THE EFFECTS OF PREHARVEST TREATMENTS ON THE MILLING EFFICIENCY OF RED LENTIL

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ABSTRACT

Canada is currently the world leader in red lentil exports, a crop of significant economic importance to Western Canadian producers. It is important for the maintenance and growth of foreign markets that our growers are able to provide a consistent product. In the past few years, our exported red lentils have had variable quality, largely due variable weather conditions.

A study was conducted to determine the effect of various preharvest treatments on the milling quality of our current red lentil cultivars. These cultivars, listed in order of increasing seed size, were CDC Robin, CDC Imperial CL, CDC Rosetown, CDC Blaze, CDC Impact CL, CDC Rouleau, CDC Redberry and CDC Red Rider. Replicated plots of each variety were grown in the summers of 2005 and 2006 at Floral, SK and Rouleau, SK. These were chosen with the intent of maximizing environmental differential between locations, especially in terms of soil texture and moisture availability. All locations were laid out using a randomized complete block design with four replicates. Replicated plots of each cultivar were subjected to preharvest treatments of desiccation with Diquat or swathing at early, recommended and late stages of maturity. The milling quality of the harvested lentils was determined for all treatment and cultivar combinations.

Before preharvest treatments were applied, each plot was assigned a maturity rating based on a 1 (immature) – 9 (very mature) scale. Plants exhibiting pods with a 'buckskin' colour and texture on the bottom third of the plant were considered to be at early maturity and assigned a rating of 3. Similarly, when pods of buckskin colour and texture were found in the middle third of the plant, a maturity rating of 6 was assigned while a value of 9 would be assessed when

the entire plant had all brown, rattling pods except for a small portion of buckskin pods in the top third of the canopy.

Based on this 1-9 scale, a total of six different harvest treatments were carried out: swathing or chemical desiccation at early, intermediate or late stages of maturity. Swathed plots were cut using a gas-powered sickle-mower, then covered with bird mesh which was staked to the ground until harvest to prevent wind damage. Desiccated plots were sprayed with Reglone ™ (diquat) using a CO_2-pressurized backpack sprayer. They were left standing until harvest. Following mechanical harvest, seed from each plot was placed in mesh bags and forced-air-dried to approximately 13% moisture, then placed in a controlled storage chamber held at 5^{o}C.

Seed samples of two complete sets of replicated treatments were cleaned, then sized by passing them over round, then slotted sieves using the 'forty-shakes' method. The two most frequent seed diameter and thickness fractions from each plot were set aside for milling. Samples were hydrated to 12.5% moisture which is the ideal moisture content for high milling quality according to research conducted by Dr. Ning Wang at the Grain Research Laboratory in Winnipeg, MB. The samples were then milled using either a Satake or a Turkish table top pulse dehuller. Following milling, samples were passed through a Carter dockage tester (Simon-Day Ltd., Winnipeg, MB) to separate whole and split seeds from broken or damaged seeds and hull material. Each sample was assessed for: 1) milling efficiency (percent split and unsplit cotyledons recovered from the total sample); 2) football recovery (percent dehulled lentils with unsplit cotyledons); and 3) dehulling efficiency (percent of cotyledons with over 98% of the seed coat removed. Dehulling efficiency values were assessed using a DuPont Acurum^{TM} seed scanner (DuPont Canada, Toronto, ON).

Under favorable harvest conditions, preharvest treatments had no effect on milling efficiency, percent football recovery or dehulling efficiency. However, plots subjected to cool, wet harvest conditions produced lentil samples of highly variable milling quality. Early desiccation significantly reduced milling efficiency to below 70%, whereas early swathing resulted in milling efficiency above 85%. CDC Robin and CDC Imperial CL had the highest milling efficiencies. Similarly, cool wet harvest conditions caused percent football recovery to drop from approximately 80% to around 50%. Early swathing was the most effective for producing footballs, with smaller-seeded varieties producing the most. Cool, wet harvest caused dehulling efficiency to drop from the 97.3 – 99.9% range to 91.5 – 98.7%. Early desiccation had the most negative effect on dehulling efficiency, whereas early swathing produced the highest values. Under these conditions, smaller-seeded varieties had the lowest dehulling efficiencies.

The results of this study will be valuable for developing agronomic practices specific to red lentil and for improving the quality of Canada's exported product.

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1. INTRODUCTION

Lentil (*Lens culinaris* (L.) Medik) originated in Asia and is one of the world's oldest cultivated crops. It is a member of the Leguminosae family and performs best in cool temperate climates (Agriculture and Agri-Food Canada, 2008). In developing countries, lentil is valued for its protein content (approximately 22%) and is an important source of fibre, starch, Vitamin A, calcium, copper, iron, phosphorus and manganese in human diets (Saskatchewan Pulse Growers, 2008). Red cotyledon lentil accounts for approximately 80% of world lentil production.

Lentil production has become increasingly important to Canadian producers since the late 1960s when the crop was first grown in Saskatchewan. Although promoted as a cash crop at a time when wheat was an abundant, low-value crop, lentil acreage was slow to expand. This was largely because of production problems caused by poor weather conditions and undeveloped agronomic principles (Slinkard and Vandenberg, 1995). With time, however, lentil production gradually increased to its present level. Canada is now the second largest lentil producer, and the largest exporter of lentil in the world. In 2007, Canadian lentil production reached 616,000 MT produced on nearly 1.3 million acres (526,000 ha) (Agriculture and Agri-Food Canada, 2008). Canada contributed approximately 570,000 MT of lentil to the world market, with its largest importers including Colombia, Algeria, Mexico and India (Saskatchewan Pulse Growers, 2008).

Saskatchewan is Canada's prime producer of lentils, contributing 97% of the nation's crop in 2007, (Agriculture and Agri-Food Canada, 2008), with the majority of the provincial crop grown in the Regina-Moose Jaw and Swift Current-Rosetown regions (Saskatchewan Pulse Growers, 2008). Reasons for the success of this crop in Saskatchewan are numerous. Firstly, it allows for crop diversification and provides an excellent alternative to cereals in a crop rotation.

The inclusion of lentil in the annual crop rotation provides a break in many cereal crop disease cycles and allows for a transition from the traditional cereal herbicides, therefore aiding in weed control. Secondly, lentil is suited to the local climate because it is a cool season crop and has moderate resistance to drought and high temperature (Nielsen, 2001). Thirdly, when inoculated with the proper strain of *Rhizobium*, this legume crop is capable of fixing some of its own nitrogen. The result is a reduction in crop input costs to the producer (Saskatchewan Pulse Growers, 2008).

The majority of red lentil consumption is in the form of dehulled seed that is either split or left intact with the cotyledons still attached (football type). Dehulling is one of the most important steps in red lentil processing and is usually done to improve palatability and digestibility and to reduce cooking time by reducing tannins, antinutritional factors and barriers to water absorption associated with the seed coat (Singh and Singh, 1992; Deshpande et al., 1982; Kon et al., 1973). The methods and scale of seed coat removal vary from simple, home-based mortars and pestles (Dovlo et al., 1976) to large, industrial abrasive or attrition-type dehullers (DeMan et al., 1973; Reichert et al., 1984). The milling techniques used in this experiment were modeled after research conducted by Wang (2005) on the optimization of a laboratory dehulling protocol for lentil. Despite the importance of the dehulling process to the Canadian lentil industry, literature on dehulling quality is not readily available. Although the Canadian red lentil crop is either chemically desiccated or swathed prior to harvest, the effects of these preharvest techniques on milling quality have not been determined.

Thus, the objectives of this study were: i) to determine the effect of swathing and desiccation at three different stages of maturity on a range of quality characteristics of nine current red lentil varieties; ii) to determine milling recovery of whole and split seed in order to develop correlations with other quality parameters; and iii) to develop recommendations for swathing and desiccation protocols that promote optimal milling efficiency of red lentils in Saskatchewan.

This thesis will begin with a Literature Review, which provides background information from similar studies. Next, the Materials and Methods section presents an overview of how the project was set up and executed, followed by the Results and Discussion section in which the findings of this project are presented. In closing, there is a Summary and Conclusions section in which the final results will be presented, followed by a list of References and an Appendices section in which additional data recorded during this study are presented. .

2. LITERATURE REVIEW

Although literature pertaining to studies on lentil milling efficiency is scarce, results from studies on other crops are more abundant. The following chapter will explore the effects of various milling procedures, seed structural components and preharvest techniques of lentil and other crops and discuss them as they relate to this research project.

2.1 Dehulling of Pulse Seeds

Dehulling of pulses may be described as the removal of the testa or seed coat enveloping the cotyledons. Seed coat thickness varies depending on the crop. Cowpea (*Vigna unguiculata* (L.) Walp.) and green gram (*Vigna radiata* (L.) Wilczek) tend to have thin coats, comprising 5-10% of the seed weight, whereas the seed coat of lupin (*Lupinus abramsii* C.P. Sm.) may account for 28-30% of the grain (Kurien, 1984). While studying milling of desi chickpea (*Cicer arietinum* L.), Wood et al. (2007) noted a range of 13.8 - 17.4% seed coat for seeds sized with 6-7 mm round hole screens. The seed coat of lentil tends to be thinner than that of most other legumes (Hughes and Swanson, 1986). It normally ranges between 6-7% of the seed weight (Erskine et al., 1991; Singh et al., 1968), with a mean of 7.3% (Wang, 2005). Usually a gum (such as galactomannan) or lignin layer binds the cotyledons to the hull (Wood et al., 2007; Kurien, 1981 and 1984; Siegel and Fawcett, 1976; Kurien, 1977). Among pulse species, variability in the depth and tackiness of this layer results in different binding strength between the seed coat and the cotyledons (Muller, 1967; Zimmerman et al., 1967). Reports on the effects of seed coat thickness on seed coat durability are contradictory. Ehiwe (1985) cited findings by Kannenberg and Allard (1964) and Atkin (1959) stating that in field pea (*Pisum sativum* L.), thicker seed coats were less susceptible to damage. Conversely, a study by Dorrell (1968) on lentil found no relationship between seed coat thickness and breakage. Moreover, Wood et al. (2007) noted the absence of a consistent correlation between seed coat content and dehulling efficiency and splitting yield when investivating milling efficiency in Desi chickpea.

2.2 Milling Efficiency

Seeds of pulses cook more quickly when the seed coat is removed. Traditional methods of milling or mechanical removal of the seed coat became established in many pulse producing regions of the world, often using a simple mortar and pestle system. Milling parameters for pulses may be defined in a variety of ways. Ehiwe and Reichert (1987) described dehulling efficiency as the percent of hull removed from the cotyledon and the yield of the dehulled grain obtained from this process. Wang (2005) defined milling efficiency as the sum of percent whole dehulled seeds and split dehulled seeds. Regardless of terminology, milling recovery influences economics because the by-products of milling (seed coat, embryo, broken pieces and flour) are of comparatively low value.

Although little precedence exists regarding lentil milling efficiency, commercial market experience suggests that efficiency should be more than 80% to be economical (Wang, 2005). Literature on other pulse crops suggests that variability in milling efficiency exists both within and among species. Wood et al. (2007) found dhal (dehulled pulse seed) recovery in commercial chickpea mills in the Indian subcontinent to average 80%. In a study on seed coat durability in field pea, Reichert and Ehiwe (1987) reported significant differences among cultivars. Similarly, Ehiwe and Reichert (1987) found that dehulling characteristics differed significantly among 11 cowpea, 23 pigeon pea (*Cajanus cajan* (L.) Millsp.) and 24 green gram cultivars. Similarly, Wood et al. (2007) noted significant differences in milling efficiency in a study of six commercial Desi chickpea varieties. Ehiwe and Reichert (1987) further noted that legumes exhibiting hard seeds with loosely adhering seed coats were most desirable for milling. Research by Reichert et al. (1984) showed that marked differences existed within and among soybean (*Glycine max* (L.) Merr.), faba bean (*Vicia faba* (L.), field pea, cowpea and green gram in terms of milling efficiency. This agrees with the findings of Ramakrishnaiah and Kurien (1983) regarding cowpea and pigeon pea cultivars, which suggested that differences in dehulling efficiency between these two crops may vary by as much as a factor of four. While studying dehulling in field pea, Black et al. (1998) noted dehulling efficiency to be positively correlated with seed size and negatively correlated with both seed breakage and hull content. They did not observe a correlation between dehulling efficiency and grain density.

In general, the major factors affecting dehulling of pulses are seed diameter and thickness (Ehiwe and Reichert, 1987; Singh et al., 1992). Larger-seeded lentils tend to have lower percentage loss during decortication because the proportion of hull to seed mass is lower. For example, Erskine et al. (1985) found that seeds with a mean diameter of 4 mm lost an average of 8.19% of their weight during decortication, whereas losses from 3 mm seeds averaged 9.80%.

2.3 Methods of Dehulling Lentil

Numerous methods of varying sophistication exist for dehulling lentil. In some cases, the hull is removed in small commercial or home-scale operations by grinding in a hand operated stone or wooden mill. The hull is then removed by winnowing (Kurien, 1984). Commercial processes are much more sophisticated, involving power operated grinders and aspirators. Although all dehulling systems operate on the same basic principle of friction between the seed and a surface or another seed, a variety of horizontal and vertical shaft configurations exist. Examples of mill designs include attrition-type dehullers (DeMan et al., 1973), roller mills (Singh and Sokhansanj, 1984) or abrasive-type dehullers such as the tangential abrasive dehulling device (TADD) (Reichert et al., 1984) which is intended for laboratory analysis. Depending on mill configuration, efficiency can be optimized in these systems by adjusting factors such as stone speed, diameter, texture and clearance, as well as the time each batch remains in the mill. Seed moisture content is another important factor affecting milling efficiency. Wang (2005) observed that lentil seed should be hydrated to 12.5% for optimum milling.

