B1+B2+B3) flours**

| Moisture conditioning level | Scour level | Dup | Chickpea flours (B1+B2+B3) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | d(0.1), µm | d(0.5), µm | d(0.9), µm | VWM, µm | Span | Uniformity |
| 0% | Unscoured | 1.1 | 11.7 | 34.5 | 155.6 | 111.3 | 4.18 | 2.68 |
| | | 1.2 | 11.6 | 34.1 | 165.3 | 118.6 | 4.51 | 2.93 |
| | | 2.1 | 12.0 | 39.2 | 182.4 | 118.8 | 4.35 | 2.52 |
| | | 2.2 | 11.9 | 38.8 | 176.9 | 121.2 | 4.25 | 2.60 |
| | Scoured | 1.1 | 12.1 | 38.2 | 550.4 | 157.9 | 14.10 | 3.61 |
| | | 1.2 | 12.0 | 38.1 | 512.5 | 151.9 | 13.13 | 3.46 |
| | | 2.1 | 12.2 | 38.0 | 463.0 | 143.5 | 11.85 | 3.25 |
| | | 2.2 | 12.0 | 37.5 | 417.2 | 138.4 | 10.81 | 3.16 |
| 0.5% | Unscoured | 1.1 | 11.5 | 31.6 | 179.3 | 108.3 | 5.31 | 2.86 |
| | | 1.2 | 11.5 | 31.8 | 197.5 | 110.3 | 5.84 | 2.90 |
| | | 2.1 | 11.2 | 28.8 | 114.6 | 75.6 | 3.59 | 2.04 |
| | | 2.2 | 11.1 | 28.7 | 115.6 | 75.2 | 2.64 | 2.03 |
| | Scoured | 1.1 | 10.9 | 28.7 | 123.3 | 88.7 | 3.92 | 2.51 |
| | | 1.2 | 10.9 | 28.7 | 121.0 | 84.4 | 3.84 | 2.36 |
| | | 2.1 | 11.9 | 36.8 | 167.9 | 102.4 | 4.24 | 2.25 |
| | | 2.2 | 11.9 | 36.8 | 173.5 | 108.0 | 4.40 | 2.40 |
| 1% | Unscoured | 1.1 | 11.3 | 28.4 | 99.7 | 43.2 | 3.12 | 0.92 |
| | | 1.2 | 11.2 | 28.3 | 99.6 | 43.1 | 3.12 | 0.93 |
| | | 2.1 | 11.1 | 27.7 | 95.2 | 41.5 | 3.03 | 0.90 |
| | | 2.2 | 11.1 | 27.6 | 95.1 | 41.4 | 3.04 | 0.90 |
| | Scoured | 1.1 | 11.8 | 35.3 | 263.4 | 157.9 | 7.12 | 3.93 |
| | | 1.2 | 11.8 | 35.4 | 231.0 | 158.0 | 6.19 | 3.92 |
| | | 2.1 | 11.8 | 32.7 | 752.9 | 175.9 | 22.67 | 4.81 |
| | | 2.2 | 11.7 | 32.6 | 747.0 | 175.9 | 22.54 | 4.83 |