2.4 Influence of the Chemical Composition of the Seed coat

Much genetic and phenotypic variability exists in the seed coat colour of lentil. The seed coat may range in colour from black and solid grey to brown, tan or green, and may also exhibit a variety of patterns (Vandenberg and Slinkard, 1990). The seed coat is structurally important for the protection of the cotyledons and embryo axis from damage caused by insects, weathering, harvest and handling (McEwen et al., 1974). Observations made under field conditions suggest that seed coat colour may affect the weathering ability of lentil seed (Vandenberg, personal communication), and that grey-coloured seed coats tend to withstand unfavorable wet weather prior to harvest better than brown seed coats. This has been observed in other crops. Beninger et al. (1998) found that in the case of common bean (*Phaseolus vulgaris* L.), seed coat colour was associated with the physical and chemical characteristics of the seed. Siddique and Goodwin (1980) observed that snap bean varieties with coloured seed tended to tolerate a wider range of maturation temperatures than did white-seeded varieties. Swanson et al. (1985) reported that differences in the cotyledon and seed coat microstructure among white-seeded and black-seeded beans were related to a more rapid uptake of water by white-seeded beans. Agbo et al. (1986, 1987) demonstrated that the presence of seed coat colour resulted in demonstratable differences in seed coat pallisade cell layer thickness and water imbibition among two bean lines. While studying lima bean (*Phaseolus lunatus* L.), Kannenberg and Allard (1964) found white-seeded lima bean to be agronomicaly inferior to coloured-seeded varieties. They also observed that white seed had thinner seed coats with broader and shorter cells in the palisade layer, resulting in fewer cells per unit area as well as a tendency to exchange moisture more rapidly and to sustain physical damage more easily.

Seed coat strength may also be affected by its fibre content. Kannenberg and Allard (1964) found that for lima bean, lignin comprised 15% of the total seed coat weight of coloured seed but only 1% in white seed. Because of the importance of lignin as a structural and protective component of the seed coat, they further postulated that the lack, or reduced level, of lignin in white seeds leads both directly and indirectly to increased susceptibility to seed damage. To support the notion that lignin may be an important factor related to seed coat durability, Dorrell (1968) also reported an inverse relationship between seed coat breakage and crude fibre content. However, work done by Reichert and Ehiwe (1987) on seed coat durability in field pea refutes the importance of lignin for resistance to damage. In fact, they found no significant relationship between seed coat breakage and lignin, neutral detergent fibre or hemicellulose content. Moise et al. (2005) noted that in red clover (*Trifolium pratense* L.), medium-sized vacuoles located in the cytoplasm of the microsclereids contained tannins which contributed to coat hardening. A study by Bate-Smith (1958) quoted by Stanley (1992) on the role of tannins in hardening the seed coat of common bean yielded similar results. Other studies have shown that seed coat strength is aided by cell walls in the palisade layer and by hourglass cells (Algan and Buyukkartal, 2000; Wang and Grusak, 2005).

Research by Ehiwe (1985) suggested that properties such as chemical composition, tightness of seed coat/cotyledon adhesion and differences in architectural features might affect seed coat durability in pulses. Ehiwe (1985) went on to cite research from other sources suggesting that seed coat durability was directly proportional to the presence of Mg and Ca (Dickson et al., 1973) and pectic substances (Dorrell 1968). Bate-Smith (1958) noted a connection between phenolic substances and textural quality in common bean seed. It was further observed that lignin was not the only material responsible for the incrustation and toughening of plant cell walls. According to this study, condensed tannins, formed by polymerized leucoanthocyanins, are found in the testa and contribute to seed coat durability. By extension, such logic can be applied to the ability of lentil seed to withstand adverse weather conditions and milling processes and its relationship to hull colour as dictated by the chemistry of lignins, tannins and other pigmented compounds.

2.5 Influence of Seed Size on Milling

When studying red lentil milling, Erskine et al. (1991) found significant differences in dehulling efficiency among large and small seeds. In their study, larger seeds (4-5 mm) milled less efficiently (80.1% yield) than smaller (4 mm) seeds (82.0% yield). This difference in efficiency resulted from a higher level of broken seeds and split seeds with the fraction of larger seeds. They also noted that large seeds yielded higher percentages of split seeds following milling. In an earlier study, Erskine et al. (1985) found that within a given range of seed diameters, larger seeds tended to have lower percentage loss during decortication.

2.6 Interaction of Genetics and the Environment on Milling Efficiency

The effects of environment and genotype on the milling characteristics of some grain legume seeds have been reported. While examining the performance of Desi chickpea in Australia, Wood et al. (2007) reported that environmental stresses that affect yield have no apparent influence on the efficiency of seed coat removal. This contradicts the results of some studies of other grain legumes. Ehiwe (1985) stated that variations in field pea seed characteristics are controlled by both hereditary and environmental conditions. He elaborated, stating that the most important environmental factors include temperature at seed maturation and moisture content during maturation and harvest. When studying seed coat breakage in field pea, Reichert and Ehiwe (1987) reported significant differences due to both cultivar and environment. They found, as also reported by Thomson (1979), that hot or dry fall conditions in the Canadian prairies produced peas with reduced seed coat durability. Similarly, Siddique and Goodwin (1980) found that high temperature during seed maturation increased susceptibility to mechanical damage in snap bean seeds. They reasoned that high temperature leading to rapid desiccation of pods and seeds might be to blame for this. It may, therefore, stand to reason that such conditions may in turn lead to favorable milling qualities in lentil. However, if the seed is brittle (caused by low temperature, (Ehiwe, 1985)) it may produce more fines during dehulling. In a study on common bean seed, Stanley (1992) explained that storage of seed at high temperate and humidity leads to seed coat hardening. Studies by Erskine et al. (1985) and Williams and Singh (1987) revealed that dehulling efficiency of pulses is a varietal characteristic which may be strongly influenced by growing season and location. Later research by Erskine et al. (1991) contradicted this result. When they compared dehulling efficiencies of lentil grown at three locations in Lebanon and Syria, they found location to be of only minor importance and variations in genotype to be of greater importance. Black et al. (1998) supported these findings when studying field pea. Their research noted large variability in dehulling quality when 23 genotypes were compared.

2.7 Influence of Seed Moisture Content on Milling Efficiency

Optimum moisture content is important in the handling, storage and processing of red lentil, as it is for other grains. Moisture content affects the test weight and appearance of the grain. Seed that was too dry was more prone to mechanical damage and losses during handling and milling of Navy bean (*Phaseolus vulgaris* L.) (Barriga, 1961). Conversely, too much equilibrium moisture in lentil seeds led to spoilage during storage and reduced milling values during processing (Erskine et al. 1991). When studying wheat grinding protocols, Kosmolak (1978) observed differences in the grinding time of various wheat cultivars due to equilibrium moisture content. It was noted that at moisture contents higher than 10%, the amount of time required for grinding increased.

The effect of moisture content on milling values has been studied for red lentil. The optimal moisture content for storage of red lentil is 13% wet basis (wb) (Canadian Grain Commission, 2006). The maximum recommended moisture content for maximizing dehulling efficiency (DE), defined as the sum of percent dehulled split seed and percent dehulled whole seed, as well as minimizing seed coat adherence (SCA) is 12.5% (Wang 2005). Optimal hydration levels may differ among legume species. For example, Wood et al. (2007) equilibrated their Desi chickpea samples to 10% equilibrium moisture prior to milling. In a study on red lentil milling, Erskine et al. (1991) found that dehulling efficiency was highest with seed moisture content of approximately 8% followed by immersion in water for 1 minute compared to 5, 10 and 30 minute immersion times. They stated that the key to productive lentil processing lies in understanding the relationship between seed moisture content and dehulling efficiency.

2.8 Dehulling Methods of Other Saskatchewan Crops

Legumes are not the only crops dehulled during processing. Removing the hull from oat increases the protein, lipid and β-glucan values and reduces the fibre content of a sample, thus increasing the nutritional value of the groat Doehlert et al. (2001[*]). While researching optimal oat dehulling techniques, Doehlert et al. (2001[**]) found that seed equilibrium moisture affected oat dehulling efficiency. Their research showed that oat dehulling efficiency decreased as seed moisture increased from 7.5 to 15%. Similarly, Bhatty (1999) stated that barley is often dehulled prior to being used for human consumption.

2.9 Harvesting Lentil

Lentil has an indeterminate growth habit. This usually makes it necessary for Canadian lentil growers to apply a preharvest treatment to their lentil crops (swathing or chemical desiccation) in order to force maturity, as a way to maximize yield and quality. Despite the popularity of forcing maturity prior to mechanical harvest in Canada, almost no literature exists documenting the effects of treatment method and timing on yield and seed quality of lentil, let alone the effects on milling parameters. In almost all other lentil producing countries, the crop is harvested prior to the onset of hot and dry summer conditions.

2.9.1 Swathing

Some lentil producers prefer swathing as a method of forcing crop maturity prior to harvest. Swathing, also know as windrowing, is accomplished by a self-propelled or tractor-powered machine equipped with an oscillating cutter bar that severs the plants near ground level. A spinning reel directs cut material back onto conveyors, or canvasses, that drop the product into a swath as the implement moves across the field. Swathing is commonly practiced with a variety of other crops. For example, Cenkowski et al. (1989) stated that in western Canada, canola (*Brassica napus* L.) is commonly swathed and allowed to dry naturally before threshing and binning. Similarly, Gubbels et al. (1993) reported that flax (*Linum usitatissimum* L.) drying can be accelerated by swathing and May et al. (2005) found that oat yield and quality may be optimized by properly managing of timing of swathing. Potential risks associated with swathing include yield and quality losses due to unfavorable weather (wet and or windy) which can prolong drying or blow swaths around, making them impossible to harvest. Swathed lentil crops are also slower to dry than standing material. This may increase the risk of water damage in the form of discolouration and sprouting of the seeds. Another aversion to swathing is the possibility of shattering caused by the mechanical movement of the plants. This may be avoided by swathing while the plants are less mature or when humidity levels are high (Saskatchewan Pulse Growers, 2008). Swathing generally poses a greater risk to yield and quality in comparison to desiccation, based on experience with green lentil crops.

2.9.2 Desiccation

The most common preharvest treatment for Canadian lentil crops is chemically induced desiccation with diquat (Reglone®). Diquat is a nonselective plant growth regulating chemical registered as a group 22 herbicide for agricultural use in Canada. Diquat is registered for use in a variety of crops including canola, potato and pulses and is a preferred desiccant because of the speed at which it causes plant material and seeds to dry down to harvestable moisture levels

(Saskatchewan Ministry of Agriculture, 2007). It is routinely used on lentil crops and is typically applied when one-third of the pods have turned brown and rattle when shaken (Saskatchewan Pulse Growers, 2008). Liquid desiccants are applied to crops with a field sprayer. Field sprayers have a variety of configurations but are essentially a self-propelled or tractor powered implement consisting of a tank, which contains the liquid herbicide solution or suspension, and a pumping system that forces the chemical through hoses to evenly spaced nozzles that apply the desiccant to the crop in a uniform mist. The crop is left then standing until seed moisture is sufficiently reduced to allow for mechanical harvest.

As with lentil, chemical desiccants are used on other grain crops prior to harvest for the purposes of reducing seed moisture, preserving seed quality and yield, and the control of weeds that interfere with mechanical harvest and storage (Baur et al., 1977; Bovey et al., 1999; Yenish and Young, 2000). Crops, including wheat (*Triticum aestivum* L.), flax, field pea, chickpea and common bean are routinely desiccated in Canada (Bovey and McCarty, 1965; Yenish and Young, 2000; Gubbels et al., 1993). Gubbels et al. (1993) found that flax yields could be improved through advancing maturity with applications of diquat (Reglone®), glufosinate-ammonium (Liberty®) or glyphosate (Roundup®). Timing of desiccation can be important to seed quality following harvest, depending on the crop and its end use. When studying the effects of glyphosate on seed and seedling quality of spring wheat, Yenish and Young (2000) found that the stage of development of wheat during glyphosate application is more important to seed and seedling quality than the herbicide rate used. Baur et al. (1977) found that glyphosate timing in sorghum is important. Their research showed that seed damage occurs when glyphosate is applied 25 days after flowering. However, damage decreases as time of treatment increases after flowering. Bovey and McCarty (1965) found diquat to be effective at reducing sorghum grain moisture when compared to flaming and swathing treatments.

Aversions associated with desiccation include the risks associated with handling toxic chemicals and the expense involved with purchasing and applying the chemical. However, these drawbacks are usually offset by the benefits associated with quick crop and weed dry down, and reduced risk of seed quality loss during wet weather.

2.10 Summary

Seed coat removal is a vital step in lentil processing. Although it is known that numerous morphological, mechanical and environmental factors affect the efficiency of this process, little research has been conducted to explore the interactions between these variables and lentil milling efficiency. Of particular importance to the Canadian red lentil industry are the interactions between preharvest treatment method and the efficiency of the milling process in terms of recovered product and its visual appearance following seed coat removal. More research is required to understand the effects of these variables on lentil milling.

3. MATERIALS AND METHODS

The following chapter will explain the procedures used to carry out this experiment. It will provide an overview of field and laboratory terminology and procedures in addition to listing and discussing the lentil varieties studied, growing locations and preharvest staging procedures utilized throughout this experiment.

3.1 Overview of Field and Laboratory Terminology

A series of experiments were conducted to determine the effects of various preharvest agronomic techniques on the milling quality of red lentil. Six preharvest treatments were applied. These involved either swathing (S) or chemically desiccating (D) plots at three different stages of plant maturity; early (E), recommended (R) and late (L). Preharvest treatments will, therefore, be referred to as SE, SR, SL, DE, DR and DL for plots swathed or desiccated at early, recommended or late stages of maturity, respectively.

Laboratory investigation involved analyzing milled lentil seed samples for various quality parameters. Percent milling recovery (%MR) indicates the proportion of the sample following dockage removal and milling that is suitable for sale (footballs and split cotyledons) excluding the byproducts of milling such as testas, broken pieces and flour. Percent football recovery (% FR) is a common industry term that refers to the proportion of the total recovered sample (split and whole) after dehulling that consists of seed with intact cotyledons. Percent dehulling efficiency (%DE) refers to the proportion of the milled sample, composed of footballs and split cotyledons, that has two percent or less seed coat adherence following milling. The results of this project will define milling efficiency parameters in terms of %MR, %FR and %DE. A flow chart outlining the handling of lentil samples from harvest through milling and quality analysis is shown in Figure 3.1.

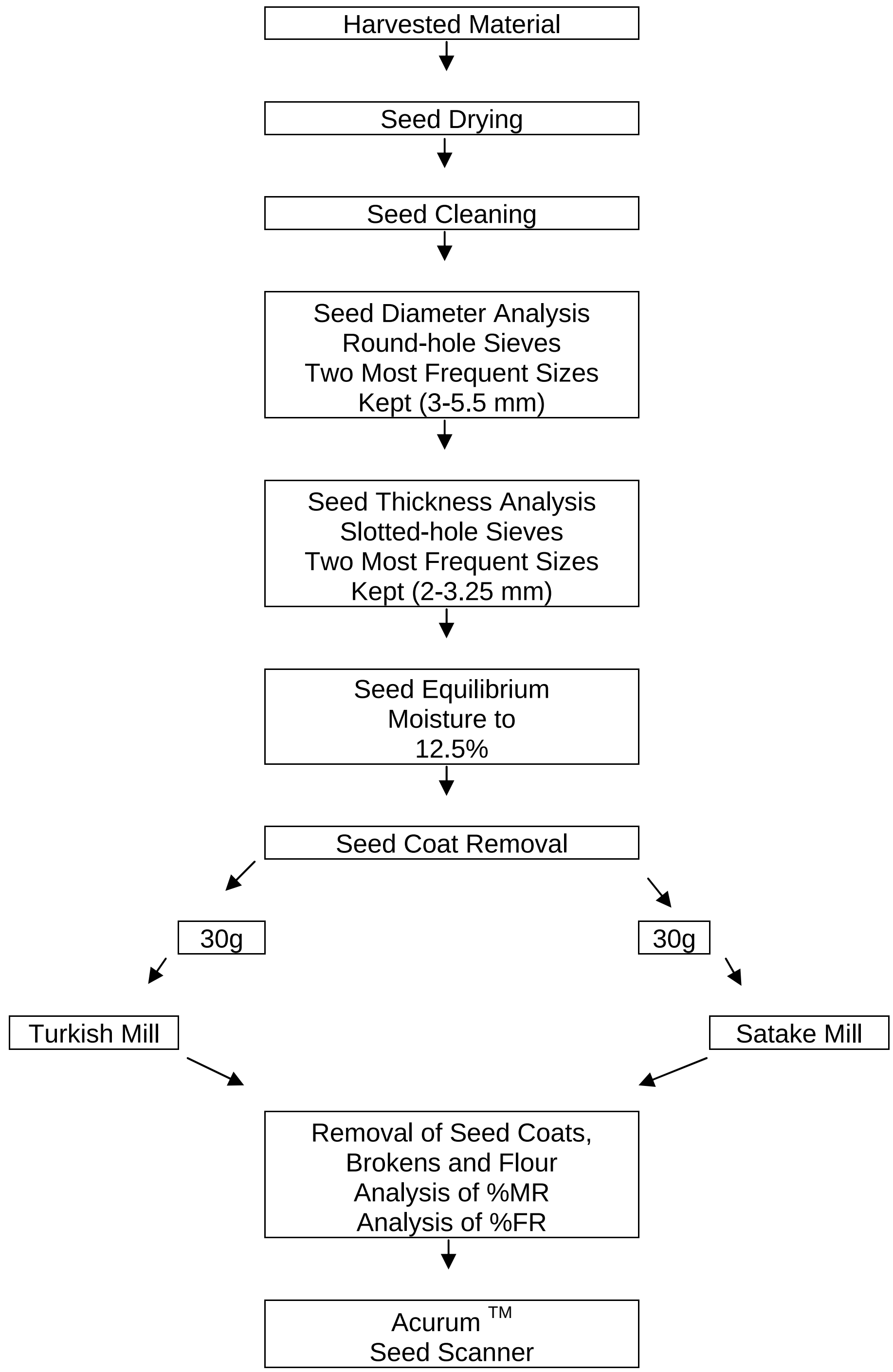

Figure 3.1 Flow chart of laboratory procedures.

3.2 Genotypes and Field Environments

The objective of this experiment was to determine the effect of six preharvest techniques on the milling efficiency of red lentil. Milling characteristics were described in terms of %FR, %DE and %MR.

Eight cultivars of commercially available red lentil were grown in the field in 2005 and 2006 (Table 3.1). The experiment was grown as a randomized complete block design with a plot size of 1.2 m by 3.7 m. Six site-years, each with four replicates, were seeded under dryland conditions at three locations in 2005 and 2006: one on Sutherland research land east of Saskatoon, the second on the Saskatchewan Pulse Growers (SPG) research farm near Floral, SK, and the third on research land near Rouleau, SK (Table 3.2). Data from the Sutherland site were not used for milling evaluation for various technical reasons. Because of this, neither 2005 nor 2006 data were used from this site. Thus, four site-years were used for milling evaluation. Growing conditions for the Rouleau and Floral locations in 2005 and 2006 were normal with average temperature and rainfall typical to each location (Appendix VII and IX, respectively). Harvest conditions were warm and dry for Rouleau in 2005 and 2006, and also for Floral in 2006. However, Floral in 2005 received a prolonged period of cool wet weather during the harvest period, causing delayed field treatments and harvest. This prolonged period of wet conditions caused severe weathering of the seed from plots at this location. As a result, most samples harvested from Floral in 2005 had seeds with shriveled seed coats. Seed infection by white mold (*Sclerotinia sclerotiorum*) and grey mould (*Botrytis cinerea*) were common at this location.

Table 3.1 Lentil cultivars grown in the field in 2005 and 2006 for the red lentil milling efficiency experiment.

Cultivar	Seed Coat Colour	1000 Seed Weight (g)
CDC Robin	Brown	28.0
CDC Imperial	Grey-Brown	34.0
CDC Rosetown	Grey	33.1
CDC Blaze	Grey	39.8
CDC Impact	Grey	40.0
CDC Rouleau	Grey	35.9
CDC Redberry	Grey	41.0
CDC Red Rider	Grey	52.0

Table 3.2 Locations, elevation and soil type for field experiments, 2005 and 2006.

Location	Latitude & Longitude	Elevation	Soil Type	Soil Texture
Rouleau	50° 17'N 105° 8'W	579.1 m	Dark Brown	Heavy Clay
Sutherland	52° 8'N 106° 31'W	518.2 m	Dark Brown	Clay
Floral	52° 3'N 106° 27'W	518.2 m	Dark Brown	Loam

3.3 Preharvest Treatments and Timing

Plots sized 1.2 m x 3.7 m with 30-cm row spacings were seeded at recommended seeding rates between May 4 and May 25, and harvested between August 12 and October 3, depending on weather conditions (Table 3.3). To ensure proper preharvest treatment timing, plot maturity was assessed visually and texturally on a scale of 1-9 (Table 3.4). As plots matured, their maturity rating advanced to higher values. A maturity rating of 1 represented plants still actively flowering, with green, immature pods forming at the bottom of the canopy. Early treatments were applied at approximately stage 3 maturity. At this stage, the bottom third of the plant contained pods with a colour and texture resembling buckskin. When squeezed, seed cotyledons would remain intact but would separate easily from the seed coat.

Recommended treatment timings occurred at approximately stage 6 maturity. By this point, pods in the bottom third of canopy were browning and rattled when shaken, whereas the ‘buckskin’ pods had progressed to the middle third of the canopy.

Late treatments were applied when plots reached stage 8-9 maturity. At this point, nearly all pods were brown and rattled when shaken. No ‘buckskin’ pods were visible, even at the top of the canopy because the plants were in the final stages of maturity. In most instances, swathing and desiccation treatments were applied on the same day. However, in a few cases, windy weather conditions made this impossible and desiccation treatments were delayed until the next day. Although preharvest treatment timings were tentatively scheduled at two-week intervals, extremes in weather sometimes advanced or delayed plant maturity and application dates.

Table 3.3 Seeding, treatment and harvest dates for both sites, 2005 and 2006*.

Location	Year	Treatment Dates							
		Seeding	SE	SR	SL	DE	DR	DL	Harvest
Rouleau	2005	May 5	Aug 11	Aug 19	Sep 2	Aug 15	Aug 22	Sep 2	Sep 7
	2006	May 4	Aug 1	Aug 4	Aug 7	Aug 1	Aug 4	Aug 7	Aug 12
Floral	2005	May 2	Aug 5	Sep 17	Sep 22	Aug 5	Sep 17	Sep 22	Oct 3
	2006	May 17	Aug 14	Aug 21	Aug 30	Aug 14	Aug 22	Aug 30	Sep 8

* SE, SR, SL, DE, DR and DL represent preharvest treatments of swathing (S) or desiccation (D) at early (E), recommended (R) and late (L) stages of maturity, respectively.

Table 3.4 Treatment timing and maturity rating stage for preharvest swathing and desiccation applications.

Treatment Timing	Maturity Rating
Early	1
	2
	3
Recommended	4
	5
	6
Late	7
	8
	9

Shading indicates maturity stage of each treatment timing. Each stage lasts approximately 2-3 days.

3.3.1 Harvest Methods

Each plot was periodically assessed and rated for maturity to determine the best time to apply preharvest treatments. Swathed plots were cut near ground level with a gas-powered sickle mower and raked into windrows to dry naturally. To prevent windrows from blowing away, each plot was covered with plastic mesh with 2-cm squares, which was staked to the ground where it remained until harvest. Desiccated plots were sprayed with a 240 g/L formulation of diquat solution at a rate of 0.9 L/acre diquat suspended in approximately 91 L/acre of water (Saskatchewan Crop Protection Guide, 2007). Chemical was applied with a

CO_2-pressurized backpack sprayer with a hand-boom capable of covering the entire width of a plot in one pass. Desiccated plots were left standing until harvest.

All plots for each location were harvested at the same time, regardless of treatment timing. Harvested seed was placed in mesh bags and set on artificial seed dryers overnight to ensure safe storage until seed cleaning.

3.4 Postharvest Seed Handling

Lentil seed size affects dehulling characteristics (Wang, 2005). Because of this, seed harvested from each plot as cleaned, then passed through round-hole and slotted hand sieves to obtain samples with specific seed diameter and seed thickness. All sieving procedures involving the round-hole and slotted sieves were carried out as specified by the "forty shakes screening method". This involves shaking the pan 40 times back and forth in the direction parallel to the slots (Pulse Australia, 2004). Seed samples were first placed on stacked round-hole sieves with aperatures ranging in size from approximately 3.0 mm to 5.5 mm. The weight of the seed retained on each of the sieves was weighed and recorded. Seed from the two sieves that retained the most seed by weight was kept aside and passed through stacked, slotted sieves with aperatures ranging in size from 2.0 mm to 3.5 mm. Again, the weight of the seed retained on each of the sieves was determined. Seed from the two slotted sieves retaining the most seed by weight was kept aside for milling analysis. The two most abundant fractions following sieving varied based on the genotype being screened (Table 3.5).

Table 3.5 Average diameter and thickness of lentil varieties used in the red lentil milling experiment.

	Hole Dimension			
	Millimeters		Inches	
Cultivar	Round	Slotted	Round	Slotted
CDC Robin	4.0-4.5	2.4-2.6	10/64 -11/64	6/64 - 6.5/64
CDC Imperial	4.0-4.5	2.4-2.6	10/64 -11/64	6/64 - 6.5/64
CDC Rosetown	4.5-4.75	2.2-2.4	11/64 - 12/64	5.5/64 -6/64
CDC Blaze	4.75-5.0	2.4-2.6	12/64 - 13/64	6/64 - 6.5/64
CDC Impact	4.75-5.0	2.4-2.6	12/64 - 13/64	6/64 - 6.5/64
CDC Rouleau	4.75-5.0	2.4-2.6	12/64 - 13/64	6/64 - 6.5/64
CDC Redberry	4.75-5.0	2.6-2.8	12/64 - 13/64	6/64 - 6.5/64
CDC Red Rider	4.75-5.0	2.6-2.8	12/64 - 13/64	6/64 - 6.5/64

3.5 Sample Moisture Equilibration

Seed moisture content affects milling characteristics. Therefore, prior to milling, all samples were equilibrated to 12.5% moisture (Wang, 2005). This was accomplished by placing samples in mesh bags and storing them in a controlled-environment chamber designed for this purpose. Desired seed moisture balance was reached and maintained in approximately 5 days at a relative humidity setting of 64% and a temperature of 21°C.

3.6 Seed Coat Removal

Thirty-gram samples of lentil were passed through each of the two table-top laboratory mills used in this experiment. The 'Turkish' mill is a less technical, medium-grit, five-stone, vertical-shaft model manufactured privately in Mersin, Turkey. The instrument was modified by adding a chute at the bottom to allow the free flow of milled material from the chamber enclosing the mill stones. No adjustments to speed or clearance were possible. Because of this, material was gravity-fed through the system and could not be contained within the mill for a predetermined length of time. Samples were poured into a hopper at the top of the apparatus. As they passed between the abrasive wheels and the perforated chamber walls, the seed coat was removed. All material, including intact seed, testa and broken pieces, flowed out of the modified cone at the base of the mill and was collected in a sealed plastic bag.