**Appendix 26. Particle size distribution (raw data) for pre-treated chickpea middling (1M) flours**

| Moisture conditioning level | Scour level | Dup | Chickpea flours (1M) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | d(0.1), µm | d(0.5), µm | d(0.9), µm | VWM, µm | Span | Uniformity |
| 0% | Unscoured | 1.1 | 11.9 | 39.1 | 106.4 | 50.2 | 2.42 | 0.76 |
| | | 1.2 | 11.9 | 39.1 | 106.5 | 50.3 | 2.42 | 0.76 |
| | | 2.1 | 11.7 | 35.7 | 99.4 | 46.8 | 2.46 | 0.76 |
| | | 2.2 | 11.6 | 35.5 | 99.4 | 46.7 | 2.47 | 0.77 |
| | Scoured | 1.1 | 11.5 | 37.3 | 104.1 | 48.8 | 2.48 | 0.78 |
| | | 1.2 | 11.4 | 37.1 | 104.4 | 48.8 | 2.50 | 0.79 |
| | | 2.1 | 11.3 | 34.3 | 97.7 | 45.6 | 2.52 | 0.78 |
| | | 2.2 | 11.2 | 34.2 | 97.4 | 45.4 | 2.52 | 0.78 |
| 0.5% | Unscoured | 1.1 | 12.1 | 41.5 | 108.6 | 51.9 | 2.33 | 0.74 |
| | | 1.2 | 12.0 | 41.5 | 108.6 | 51.9 | 2.33 | 0.74 |
| | | 2.1 | 12.2 | 40.9 | 109.7 | 52.1 | 2.39 | 0.76 |
| | | 2.2 | 12.1 | 40.9 | 109.5 | 52.0 | 2.38 | 0.75 |
| | Scoured | 1.1 | 11.4 | 37.4 | 103.5 | 48.6 | 2.46 | 0.77 |
| | | 1.2 | 11.6 | 37.6 | 103.7 | 48.7 | 2.45 | 0.77 |
| | | 2.1 | 11.6 | 34.8 | 98.4 | 46.1 | 2.49 | 0.77 |
| | | 2.2 | 11.6 | 34.5 | 97.8 | 45.7 | 2.50 | 0.78 |
| 1% | Unscoured | 1.1 | 11.8 | 39.9 | 108.0 | 51.0 | 2.41 | 0.76 |
| | | 1.2 | 11.7 | 39.9 | 108.3 | 51.0 | 2.42 | 0.77 |
| | | 2.1 | 12.0 | 39.9 | 107.0 | 50.8 | 2.38 | 0.75 |
| | | 2.2 | 12.0 | 39.9 | 106.6 | 50.6 | 2.37 | 0.75 |
| | Scoured | 1.1 | 11.7 | 35.5 | 98.9 | 46.5 | 2.46 | 0.77 |
| | | 1.2 | 11.6 | 35.5 | 98.9 | 46.5 | 2.46 | 0.77 |
| | | 2.1 | 11.9 | 36.4 | 99.1 | 47.0 | 2.39 | 0.75 |
| | | 2.2 | 11.8 | 36.4 | 99.0 | 47.0 | 2.40 | 0.75 |

Appendix 27. Particle size distribution (raw data) for pre-treated chickpea middling (2M+3M) flours

| Moisture conditioning level | Scour level | Dup | Chickpea flours (2M+3M) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | d(0.1), µm | d(0.5), µm | d(0.9), µm | VWM, µm | Span | Uniformity |
| 0% | Unscoured | 1.1 | 10.4 | 30.2 | 94.0 | 83.0 | 2.77 | 2.18 |
| | | 1.2 | 10.5 | 30.4 | 98.9 | 89.1 | 2.90 | 2.36 |
| | | 2.1 | 10.4 | 28.5 | 87.4 | 71.0 | 2.70 | 1.91 |
| | | 2.2 | 10.3 | 28.4 | 88.7 | 76.3 | 2.76 | 2.10 |
| | Scoured | 1.1 | 10.9 | 31.2 | 90.3 | 42.4 | 2.54 | 0.79 |
| | | 1.2 | 10.9 | 31.0 | 89.8 | 42.0 | 2.55 | 0.78 |
| | | 2.1 | 10.6 | 28.5 | 89.0 | 74.0 | 2.75 | 2.01 |
| | | 2.2 | 10.5 | 28.4 | 89.1 | 73.8 | 2.77 | 2.02 |
| 0.5% | Unscoured | 1.1 | 10.6 | 31.2 | 88.9 | 41.8 | 2.51 | 0.78 |
| | | 1.2 | 10.6 | 31.1 | 89.4 | 41.9 | 2.54 | 0.78 |
| | | 2.1 | 10.8 | 31.5 | 90.2 | 42.4 | 2.52 | 0.78 |
| | | 2.2 | 10.7 | 31.6 | 90.7 | 42.5 | 2.53 | 0.78 |
| | Scoured | 1.1 | 10.4 | 28.5 | 88.3 | 67.2 | 2.74 | 1.78 |
| | | 1.2 | 10.3 | 28.3 | 87.6 | 64.5 | 2.74 | 1.70 |
| | | 2.1 | 10.7 | 28.3 | 87.1 | 79.2 | 2.70 | 2.21 |
| | | 2.2 | 10.4 | 27.9 | 86.3 | 78.9 | 2.72 | 2.24 |
| 1% | Unscoured | 1.1 | 10.5 | 30.5 | 86.1 | 40.4 | 2.48 | 0.76 |
| | | 1.2 | 10.4 | 30.4 | 87.8 | 40.8 | 2.55 | 0.78 |
| | | 2.1 | 10.9 | 31.3 | 89.9 | 42.0 | 2.53 | 0.77 |
| | | 2.2 | 10.8 | 31.1 | 89.3 | 41.7 | 2.53 | 0.77 |
| | Scoured | 1.1 | 10.6 | 29.3 | 92.3 | 89.8 | 2.79 | 2.48 |
| | | 1.2 | 10.5 | 29.3 | 93.3 | 89.5 | 2.83 | 2.47 |
| | | 2.1 | 10.3 | 28.6 | 86.7 | 64.7 | 2.67 | 1.68 |
| | | 2.2 | 10.1 | 28.4 | 85.6 | 63.5 | 2.66 | 1.66 |