The Satake grain testing mill (TM05C, Satake Engineering Co., Hiroshima, Japan) is a more technical, medium-grit, horizontal-stone model. This allowed for the application of more specific settings. The machine was fitted with a 36-mesh abrasive wheel rotating at 1,100 rpm. Material was milled for a set time of 38 seconds as specified by research conducted by Wang (2005). With this mill, lentil samples were milled for 38 seconds. The milled material and by-product were then collected in a sealed plastic bag.

3.7 Separation of Milled Lentil Samples

Following milling, each sample was separated into whole seeds, split seeds, broken seeds and hulls using a Carter dockage tester (Simon-Day Ltd., Winnipeg, MB). The dockage separator was fitted with a 5/64" slotted sieve and a 9/64" round hole sieve, and was operated with the air setting at maximum and the feed at minimum. The bulk samples were weighed prior to separation and each fraction was weighed separately afterwards. Following weighing, hulls and broken pieces discarded and split and whole seeds were kept aside for %DE analysis.

3.8 Dehulling Efficiency Analysis

After removal, the spit cotyledon and whole seed fractions from each sample were each analyzed separately for seed coat adherence using a DuPont Acurum™ seed scanner (DuPont Canada, Toronto, ON). The Acurum™ scanner images and counts every seed that passes through it. It was programmed to differentiate between milled and unmilled seeds based on the colour variance between seed coats and cotyledons. The software designated any seed with 2% or more seed coat adherence as 'unmilled'. Dehulling efficiency percentages were then determined by dividing the mass of unmilled seeds by the total mass of seeds passed through the scanner. Equations 3.2, 3.2 and 3.3 were used to calculate %MR, %FR and %DE, respectively.

$$\%MR = \left[\frac{\text{Mass of Milled Seeds}}{\text{Total Mass of Sample}}\right] X\,100 \qquad \text{………. } \mathbf{3.1}$$

$$\%MR = \left[\frac{\text{Mass of Footballs}}{\text{Total Mass of Sample}}\right] X\,100 \qquad \text{………. } \mathbf{3.2}$$

$$\%\,DE = 1 - \left[\frac{\text{Mass of Undehulled Seeds}}{\text{Total Mass of Sample}}\right] X\,100 \qquad \text{………. } \mathbf{3.3}$$

4. RESULTS AND DISCUSSION

The following chapter will outline and discuss the findings of this experiment. It will begin by describing the general trends observed in the results of this project and go on to discuss the effects that various lentil varieties, preharvest treatments, growing conditions and milling procedures had on the milling characteristics of red lentil in this study. Six preharvest treatments were applied. These involved either swathing (S) or chemically desiccating (D) plots at three different stages of plant maturity; early (E), recommended (R) and late (L). Preharvest treatments will, therefore, be referred to as SE, SR, SL, DE, DR and DL for plots swathed or desiccated at early, recommended or late stages of maturity, respectively.

4.1 Perspectives on Lentil Quality

Factors affecting the economics of the red lentil industry differ based on whether they are being viewed from the perspective of the grower or the processor. For the producer, the most important factors are yield, quality and price. From the processor's perspective, the most important economic drivers of red lentil processing are cost and the specific milling characteristics, %MR, %FR and %DE. Each of these factors will be discussed in the following sections in the context of the results of this research project.

4.1.1 General Observations

Two environmental trends occurred at harvest across the four sites used for these experiments. Lentil samples from Floral in 2005 were exposed to approximately one month of cool wet weather following preharvest treatment (PHT) and conditions leading up to this were humid, which delayed maturity. These conditions resulted in lentil samples with poor milling qualities. The other three sites, Floral in 2006 and Rouleau in 2005 and 2006, were exposed to warm dry weather leading up to and including harvest. Samples from these sites were generally of high quality.

4.1.2 Effects of Cultivar and Preharvest Treatment on Seed Yield

The effects of preharvest treatments (PHT) on seed yield are reported in Table 4.1. Coefficients of variation were in the range of 18-22% (Appendix III, ANOVA Table). These values are about 10% higher than would typically be expected in yield trials and reflect shattering losses, pod loss and the range in yield caused by the wide range of PHTs. In both years, yield was greater at Floral than at Rouleau, mainly because of higher rainfall and stored soil moisture. Yield values across the range of cultivars were as expected. The two oldest cultivars, CDC Robin and CDC Blaze, and their corresponding back-cross derived cultivars, CDC Imperial and CDC Impact, respectively, tended to fall in the lower half of the yield range. The two newest cultivars, CDC Rosetown and CDC Red Rider were usually in the upper half of the yield range. CDC Redberry tended to yield below the average in the drier sites which is consistent with long term records for this cultivar (Saskatchewan Ministry of Agriculture, 2008). To summarize, seed yield data were consistent with long term records and were not considered to play an important role in milling results.

The effects of PHT on yield varied across environments. At Floral 2005, DE resulted in significantly lower yield than all other treatments. SR and SL treatments yielded lower than their corresponding desiccation treatments. Although all three swathing treatments were similar, as were DR and DL treatments, the highest yields corresponded with SE and DR treatments.

At Floral in 2006, the highest yields were obtained from SR, DE and DL treatments. Yields from these plots were significantly higher than for other treatments, with DE yielding the highest.

At Rouleau in 2005, SE was the lowest yielding treatment, and together with SR, yielded significantly lower than all desiccation treatments. SL was the highest yielding swathing treatment, whereas yields for DE averaged the highest overall. Conversely, results from Rouleau in 2006 showed SE treatments yielding the highest, and SL the lowest, among swathing treatments. Plots receiving the DR treatment yielded significantly higher than the other desiccation treatments, but were similar to the SE treatments.

Results showed that the effects of PHT on yield were inconsistent across growing environments, particularly when conditions were hot and dry during harvest. This might be expected because of the environmental differences between the sites in terms of moisture and sunlight, and may result in part from the difficulty involved with timing PHT at sites separated by more than 250 km. Data from three of the four sites showed that yield from DE treatments was significantly reduced in comparison to DR and DL treatments. This has implications for producers hoping to speed up harvest by desiccating lentil crops when wet weather is expected. According to these data, during wet conditions, maturity may be advanced using SE treatments with no negative effect on yield. However, DE treatments had a highly significant negative effect on yield when harvest conditions were cool and wet. The DR treatment produced the highest yield in wet harvest conditions.

Table 4.1 Mean yield of 8 red lentil cultivars subjected to early, recommended and late swathing and desiccation treatments at Floral and Rouleau in 2005 and 2006.

Floral 2005	**Pre-harvest treatment and timing**						
	Swathing			**Desiccation**			
Cultivar	**Early**	**Rec.**	**Late**	**Early**	**Rec.**	**Late**	**Mean**
	kg/ha						
CDC Robin	1555	1572	1818	930	2012	1569	1576
CDC Imperial	1930	1545	1527	945	1849	2099	1649
CDC Rosetown	1768	1395	1920	1142	2446	1901	1762
CDC Blaze	1560	1129	1114	719	1189	1212	1154
CDC Impact	1536	1052	1056	824	1251	1068	1131
CDC Rouleau	1598	1855	1972	1430	2047	2448	1892
CDC Redberry	1748	1817	1681	1358	2473	2082	1860
CDC Red Rider	1676	1756	1301	775	2022	2254	1631
Mean	1671	1515	1549	1015	1911	1829	1582
LSD (0.05)	Cultivar [C] means				183		
LSD (0.05)	Pre-harvest [PH] treatment means				159		
LSD (0.05)	[C] x [PH] means				449		

Floral 2006	**Pre-harvest treatment and timing**						
	Swathing			**Desiccation**			
Cultivar	**Early**	**Rec.**	**Late**	**Early**	**Rec.**	**Late**	**Mean**
	kg/ha						
CDC Robin	1674	2209	1540	2033	1694	2221	1895
CDC Imperial	1708	1659	1154	2164	1475	2123	1714
CDC Rosetown	1523	2452	1469	2356	1269	2390	1910
CDC Blaze	1486	1768	1256	1880	1393	1727	1585
CDC Impact	1569	2024	1272	1805	1356	1677	1617
CDC Rouleau	1802	2638	1677	2473	2209	2385	2197
CDC Redberry	1455	1718	1333	2052	1434	1820	1635
CDC Red Rider	1854	2143	1639	2200	1947	2219	2000
Mean	1634	2077	1417	2120	1597	2070	1819
LSD (0.05)	Cultivar [C] means					188	
LSD (0.05)	Pre-harvest [PH] treatment means					162	
LSD (0.05)	[C] x [PH] means					460	

Rouleau 2005	**Pre-harvest treatment and timing**						
	Swathing			**Desiccation**			
Cultivar	**Early**	**Rec.**	**Late**	**Early**	**Rec.**	**Late**	**Mean**
	kg/ha						
CDC Robin	813	893	1707	1058	1497	1464	1239
CDC Imperial	931	610	1469	963	1078	1362	1069
CDC Rosetown	1185	1128	1399	1473	1757	1681	1437
CDC Blaze	815	885	1199	1126	1330	1202	1093
CDC Impact	783	935	1279	1043	1043	1299	1064
CDC Rouleau	1213	1396	1084	1550	1721	1680	1441
CDC Redberry	923	1012	1467	1218	1419	1338	1229
CDC Red Rider	1228	1425	1981	1718	1778	1882	1669
Mean	986	1035	1448	1268	1453	1488	1280
LSD (0.05)	Cultivar [C] means				136		
LSD (0.05)	Pre-harvest [PH] treatment means				117		
LSD (0.05)	[C] x [PH] means				332		

Rouleau 2006	**Pre-harvest treatment and timing**						
	Swathing			**Desiccation**			
Cultivar	**Early**	**Rec.**	**Late**	**Early**	**Rec.**	**Late**	**Mean**
	kg/ha						
CDC Robin	1372	900	928	930	1459	1291	1147
CDC Imperial	1194	902	976	741	1418	1210	1074
CDC Rosetown	1252	874	1094	1139	1499	1291	1192
CDC Blaze	1509	1147	912	734	1295	1095	1115
CDC Impact	1234	821	781	953	1011	1220	1003
CDC Rouleau	1613	1161	1039	1282	1413	1359	1311
CDC Redberry	1204	802	796	986	1318	909	1002
CDC Red Rider	1410	1400	1256	1335	1568	1466	1406
Mean	1349	1001	973	1013	1373	1230	1156
LSD (0.05)	Cultivar [C] means					135	
LSD (0.05)	Pre-harvest [PH] treatment means					117	
LSD (0.05)	[C] x [PH] means					330	

LSD - Least Significant Difference

SE - Standard Error

4.1.3 Effect of Cultivar and Preharvest Treatment on Milling Recovery Using Satake and Turkish Dehullers

Data showing the effect of cultivar (C), PHT and C x PHT interactions on the mean %MR of the lentil samples from the Satake and Turkish mills are displayed in Tables 4.2 and 4.3, respectively. Correlation coefficients were also calculated between mean %MR for the two mills by year, by location, by PHT and by C (Appendix I). Coefficients of variation for %MR were in the range of 1 to 3% for the Satake mill, and 1.5% to 3.5% for data derived from the Turkish mill (Appendix IV, ANOVA Table). These fall within the expected range based on the differences in the technical adjustment capability between the two mills.

Although the coefficients of variation for the Turkish mill were slightly higher, the range was similar to that of the Satake mill, which shows that results are highly repeatable. Erskine et al. (1991) conducted similar research on lentil milling efficiency using a laboratory dehuller consisting of two horizontal round stones. The bottom stone was stationary and the top one rotated. Fifty-gram lentil samples, from various sub-plots, and hydrated to approximately 11.4% equilibrium moisture were observed to have a range in milling recovery from 73% to 85%. They also observed higher milling recovery values for smaller seeds (4 mm) compared to larger seeds (4.5 mm) which they attributed to higher levels of broken seeds with the larger sized fraction. Their results agree with the findings of this study, which also found smaller seeds to have higher %MR. The contrast in %MR values between these two studies likely stems from differences in mill configuration and adjustability as well as differences in lentil varieties studied.

Table 4.2 Mean % milling recovery of split and whole seeds of red lentils after milling with a Satake mill for 8 red lentil cultivars subjected to early, recommended and late swathing and desiccation treatments at Floral and Rouleau in 2005 and 2006.

	Floral 2005						
	Pre-harvest treatment and timing						
	Swathing			Desiccation			
Cultivar	Early	Rec.	Late	Early	Rec.	Late	Mean
	------------------------------	% milling recovery	------------------------				
CDC Robin	84.3	74.3	77.4	57.8	72.4	76.2	73.7
CDC Imperial	84.4	75.3	74.8	60.7	77.7	76.6	74.9
CDC Rosetown	86.1	78.9	82.6	72.0	80.5	82.8	80.4
CDC Blaze	85.6	80.0	84.2	78.6	81.9	84.4	82.4
CDC Impact	88.2	78.2	84.1	79.2	83.3	82.2	82.5
CDC Rouleau	85.1	79.3	79.3	63.1	80.5	80.2	77.9
CDC Redberry	88.4	83.6	83.3	71.5	83.7	82.9	82.2
CDC Red Rider	86.2	79.9	82.3	61.8	81.5	80.5	78.7
Mean	86.0	78.7	81.0	68.1	80.2	80.7	79.1
LSD (0.05)	Cultivar [C] means			1.9		SE	1.0
LSD (0.05)	Pre-harvest [PH] treatment means			1.7		SE	0.8
LSD (0.05)	[C] x [PH] means			4.7		SE	2.4

	Floral 2006						
	Pre-harvest treatment and timing						
	Swathing			Desiccation			
Cultivar	Early	Rec.	Late	Early	Rec.	Late	Mean
	---------------------------------	% milling recovery	------------------------				
CDC Robin	82.9	85.5	85.0	85.3	82.9	79.9	83.6
CDC Imperial	83.7	82.9	80.8	83.3	83.9	86.3	83.5
CDC Rosetown	85.5	90.3	87.6	88.9	90.5	88.3	88.5
CDC Blaze	88.6	88.6	86.7	87.2	87.7	88.0	87.8
CDC Impact	84.3	87.8	85.0	88.1	88.9	87.7	87.0
CDC Rouleau	87.1	85.1	87.4	85.7	86.7	85.7	86.3
CDC Redberry	89.9	87.9	86.7	87.3	87.6	87.7	87.8
CDC Red Rider	84.3	84.9	87.3	86.4	86.0	85.2	85.7
Mean	85.8	86.6	85.8	86.5	86.8	86.1	86.2
LSD (0.05)	Cultivar [C] means				1.5	SE	0.7
LSD (0.05)	Pre-harvest [PH] treatment means				NS	SE	0.6
LSD (0.05)	[C] x [PH] means				NS	SE	1.8

	Rouleau 2005						
	Pre-harvest treatment and timing						
	Swathing			Desiccation			
Cultivar	Early	Rec.	Late	Early	Rec.	Late	Mean
	------------------------------	% milling recovery	------------------------				
CDC Robin	86.3	84.0	86.2	85.1	86.7	82.2	85.1
CDC Imperial	86.2	85.0	84.1	84.0	83.9	86.9	85.0
CDC Rosetown	86.5	86.3	87.0	87.9	86.8	87.8	87.0
CDC Blaze	88.4	87.4	86.3	84.9	86.7	87.1	86.8
CDC Impact	86.0	86.6	86.8	86.6	85.9	86.6	86.4
CDC Rouleau	85.2	85.6	84.5	86.8	85.4	85.6	85.5
CDC Redberry	87.1	87.4	86.5	86.2	86.5	86.5	86.7
CDC Red Rider	87.6	86.9	87.2	87.2	87.2	85.0	86.8
Mean	86.6	86.1	86.1	86.1	86.1	86.0	86.2
LSD (0.05)	Cultivar [C] means			1.3		SE	0.6
LSD (0.05)	Pre-harvest [PH] treatment means			NS		SE	0.5
LSD (0.05)	[C] x [PH] means			NS		SE	1.5

	Rouleau 2006						
	Pre-harvest treatment and timing						
	Swathing			Desiccation			
Cultivar	Early	Rec.	Late	Early	Rec.	Late	Mean
	---------------------------------	% milling recovery	------------------------				
CDC Robin	89.1	87.9	87.4	87.9	88.7	87.8	88.1
CDC Imperial	88.8	89.7	88.8	88.5	88.0	88.3	88.7
CDC Rosetown	89.4	89.1	89.6	90.7	89.8	89.2	89.6
CDC Blaze	90.7	90.4	90.1	88.7	89.3	89.1	89.7
CDC Impact	90.0	90.2	88.7	89.0	89.9	89.0	89.4
CDC Rouleau	88.2	88.4	88.2	89.1	88.5	89.8	88.7
CDC Redberry	88.1	88.2	89.6	89.8	88.7	89.6	89.0
CDC Red Rider	88.1	89.2	88.2	88.5	87.1	90.1	88.5
Mean	89.0	89.1	88.8	89.0	88.7	89.1	89.0
LSD (0.05)	Cultivar [C] means				0.8	SE	0.4
LSD (0.05)	Pre-harvest [PH] treatment means				NS	SE	0.3
LSD (0.05)	[C] x [PH] means				NS	SE	0.9

Percent milling recovery (% MR) indicates the proportion of the sample following milling and dockage removal that is suitable for sale, (footballs and split cotyledons) excluding the byproducts of milling such as hulls, broken pieces and flour.

LSD - Least Significant Difference

SE - Standard Error

Table 4.3 Mean % milling recovery of split and whole seeds of red lentils after milling with a Turkish mill for 8 red lentil cultivars subjected to early, recommended and late swathing and desiccation treatments at Floral and Rouleau in 2005 and 2006.

	Floral 2005						
	Pre-harvest treatment and timing						
	Swathing			Desiccation			
Cultivar	Early	Rec.	Late	Early	Rec.	Late	Mean
	% milling recovery						
CDC Robin	79.6	70.0	75.8	57.6	67.4	76.8	71.2
CDC Imperial	81.0	72.4	71.8	55.9	80.2	73.8	72.5
CDC Rosetown	81.8	73.3	79.4	63.7	77.3	73.9	74.9
CDC Blaze	78.9	71.7	77.0	72.6	74.7	75.3	75.0
CDC Impact	79.6	73.0	75.6	71.5	74.1	74.8	74.7
CDC Rouleau	81.5	71.6	76.6	55.8	74.7	77.3	72.9
CDC Redberry	81.4	74.0	78.6	68.0	77.9	76.7	76.1
CDC Red Rider	81.7	71.7	75.8	58.0	76.9	75.5	73.2
Mean	80.7	72.2	76.3	62.9	75.4	75.5	73.8
LSD (0.05)	Cultivar [C] means			2.2		SE	1.0
LSD (0.05)	Pre-harvest [PH] treatment means			1.9		SE	1.0
LSD (0.05)	[C] x [PH] means			5.3		SE	2.6

	Floral 2006						
	Pre-harvest treatment and timing						
	Swathing			Desiccation			
Cultivar	Early	Rec.	Late	Early	Rec.	Late	Mean
	% milling recovery						
CDC Robin	82.9	79.6	77.6	77.0	82.6	82.0	80.3
CDC Imperial	80.6	78.8	81.1	83.0	80.0	76.6	80.0
CDC Rosetown	86.2	87.9	84.3	86.4	86.8	86.4	86.3
CDC Blaze	80.1	80.2	80.7	82.7	81.8	80.4	81.0
CDC Impact	79.3	79.7	81.6	78.2	79.2	79.1	79.5
CDC Rouleau	84.7	79.7	80.8	81.9	83.0	83.2	82.2
CDC Redberry	79.5	79.3	80.6	81.7	81.0	78.3	80.0
CDC Red Rider	81.7	81.7	81.4	80.7	85.2	83.3	82.3
Mean	81.9	80.8	81.0	81.4	82.4	81.1	81.4
LSD (0.05)	Cultivar [C] means				2.2	SE	1.0
LSD (0.05)	Pre-harvest [PH] treatment means				NS	SE	1.0
LSD (0.05)	[C] x [PH] means				NS	SE	2.7

	Rouleau 2005						
	Pre-harvest treatment and timing						
	Swathing			Desiccation			
Cultivar	Early	Rec.	Late	Early	Rec.	Late	Mean
	% milling recovery						
CDC Robin	79.8	79.7	80.1	81.1	80.2	79.8	80.1
CDC Imperial	81.7	80.0	81.8	79.5	81.1	80.3	80.7
CDC Rosetown	82.3	82.4	81.3	81.6	80.4	82.2	81.7
CDC Blaze	76.0	77.2	76.0	74.6	74.3	75.1	75.5
CDC Impact	76.4	77.8	74.9	76.8	77.1	75.5	76.4
CDC Rouleau	80.9	78.9	80.6	78.9	79.6	77.2	79.3
CDC Redberry	78.6	77.6	77.3	79.8	78.2	77.8	78.2
CDC Red Rider	78.7	80.1	80.0	80.7	80.1	77.8	79.5
Mean	79.3	79.2	79.0	79.1	78.9	78.2	78.9
LSD (0.05)	Cultivar [C] means			1.2		SE	1.0
LSD (0.05)	Pre-harvest [PH] treatment means			NS		SE	0.0
LSD (0.05)	[C] x [PH] means			NS		SE	1.4

	Rouleau 2006						
	Pre-harvest treatment and timing						
	Swathing			Desiccation			
Cultivar	Early	Rec.	Late	Early	Rec.	Late	Mean
	% milling recovery						
CDC Robin	84.1	83.0	83.5	83.5	83.3	85.2	83.7
CDC Imperial	83.2	81.9	83.1	82.9	82.5	83.8	82.9
CDC Rosetown	85.3	85.2	85.4	84.4	85.4	86.2	85.3
CDC Blaze	80.3	82.2	83.0	80.0	81.0	82.9	81.5
CDC Impact	80.1	80.8	80.8	80.7	78.3	81.2	80.3
CDC Rouleau	81.5	80.6	80.3	80.7	81.4	80.0	80.7
CDC Redberry	80.8	79.5	79.0	79.9	80.2	80.8	80.0
CDC Red Rider	80.2	82.1	79.8	80.9	80.4	80.6	80.7
Mean	81.9	81.9	81.8	81.6	81.5	82.6	81.9
LSD (0.05)	Cultivar [C] means				0.9	SE	0.0
LSD (0.05)	Pre-harvest [PH] treatment means				NS	SE	0.0
LSD (0.05)	[C] x [PH] means				NS	SE	1.1

Percent milling recovery (% MR) indicates the proportion of the sample following milling and dockage removal that is suitable for sale, (footballs and split cotyledons) excluding the byproducts of milling such as hulls, broken pieces and flour.

LSD - Least Significant Difference

SE - Standard Error

In all environments for both mills, significant differences ($P < 0.05$) were observed in %MR among cultivars (Tables 4.2 and 4.3). Except at Floral 2005, CDC Rosetown generally displayed significantly higher %MR values than the other cultivars. In contrast, CDC Robin and CDC Imperial tended to have significantly lower %MR values, particularly when harvest conditions were wet. For Floral 2005, the wet conditions resulted in significantly higher %MR values for the cultivars CDC Blaze, CDC Impact and CDC Redberry (82.4%, 82.5% and 82.2%, respectively). This supported previous evidence from preliminary milling results that suggested that lentil cultivars with brown seed coats (CDC Robin and CDC Imperial) tend to be more susceptible to damage from wet conditions compared to cultivars with grey seed coats. Percent MR values were similar between CDC Robin and CDC Blaze and the genetically similar, respective backcross-derived cultivars, CDC Imperial and CDC Impact.

In a Mediterranean environment, location effects on milling recovery the case for lentils grown were of minor importance (Erskine et al., 1991). However, this was not under the continental environmental conditions of this experiment. In both years, samples from Rouleau displayed higher %MR values than did samples from Floral. At Rouleau 2006, samples from CDC Blaze displayed high MR values (89%) which were near the theoretical maximum %MR, (approximately 93%) based on previous research by Erskine et al. (1991). CDC Imperial, CDC Rosetown, CDC Impact and CDC Redberry all had similar MR values.

Differences between PHT means for %MR values were not significant in the three environments that experienced warm, dry harvest conditions. When conditions were cool and wet, both the Satake and Turkish mill results showed significant differences ($P < 0.05$) in %MR among PHTs. Results from the Satake mill and the Turkish mill showed that SE resulted in significantly higher %MR values (86.0% and 80.7% respectively). In the case of the Satake mill, these values approached the theoretical maximum for dehulling efficiency since lentil hulls typically comprise 6-7% of the seed (Erskine et al., 1991). The DE treatment resulted in a significant ($P < 0.05$) reduction in %MR (68.1% and 62.9% respectively) compared to all other PHTs. These values suggest that, unlike desiccating, swathing allows the continuation of biological processes specific to seed maturation which lend themselves to higher potential %MR values. Although %MR was similar for SR, DR, SL and DL, results from both mills showed that DR and SL had higher %MR values than did their counterparts.

Differences between C x PHT interaction means were significant ($P < 0.05$) only at Floral 2005. The highest %MR was produced by the Satake mill in combination with CDC Redberry and the SE treatment (88.4%), whereas the lowest was CDC Robin with a DE treatment. CDC Rosetown, which had higher mean %MR values than did the other cultivars, performed best with early swathing treatments and late desiccation treatments (86.1% and 82.8% respectively).

4.1.4 Effect of Cultivar and Preharvest Treatment on Football Recovery Using Satake and Turkish Dehullers

Data showing the effect of C, PHT and C x PHT interactions on the mean %FR of the lentil samples from the Satake and Turkish mills are displayed in Tables 4.4 and 4.5, respectively. Coefficient of variation values differed among sites and between mills (Appendix VI, ANOVA table). The range of CVs from samples passed through the Satake mill was narrow (approximately 4.5-5.0%). This range is akin to the ranges of other variables taken from this mill, indicating a low and consistent degree of variation across locations and treatments. Conversely, the range of CVs derived from samples taken from the Turkish mill was wide and inconsistent. CV values ranged from 5.9% to 7.3% in dry harvest environments to 23.9% during wet harvest conditions found at Floral, 2005.

Table 4.4 Mean %FR of the total recovered red lentils after dehulling with the Satake mill for 8 red lentil cultivars subjected to early, recommended and late swathing and desiccation treatments at Floral and Rouleau in 2005 and 2006.

	Floral 2005							Floral 2006						
	Pre-harvest treatment and timing							Pre-harvest treatment and timing						
	Swathing			Desiccation				Swathing			Desiccation			
Cultivar	**Early**	**Rec.**	**Late**	**Early**	**Rec.**	**Late**	**Mean**	**Early**	**Rec.**	**Late**	**Early**	**Rec.**	**Late**	**Mean**
	% football recovery							% football recovery						
CDC Robin	85.9	58.9	63.1	62.6	54.9	53.6	63.1	91.3	87.1	85.5	87.0	88.1	88.6	87.9
CDC Imperial	83.7	50.6	43.6	59.0	48.1	54.9	56.6	90.1	87.3	86.9	87.8	84.9	87.2	87.3
CDC Rosetown	79.0	46.1	45.0	46.2	48.4	52.2	52.8	96.0	92.9	93.2	93.3	95.0	96.1	94.4
CDC Blaze	78.1	43.2	46.4	47.6	39.7	45.2	50.0	85.0	80.7	81.3	85.2	81.2	82.5	82.6
CDC Impact	74.4	33.7	44.0	52.8	48.1	39.7	48.8	82.2	77.7	80.3	77.5	78.2	74.4	78.4
CDC Rouleau	69.6	40.4	45.6	56.6	25.5	33.8	45.3	88.8	86.6	86.9	90.6	88.8	86.9	88.1
CDC Redberry	80.2	49.6	41.8	57.2	41.2	38.4	51.4	74.9	77.4	79.9	80.0	79.1	74.0	77.5
CDC Red Rider	70.6	27.3	27.7	52.5	34.2	27.0	39.9	67.9	57.8	51.4	60.6	58.6	58.3	59.1
Mean	77.7	43.7	44.6	54.3	42.5	43.1	51.0	84.5	80.9	80.6	82.7	81.7	81.0	81.9
LSD (0.05)	Cultivar [C] means			4.9		SE	1.6	LSD (0.05)	Cultivar [C] means			3.3	SE	1.7
LSD (0.05)	Pre-harvest [PH] treatment means			4.3		SE	1.4	LSD (0.05)	Pre-harvest [PH] treatment means			NS	SE	1.4
LSD (0.05)	[C] x [PH] means			12.1		SE	3.9	LSD (0.05)	[C] x [PH] means			NS	SE	4.1

	Rouleau 2005							Rouleau 2006						
	Pre-harvest treatment and timing							Pre-harvest treatment and timing						
	Swathing			Desiccation				Swathing			Desiccation			
Cultivar	**Early**	**Rec.**	**Late**	**Early**	**Rec.**	**Late**	**Mean**	**Early**	**Rec.**	**Late**	**Early**	**Rec.**	**Late**	**Mean**
	% football recovery							% football recovery						
CDC Robin	89.1	90.3	89.3	88.8	90.4	87.6	89.2	95.6	95.9	96.1	95.6	96.2	96.8	96.0
CDC Imperial	87.3	87.9	86.2	84.5	87.3	87.4	86.7	94.6	96.3	96.4	96.4	95.4	96.2	95.9
CDC Rosetown	89.7	90.2	88.2	90.7	89.0	89.4	89.5	93.5	97.3	97.0	91.4	97.2	96.8	95.5
CDC Blaze	81.3	80.0	73.1	78.6	75.2	74.9	77.2	91.8	91.8	90.3	90.8	90.1	92.2	91.1
CDC Impact	81.4	75.5	76.1	77.7	78.9	73.1	77.1	88.0	86.7	88.1	89.5	90.7	86.8	88.3
CDC Rouleau	69.1	67.3	63.0	70.4	66.9	69.9	67.7	89.5	91.3	91.6	90.1	92.4	92.8	91.3
CDC Redberry	82.7	75.9	68.5	70.1	69.8	72.7	73.3	85.1	79.0	89.0	86.9	77.0	81.7	83.1
CDC Red Rider	69.6	67.4	58.6	65.7	59.1	57.4	62.9	76.6	65.0	75.3	73.8	61.5	68.5	70.1
Mean	81.2	79.3	75.4	78.3	77.1	76.5	78.0	89.3	87.9	90.4	89.3	87.5	89.0	88.9
LSD (0.05)	Cultivar [C] means			3.2		SE	1.6	LSD (0.05)	Cultivar [C] means			3.3	SE	2.8
LSD (0.05)	Pre-harvest [PH] treatment mea			2.7		SE	1.4	LSD (0.05)	Pre-harvest [PH] treatment means			NS	SE	2.3
LSD (0.05)	[C] x [PH] means			NS		SE	3.9	LSD (0.05)	[C] x [PH] means			NS	SE	0.8

Percent football recovery (% FR) refers to the proportion of the total recovered sample (split and whole) that contains seeds with un-separated cotyledons following milling.

LSD - Least Significant Difference

SE - Standard Error

Table 4.5 Mean %FR of the total recovered red lentils after dehulling with the Turkish mill for 8 red lentil cultivars subjected to early, recommended and late swathing and desiccation treatments at Floral and Rouleau in 2005 and 2006.

	Floral 2005							Floral 2006						
	Pre-harvest treatment and timing							Pre-harvest treatment and timing						
	Swathing			Desiccation				Swathing			Desiccation			
Cultivar	**Early**	**Rec.**	**Late**	**Early**	**Rec.**	**Late**	**Mean**	**Early**	**Rec.**	**Late**	**Early**	**Rec.**	**Late**	**Mean**
	% football recovery							% football recovery						
CDC Robin	67.8	32.1	33.4	29.6	29.7	25.7	36.4	79.4	81.1	74.0	77.7	76.4	81.0	78.2
CDC Imperial	70.5	26.9	24.1	32.9	28.6	26.3	34.9	75.0	73.5	78.4	76.6	70.1	80.5	75.7
CDC Rosetown	59.0	24.9	35.0	25.0	27.3	25.8	32.8	84.5	83.6	81.3	84.9	85.5	87.4	84.5
CDC Blaze	46.8	12.0	20.5	22.5	17.7	16.1	22.6	59.0	57.9	59.4	61.4	59.6	61.2	59.7
CDC Impact	43.4	14.8	21.2	28.1	18.3	17.1	23.8	56.9	62.0	60.1	60.5	58.4	55.2	58.8
CDC Rouleau	41.4	10.2	11.6	32.6	4.6	10.5	18.5	59.8	65.7	63.3	69.1	62.2	64.6	64.1
CDC Redberry	43.9	17.9	13.8	30.2	14.3	12.9	22.2	41.2	40.1	40.3	46.7	37.8	39.1	40.9
CDC Red Rider	39.6	2.6	3.3	12.8	6.8	3.4	11.4	43.3	25.7	24.5	41.4	28.4	25.5	31.4
Mean	51.5	17.7	20.3	26.7	18.4	17.2	25.3	62.4	61.2	60.1	64.8	59.8	61.8	61.7
LSD (0.05)	Cultivar [C] means			5.0		SE	2.5	LSD (0.05)	Cultivar [C] means			3.4	SE	1.7
LSD (0.05)	Pre-harvest [PH] treatment means			4.3		SE	2.1	LSD (0.05)	Pre-harvest [PH] treatment means			3.0	SE	1.5
LSD (0.05)	[C] x [PH] means			NS		SE	6.1	LSD (0.05)	[C] x [PH] means			NS	SE	4.2

	Rouleau 2005							Rouleau 2006						
	Pre-harvest treatment and timing							Pre-harvest treatment and timing						
	Swathing			Desiccation				Swathing			Desiccation			
Cultivar	**Early**	**Rec.**	**Late**	**Early**	**Rec.**	**Late**	**Mean**	**Early**	**Rec.**	**Late**	**Early**	**Rec.**	**Late**	**Mean**
	% football recovery							% football recovery						
CDC Robin	71.0	66.7	66.1	67.8	66.2	68.0	67.6	90.4	91.5	90.7	89.7	90.0	88.9	90.2
CDC Imperial	72.7	65.9	65.0	64.7	67.9	65.3	66.9	91.3	89.6	88.7	87.3	90.8	88.5	89.3
CDC Rosetown	72.9	70.2	68.8	68.0	66.8	64.5	68.5	90.4	92.0	91.7	88.1	93.1	92.8	91.4
CDC Blaze	41.1	36.7	35.8	38.7	37.7	37.1	37.8	72.4	71.9	70.6	68.0	71.9	66.4	70.2
CDC Impact	47.4	45.3	37.3	47.4	44.8	34.8	42.8	70.2	68.8	69.8	68.8	66.7	69.0	68.9
CDC Rouleau	34.7	34.6	26.8	35.5	30.9	33.3	32.6	57.8	68.8	66.3	64.4	59.8	71.0	64.7
CDC Redberry	51.3	34.4	27.8	37.0	31.1	29.6	35.2	51.9	50.4	50.6	54.6	50.1	43.7	50.2
CDC Red Rider	37.1	29.8	21.0	32.2	21.1	21.4	27.1	42.4	36.2	42.7	36.1	35.7	37.5	38.4
Mean	53.5	47.9	43.6	48.9	45.8	44.2	47.3	70.8	71.1	71.4	69.6	69.8	69.7	70.4
LSD (0.05)	Cultivar [C] means			2.9		SE	1.4	LSD (0.05)	Cultivar [C] means			3.4	SE	2.9
LSD (0.05)	Pre-harvest [PH] treatment means			2.5		SE	1.2	LSD (0.05)	Pre-harvest [PH] treatment means			NS	SE	2.4
LSD (0.05)	[C] x [PH] means			7.0		SE	3.5	LSD (0.05)	[C] x [PH] means			NS	SE	0.9

Percent football recovery (% FR) refers to the proportion of the total recovered sample (split and whole) that contains seeds with un-separated cotyledons following milling.

LSD - Least Significan Difference

SE - Standard Error

Results from both mills showed significant differences ($P < 0.05$) in %FR between cultivars for each location. As a general rule, both mills produced lower %FR as seed size increased. In all cases, the largest seeded cultivar, CDC Red Rider, produced significantly ($P < 0.05$) lower %FR values than all other cultivars. Conversely, the smaller seeded varieties, CDC Robin, CDC Imperial and CDC Rosetown, consistently produced the highest %FR by a considerable margin. At Floral 2005, the wet harvest site, CDC Robin produced the highest %FR. In contrast, except for Rouleau 2006, CDC Rosetown had the highest %FR, during dry harvest conditions, for both mills. The reason larger seeded varieties tended to produce less footballs than smaller varieties has to do with the lack of adjustability of the mills. Larger seeds made more contact with the abrasive surfaces than smaller seeds and therefore tended to split apart more frequently.

The range in mean %FR differed greatly depending on the mill. The range of means across cultivars for the Satake mill was 23.2% in wet harvest conditions to 35.3 % in dry conditions. Conversely, the Turkish mill produced a range in means of about 25% between high and low %FR values during wet harvest conditions whereas the range in means between cultivars spanned 53% during dry conditions. The increased range in %FR produced by the Turkish mill reflects its relatively crude design, which reduced %FR values, particularly when larger seeded cultivars were involved. Both mills produced samples with much lower %FR when the milled seed was subjected to wet harvest conditions like those experienced at Floral in 2005.

Results from both the Satake and Turkish mill revealed that the effects of PHT on %FR were exaggerated during wet harvest conditions. At Floral 2005, early application of swathing or desiccation produced significantly ($P < 0.05$) higher %FR values compared to recommended and late treatment timings, which had similar results. Moreover, results from both mills showed at least a 20% increase in %FR with SE treatments over DE treatments. Half of the cultivars displayed significant ($P < 0.05$) differences in %FR between treatments when subjected to dry harvest conditions. In these instances, earlier treatments tended to yield the highest %FR, with swathing typically outperforming desiccation.

At three sites, C x PHT interactions were not significant. The Satake mill results showed that at Floral 2005, higher %FR values were obtained from CDC Robin combined with SE (85.9 %FR), whereas CDC Red Rider with DL produced the lowest %FR (27.0%).

4.1.5 Effect of Cultivar and Preharvest Treatment on Dehulling Efficiency of Footballs Using Satake and Turkish Dehullers

The effects of C, PHT and C x PHT on %DE for each cultivar following dehulling in the Satake and Turkish mills are presented in Tables 4.6 and 4.7, respectively. Coefficients of variation were also calculated for values produced by both mills for each site. The Satake mill produced CV values of approximately 0.4% for both years at Rouleau, but showed higher values for Floral, particularly when harvest conditions were wet (3.8%). A similar trend appeared in the %DE data obtained from the Turkish mill, with average values of 2.3% and 11.0% for the Rouleau and Floral sites, respectively. This similarity in values again reflects the less refined design of the Turkish mill, and may also suggest that higher latitudes or higher seasonal moisture may produce less uniform samples in terms of %DE (Climate Data, Appendix VII and VIII). These values imply the importance of seeding early, which can minimize risk by maximizing use of early season moisture. This would also improve the chances of harvesting product with higher milling qualities by avoiding late season moisture during harvest.

Table 4.6 Mean % dehulling efficiency following decortication with a Satake mill for 8 red lentil cultivars subjected to early, recommended and late swathing and desiccation treatments at Floral and Rouleau in 2005 and 2006.

	Floral 2005						
	Pre-harvest treatment and timing						
	Swathing			Desiccation			
Cultivar	Early	Rec.	Late	Early	Rec.	Late	Mean
	% dehulling efficiency						
CDC Robin	99.0	91.3	88.5	90.7	96.6	86.6	92.1
CDC Imperial	97.1	95.0	96.9	69.5	95.0	96.0	91.5
CDC Rosetown	97.5	91.1	92.8	97.1	96.0	96.1	95.1
CDC Blaze	99.4	95.1	95.1	91.2	98.5	95.6	95.8
CDC Impact	98.8	94.3	99.0	97.0	98.0	96.4	97.2
CDC Rouleau	98.7	94.7	98.7	88.2	98.8	96.9	96.0
CDC Redberry	99.9	97.7	99.7	97.0	99.2	98.7	98.7
CDC Red Rider	99.8	98.6	98.5	92.5	95.0	96.4	96.8
Mean	98.8	94.7	96.1	90.4	97.1	95.3	95.4
LSD (0.05)	Cultivar [C] means			3.0	SE	1.48	
LSD (0.05)	Pre-harvest [PH] treatment means			2.6	SE	1.28	
LSD (0.05)	[C] x [PH] means			7.3	SE	3.63	

	Floral 2006						
	Pre-harvest treatment and timing						
	Swathing			Desiccation			
	Early	Rec.	Late	Early	Rec.	Late	Mean
	% dehulling efficiency						
CDC Robin	98.4	97.8	96.6	96.8	98.2	98.0	97.6
CDC Imperial	96.8	95.3	99.0	99.3	96.9	96.7	97.3
CDC Rosetown	96.8	98.7	97.4	98.1	97.2	97.7	97.6
CDC Blaze	96.6	97.8	97.9	99.7	98.6	98.5	98.2
CDC Impact	96.9	99.6	98.8	98.1	98.0	99.7	98.5
CDC Rouleau	99.9	99.7	99.6	99.6	99.7	99.7	99.7
CDC Redberry	96.5	97.2	98.7	99.1	97.5	97.7	97.8
CDC Red Rider	97.4	98.0	98.3	98.6	98.0	98.3	98.1
Mean	97.4	98.0	98.3	98.6	98.0	98.3	98.1
LSD (0.05)	Cultivar [C] means				1.5	SE	0.8
LSD (0.05)	Pre-harvest [PH] treatment means				NS	SE	0.7
LSD (0.05)	[C] x [PH] means				NS	SE	1.9

	Rouleau 2005						
	Pre-harvest treatment and timing						
	Swathing			Desiccation			
Cultivar	Early	Rec.	Late	Early	Rec.	Late	Mean
	% dehulling efficiency						
CDC Robin	99.8	99.7	99.7	99.6	99.7	100.0	99.7
CDC Imperial	99.6	99.9	99.9	99.7	99.7	99.6	99.7
CDC Rosetown	99.7	99.6	99.6	99.7	99.3	99.9	99.6
CDC Blaze	99.7	99.7	99.3	99.9	100.0	99.4	99.7
CDC Impact	99.7	99.2	99.8	99.1	99.5	100.0	99.5
CDC Rouleau	99.9	99.8	99.3	99.2	99.8	99.4	99.5
CDC Redberry	99.8	98.5	99.5	100.0	99.4	99.8	99.5
CDC Red Rider	99.1	99.3	99.4	99.7	99.3	99.1	99.3
Mean	99.7	99.4	99.5	99.6	99.6	99.6	99.6
LSD (0.05)	Cultivar [C] means			0.3		SE	0.2
LSD (0.05)	Pre-harvest [PH] treatment means			NS		SE	0.2
LSD (0.05)	[C] x [PH] means			NS		SE	0.4

	Rouleau 2006						
	Pre-harvest treatment and timing						
	Swathing			Desiccation			
	Early	Rec.	Late	Early	Rec.	Late	Mean
	% dehulling efficiency						
CDC Robin	99.8	99.9	99.9	99.4	99.5	99.6	99.6
CDC Imperial	99.5	99.0	99.8	99.0	99.5	99.7	99.4
CDC Rosetown	99.7	100.0	100.0	99.6	99.9	99.9	99.8
CDC Blaze	99.8	99.7	99.8	99.8	99.7	99.9	99.8
CDC Impact	100.0	99.7	99.9	99.6	99.9	99.7	99.8
CDC Rouleau	100.0	99.9	99.9	99.8	100.0	99.9	99.9
CDC Redberry	99.6	100.0	100.0	99.8	99.9	99.9	99.9
CDC Red Rider	99.5	98.8	99.5	99.1	99.6	99.2	99.3
Mean	99.7	99.6	99.8	99.5	99.7	99.7	99.7
LSD (0.05)	Cultivar [C] means				0.3	SE	1.2
LSD (0.05)	Pre-harvest [PH] treatment means				NS	SE	1.0
LSD (0.05)	[C] x [PH] means				NS	SE	0.3

Percent dehulling efficiency (% DE) refers to the proportion of the milled sample displaying footballs with two percent or less seedcoat adherence following milling.

LSD - Least Significant Difference

SE - Standard Error

Table 4.7 Mean % dehulling efficiency following decortication with a Turkish mill for 8 red lentil cultivars subjected to early, recommended and late swathing and desiccation treatments at Floral and Rouleau in 2005 and 2006.

	Floral 2005						
	Pre-harvest treatment						
	Swathing			Desiccation			
Cultivar	Early	Rec.	Late	Early	Rec.	Late	Mean
	---------------------- % dehulling efficiency ----------------						
CDC Robin	67.9	64.9	44.7	56.5	62.2	35.7	55.3
CDC Imperial	68.1	66.6	63.1	41.8	55.7	60.3	59.2
CDC Rosetown	68.4	55.9	47.3	61.3	47.4	67.8	58.0
CDC Blaze	84.1	70.7	67.2	58.3	73.7	67.8	70.3
CDC Impact	77.4	72.3	70.9	65.3	66.5	66.9	69.9
CDC Rouleau	73.9	71.2	64.0	43.9	70.0	58.2	63.5
CDC Redberry	90.7	84.6	80.6	71.1	75.3	86.9	81.5
CDC Red Rider	87.3	67.0	72.7	58.4	70.0	75.0	71.7
Mean	77.2	69.1	63.8	57.1	65.1	64.8	66.2
LSD (0.05)	Cultivar [C] means			6.5		SE	3.2
LSD (0.05)	Pre-harvest [PH] treatment means			5.6		SE	2.8
LSD (0.05)	[C] x [PH] means			NS		SE	7..86

	Floral 2006						
	Pre-harvest treatment						
	Swathing			Desiccation			
Cultivar	Early	Rec.	Late	Early	Rec.	Late	Mean
	--------------------------- % dehulling efficiency ---------------------------						
CDC Robin	73.2	72.0	83.5	72.6	67.6	67.6	72.7
CDC Imperial	80.5	79.2	77.0	74.2	80.4	82.2	78.9
CDC Rosetown	70.3	60.9	77.9	73.2	63.0	62.5	67.9
CDC Blaze	76.7	75.1	74.4	71.5	69.2	78.0	74.1
CDC Impact	78.7	75.1	69.8	85.9	77.5	78.1	77.5
CDC Rouleau	74.7	89.7	87.4	86.0	81.2	90.8	84.9
CDC Redberry	91.5	88.1	86.7	87.8	85.3	90.5	88.3
CDC Red Rider	83.0	74.9	87.1	92.2	80.5	73.0	81.8
Mean	78.5	76.8	80.4	80.4	75.6	77.8	78.3
LSD (0.05)	Cultivar [C] means				6.5	SE	3.2
LSD (0.05)	Pre-harvest [PH] treatment means				NS	SE	2.8
LSD (0.05)	[C] x [PH] means				NS	SE	7.9

	Rouleau 2005						
	Pre-harvest treatment						
	Swathing			Desiccation			
Cultivar	Early	Rec.	Late	Early	Rec.	Late	Mean
	---------------------- % dehulling efficiency ----------------						
CDC Robin	89.7	86.2	88.9	87.6	88.6	86.9	88.0
CDC Imperial	88.0	86.1	87.5	89.0	90.4	89.7	88.4
CDC Rosetown	87.2	89.4	93.9	91.2	92.5	89.8	90.7
CDC Blaze	92.8	87.3	91.3	93.5	93.6	93.2	91.9
CDC Impact	92.0	85.2	93.7	91.4	89.5	89.9	90.2
CDC Rouleau	88.7	93.5	92.5	94.1	91.5	94.8	92.5
CDC Redberry	95.5	95.3	94.0	94.7	95.3	96.3	95.2
CDC Red Rider	97.0	96.4	93.9	95.3	94.0	95.9	95.4
Mean	91.3	89.9	91.9	92.1	91.9	92.0	91.5
LSD (0.05)	Cultivar [C] means			2.2		SE	1.1
LSD (0.05)	Pre-harvest [PH] treatment means			NS		SE	0.9
LSD (0.05)	[C] x [PH] means			NS		SE	2.6

	Rouleau 2006						
	Pre-harvest treatment						
	Swathing			Desiccation			
Cultivar	Early	Rec.	Late	Early	Rec.	Late	Mean
	% dehulling efficiency ----------------						
CDC Robin	90.8	92.9	91.7	90.0	90.2	90.5	91.0
CDC Imperial	93.1	95.4	95.1	93.2	94.5	92.3	93.9
CDC Rosetown	93.7	96.0	94.8	93.2	96.1	94.1	94.6
CDC Blaze	95.4	92.7	92.5	93.7	94.7	91.5	93.4
CDC Impact	96.2	93.7	95.5	95.2	94.5	95.1	95.0
CDC Rouleau	96.5	97.7	97.7	97.1	98.2	98.3	97.6
CDC Redberry	96.2	98.7	98.6	98.5	97.9	95.4	97.5
CDC Red Rider	96.7	93.4	96.6	95.3	97.9	97.5	96.2
Mean	94.8	95.0	95.3	94.5	95.5	94.3	94.9
LSD (0.05)	Cultivar [C] means				1.4	SE	1.2
LSD (0.05)	Pre-harvest [PH] treatment means				NS	SE	1.0
LSD (0.05)	[C] x [PH] means				NS	SE	0.3

Percent dehulling efficiency (% DE) refers to the proportion of the milled sample displaying footballs with two percent or less seedcoat adherence following milling.
LSD - Least Significant Differnence
SE - Stnadard Error

Results for %DE for both mills showed that significant differences existed between cultivars at all locations. As expected, the Turkish mill produced a much higher range in %DE values. Moreover, both mills produced higher %DE values for the larger seeded cultivars, CDC Redberry and CDC Red Rider, in particular. This stands to reason since larger seeds would make more contact with the milling stones, therefore producing less %FR but higher %DE values.

It is clear from these data that drier environments (Appendix VIII and IX) lend themselves to greater dehulling efficiencies. Both mills displayed a trend of increasing %DE, not only when comparing samples taken from wet harvest conditions (Floral, 2003) to those taken from drier situations, but also when comparing samples from cooler, more moist locations (Floral) with those from warmer, drier locations (Rouleau) within a single year (Appendix VII and VIII, Weather Data).

Effects of PHT on %DE were significant for both mills only in situations where harvest conditions were wet (Floral 2005). In this environment, SE treatments resulted in significantly higher %DE than all other treatments. The converse occurred with desiccation scenarios. In these cases, early treatments produced significantly lower %DE values than the later treatments. This suggests that in environments with cool wet harvest conditions, red lentil processors may optimize their dehulling efficiencies by buying lentils that were swathed at early maturity, but that buying material that was desiccated at an immature stage may reduce dehulling efficiencies. The results of this study show definite differences in seed coat adhesion between swathed and desiccated samples. Perhaps swathing allows biological processes related to decreased seed coat adherence to continue, whereas desiccating halts the biological process too quickly for this to occur. Significant C x PHT interactions were shown only by the Satake mill for Floral 2005. In this instance, cultivars with larger seeds combined with SE or DR treatments had the highest %DE, although these differences may not be readily apparent in an industrial milling situation. While no previous literature exists documenting the effect of C x PHT interactions on milling characteristics, Wang (2005) and Erskine et al. (1991) noted the effect of seed size. Although no specific details were provided, Wang (2005) noted in preliminary studies for his research on the optimization of a laboratory process for dehulling lentil, that seed size affected dehulling characteristics and, therefore, he conducted his study on seeds 4.5-5.0 mm in diameter. It is likely that in an industrial milling situation, the same genotype would produce less consistent milling characteristics if a broader range in seed sizes were milled at one time.

4.1.6 Correlation Analyses

Correlation analyses were conducted by year, by location and year, by preharvest treatment and by variety for the milling parameters %MR, %FR and %DE (Appendix I, II and III). Correlation coefficient values calculated by year showed a highly significant positive relationship among all samples in 2005. Correlations calculated by location revealed highly significant positive relationships for %MR from Floral 2005 and 2006. Correlation coefficients for %FR between milling methods were also calculated for year, location x year, PHT and C. All scenarios produced highly significant positive correlations.

Correlation analysis of %MR, %FR and %DE values revealed highly significant correlations within each variety. This reflects the low CV values, signifying that milling values for each cultivar were relatively homogenous across environments and milling methods (Appendix IV). When comparing correlations among PHTs for the three milling parameters, all treatments except SE had a highly significant positive relationship with the same treatments for other locations, varieties and milling methods. Significant positive correlations were found for

%DE when comparing C and PHT across varieties, locations and milling methods. Correlations in milling values were also significant across locations, with the exception of Rouleau 2006.

4.1.7 Yield

Although the effect of PHT on yield was not a primary focus of this experiment, it is obviously of great importance at the producer level. Overall yield values for location and cultivar were generally comparable to long term averages based on trial results (personal communication, A. Vandenberg). Results for the effect of PHT on yield during optimal harvest conditions are somewhat inconsistent, although, in general, recommended timings had the highest yield. It was clear, however, that during wet harvest conditions, early desiccation greatly reduced yield. In the case of this experiment, yield reduction from DE treatments was probably due to increased shattering or pod drop because the plants were left standing in a desiccated state longer than subsequent treatments. Sources of shattering would have been two-fold, some from splitting pods causing seed drop, and the remainder from degradation or weakening of the flower stalk leading to pod drop. It is possible that these losses may be amplified by the rapid desiccation of plant material following diquat application. Future research might focus on the specific effects and economic risks of desiccation by comparing the effects of diquat and glyphosate application with those of natural desiccation methods like swathing on the shattering characteristics of red lentil.

4.1.8 Percent Milling Recovery

Environment played the greatest role in %MR of red lentil samples in this study. During dry harvest conditions, effects of PHT and C were not significant. During wet harvest situations, lentil producers and processors can optimize %MR and reduce risk by swathing at early maturity or desiccating at recommended maturity. Furthermore, in sub-optimal weather conditions, significantly higher %MR values could be obtained with larger seeded varieties. Since lentil seed coats comprise approximately 6 to 7% of the total seed weight (Erskine et al., 1991; Singh et al., 1968), it stands to reason that a given volume of lentils will have less seed coat loss as size increases if dehulling efficiency is near its maximum potential. For example, Erskine et al. (1985) cited a study by the International Center for Agriculture Research in Dry Areas (ICARDA) that found seeds of 4 mm diameter lost an average of 8.19% of the original sample weight while seeds of approximately 3 mm diameter lost an average of 9.80%, reflecting the change in the seed surface to volume ratio. The lentil breeding program may also increase %MR by selecting for genotypes with larger diameter seeds and thinner seed coats, provided there are no negative agronomic effects from doing so. Beyond the efficiencies afforded by larger diameter genotypes referred to above, thicker seeds have rounded edges that can reduce damage in the form of chipped seed edges caused by the abrasive dehulling process.

4.1.9 Percent Football Recovery

In general, the effect of PHT on %FR was significant only in wet harvest situations. In these instances, risk to growers and processors may be reduced by applying early swathing or desiccation treatments. Although early PHT significantly increased %FR values in comparison to later treatments, this study found that %FR may be increased by over 20% by swathing instead of desiccating. Clearly, chemical desiccation caused lentil seeds to separate at the cotyledons more easily than swathing followed by natural drying. Perhaps swathing allows biological processes related to cotyledon binding to continue for a period, whereas desiccation ceases the processes too quickly, making the seeds more brittle.

Differences in mean %FR among cultivars were significant in all weather conditions. According to this study, during typical weather conditions in Saskatchewan, growers and processors can produce red lentils with high %FR by growing smaller seeded varieties. However, these data may be somewhat misleading on a commercial scale because of the lack of adjustment capability in the two mills used to generate these results. In commercial situations, adjustments in stone to seed clearance could be made to suit specific abrasive surface textures and seed thicknesses. To summarize, all things being equal, smaller diameter seeds produced higher %FR values for the techniques and instruments used in this study.

4.2. Percent Dehulling Efficiency

As with the other parameters studied, environment played the greatest role in determining %DE values. No significant differences were observed among PHTs during typical harvest conditions. However, lentil growers and processors could possibly improve %DE values by swathing early or desiccating at the recommended time. Considering the cost of diquat application, swathing would generally be considered more economical, particularly for early PHT in years with cool wet harvests. On the other hand, there are risks involved with swathing such as additional losses caused by wind. Because lentil must be cut so close to the ground in order to get the lowest pods, little stubble remains to hold the swath in place during windy conditions (Saskatchewan Pulse Growers, 2008).

4.2.1 Satake Versus Turkish Mills

Correlations between Satake and Turkish mill results were significantly ($P < 0.05$) positive. However, the Satake mill is clearly the preferred choice for research and industrial sample analysis because its milled product more closely resembles that of the potential results in a commercial mill (Wang, 2005). The results of this study show that significant differences in %MR, %FR and %DE exist among lentil cultivars and PHTs. This may allow for payment premiums for superior milling products if millers were confident that laboratory milling results increased predictive capability for milling parameters. Such a system would be less subjective and more easily organized if estimates of %MR, %FR and %DE were determined by the same process. Because of its superior design and consistent output, the Satake mill should be considered the industry and research standard for red lentil milling efficiency analysis. Red lentil processors should consider using a Satake mill in an effort to standardize the process leading to predictive milling efficiency estimates. In all cases, the milling protocol developed by Wang (2005) should be followed closely, with emphasis placed on seed moisture equilibrium at approximately 12.5%.

The usefulness of the Turkish mill should not be completely discounted. While studying milling efficiency, the Turkish mill produced a wider range in values than the Satake mill. It may be possible to use the Turkish mill for low cost visual selection of improved genotypes because the instrument can be loaded and unloaded more quickly than a Satake mill.

5. SUMMARY AND CONCLUSIONS

A series of experiments were conducted to determine the effects of various preharvest agronomic techniques on the milling quality of red lentil. Six preharvest treatments were applied. These involved either swathing (S) or chemically desiccating (D) plots at three different stages of plant maturity; early (E), recommended (R) and late (L). Preharvest treatments will, therefore, be referred to as SE, SR, SL, DE, DR and DL for plots swathed or desiccated at early, recommended or late stages of maturity, respectively.

Results from these experiments reveal three clear trends regarding red lentil production and milling. Firstly, cool wet weather at harvest has a pronounced effect on red lentil yield and %MR, %FR and %DE of milled red lentil seeds, regardless of which mill is used. These effects are relatively minor during premium harvest conditions. Secondly, red lentil producers and processors can manage risk in wet harvest situations through proper selection of PHT. Specifically, early swathing caused significant increases in yield, %MR, %FR and %DE. Conversely, early desiccation had the opposite effect, causing significant reductions in these values under poor harvest conditions. Yield was generally optimized when PHT was applied at the recommended stage. As maturity progresses to the recommended stage, desiccation results in higher milling values. Thirdly, although in most cases, the results from the Satake and Turkish mills were highly correlated, milling efficiency values using the Satake method were generally 5-10% higher that those from the Turkish method.

5.1 Suggestions for Future Research

The results of this research project bring forward questions that may be explored in future research. For example, effect of desiccation with diquat compared to swathing on shattering characteristics of red lentil genotypes is a topic that could be studied. Additionally, the effectiveness of the Satake mill in selecting for plumper, higher %MR and %FR cultivars might be explored. It may also be possible to investigate the possibility of developing lentil genotypes that are less prone to pod drop or shattering following desiccation. More detailed research on factors that influence seed coat adherence and cotyledon adherence may be warranted.

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7. APPENDICES

Appendix I: Summary of correlation analyses of means for % milling recovery of whole and split red lentils for Satake and Turkish dehullers by year, by location, by pre-harvest treatment and by cultivar.

All values are correlation coefficients.

Correlation by year

	2005	2006
2005	0.88**	
2006		0.34 ns

df=94

Correlation by location

		Floral 2005	Rouleau 2005	Floral 2006	Rouleau 2006
Floral	2005	0.92 **			
Rouleau	2005		-0.16 ns		
Floral	2006			0.48 **	
Rouleau	2006				-.03 ns

df=46

Correlation by pre-harvest treatment

	Des - E	Des - R	Des - L	Swa - E	Swa - R	Swa - L
Desiccation -Early	0.96 **					
Desiccation - Recommended		0.68 **				
Desiccation - Late			0.65 **			
Swathing - Early				0.12 ns		
Swathing - Recommended					0.87 **	
Swathing - Late						0.71 **

df=32

Correlation by cultivar

	CDC Impact	CDC Imperial	CDC Rosetown	CDC Red Rider	CDC Blaze	CDC Redberry	CDC Robin	CDC Rouleau
CDC Impact	0.85 **							
CDC Imperial		0.95 **						
CDC Rosetown			0.93 **					
CDC Red Rider				0.92 **				
CDC Blaze					0.81 **			
CDC Redberry						0.91 **		
CDC Robin							0.97 **	
CDC Rouleau								0.91 **

** Significant at P>0.01

ns = not significant

Des and Swa = Desiccated and Swathed, respectively

E, R, L = Early, Recommended and Late, respectively

Appendix II: Summary of correlation between means for percent football recovery of red lentils for Satake and Turkish dehullers by year, by location, by pre-harvest treatment and by cultivar.

All values are correlation coefficients.

Correlation by year

	2005	2006
2005	0.92 **	
2006		0.89 **
df=94		

Correlation by location and year

		Floral 2005	Rouleau 2005	Floral 2006	Rouleau 2006
Floral	2005	0.93 **			
Rouleau	2005		0.95 **		
Floral	2006			0.90 **	
Rouleau	2006				0.89 **
	df=46				

Correlation by pre-harvest treatment

	Desiccation			Swathing		
	Early	Recomm.	Late	Early	Recomm.	Late
Dessication - Early	0.92 **					
Dessication - Recommended		0.93 **				
Desiccation - Late			0.93 **			
Swathing - Early				0.90 **		
Swathing - Recommended					0.94 **	
Swathing - Late						0.92 **
df=32						

Correlation by cultivar

	CDC Impact	CDC Imperial	CDC Rosetown	CDC Red Rider	CDC Blaze	CDC Redberry	CDC Robin	CDC Rouleau
CDC Impact	0.92 **							
CDC Imperial		0.97 **						
CDC Rosetown			0.72 **					
CDC Red Rider				0.93 **				
CDC Blaze					0.92 **			
CDC Redberry						0.94 **		
CDC Robin							0.96 **	
CDC Rouleau								0.97 **

ns = not significant

** Significant at P>0.01

Des and Swa = Desiccated and Swathed, respectively

E, R, L = Early, Recommended and Late, respectively

Appendix III: Summary of Correlation of means for percent dehulling efficiency of whole and split red lentils between Satake and Turkish dehullers by year, by location, by pre-harvest treatment and by variety.

All values are correlation coefficients.

Correlation by year

	2005	2006
2005	0.75	
2006		0.84
df=94		

Correlation by location

		Floral 2005	Rouleau 2005	Floral 2006	Rouleau 2006
Floral	2005	0.71*			
Rouleau	2005		-0.34 *		
Floral	2006			0.73*	
Rouleau	2006				0.28
	df=46				

Correlation by pre-harvest treatment

	Desiccation			Swathing		
	Early	Recomm.	Late	Early	Recomm.	Late
Desiccation - Early	0.79*					
Desiccation - Recommended		0.87*				
Desiccation - Late			0.9*			
Swathing - Early				0.77*		
Swathing - Recommended					0.84*	
Swathing - Late						0.84*
df=32						

Correlation by cultivar

	CDC Impact	CDC Imperial	CDC Rosetown	CDC Red Rider	CDC Blaze	CDC Redberry	CDC Robin	CDC Rouleau
CDC Impact	0.76*							
CDC Imperial		0.75*						
CDC Rosetown			0.88*					
CDC Red Rider				0.81*				
CDC Blaze					0.88*			
CDC Redberry						0.62*		
CDC Robin							0.93*	
CDC Rouleau								0.81*

** Significant at P>0.01

ns = not significant

Des and Swa = Desiccated and Swathed, respectively

E, R, L = Early, Recommended and Late, respectively

Appendix IV: Analysis of Variance for Yield - All Sites & Years

		2005			2005			2006			2006		
Location	DF	Floral			Rouleau			Floral			Rouleau		
Total	191	MS	F-value	p	MS	F-value	p	MS	F-value	p	MS	F-value	p
Rep	3	70802.31	2.19	NS	134508.93	7.58	**	595659.13	17.53	**	188051.06	10.71	**
Variety (V)	7	641477.30	19.83	**	355609.75	20.05	**	352488.02	10.38	**	153312.97	8.74	**
Treatment (T)	5	1006526.86	31.11	**	495007.22	27.90	**	926019.89	27.26	**	335036.52	19.09	**
V x T	35	68536.95	2.12	*	31500.06	1.78	*	35992.31	1.06	NS	19853.67	1.13	NS
Error	141	32355.23			17739.95			33970.84			17551.32		
		SE	LSD .05		SE	LSD .05		SE	LSD .05		SE	LSD .05	
LSD (V)	n=24	52	102		38	76		53	105		38	75	
LSD (T)	n=32	45	89		33	66		46	91		33	65	
LSD V x T	n=4	127	251		94	186		130	257		94	185	
T-VALUE=1.97													
		CV	20.4		CV	18.6		CV	18.1		CV	20.5	

LSD - Least Significan Difference
SE - Standard Error
CV - Coefficient of Variation

Appendix V: Analysis of Variance for Percent Milling Recovery: Turkish & Satake Mills

			2005			2005			2006			2006	
Location	DF		Floral			Rouleau			Floral			Rouleau	
Total	95	MS	F-value	p	MS	F-value	p	MS	F-value	p	MS	F-value	p
Rep	1	0.11	0.02	NS	13.83	6.98	*	9.70	1.33	NS	0.26	0.20	NS
Variety (V)	7	31.47	4.58	**	53.09	26.81	**	58.78	8.04	**	42.99	33.01	**
Treatment (T)	5	579.01	84.20	**	2.50	1.26	NS	5.70	0.78	NS	2.18	1.68	NS
V x T	35	23.22	3.38	**	1.81	0.91	NS	5.60	0.77	NS	1.32	1.02	NS
Error	47	6.88			1.98			7.31			1.30		
		SE	LSD .05		SE	LSD .05		SE	LSD .05		SE	LSD .05	
LSD (V)	n=12	1	2		1	1		1	2		0	1	
LSD (T)	n=16	1	2		0	1		1	2		0	1	
LSD V x T	n=2	2.62	5.27		1.41	2.83		2.70	5.44		1.14	2.29	
T-VALUE=2.01													

Analysis of Variance for Percent Milling Recovery: Satake Mill

			2005			2005			2006			2006	
Location	DF		Floral			Rouleau			Floral			Rouleau	
	95	MS	F-value	p	MS	F-value	p	MS	F-value	p	MS	F-value	p
Rep	1	25.42	4.62	*	8.916	3.84	NS	0.106	0.03	NS	0.0001	0	NS
Variety (V)	7	141.672	25.74	**	7.803	2.26	*	43.921	13.58	**	3.981	4.78	*
Treatment (T)	5	565.543	102.73	**	0.954	0.41	NS	2.911	0.9	NS	0.419	0.5	NS
V x T	35	17.476	3.17	**	2.168	0.93	NS	4.873	1.51	NS	1.134	1.36	NS
Error	47	5.504			2.32			3.235			0.832		
		SE	LSD .05		SE	LSD .05		SE	LSD .05		SE	LSD .05	
LSD (V)	n=12	0.96	1.9		0.62	1.2		0.73	1.5		0.37	0.7	
LSD (T)	n=16	0.83	1.7		0.54	1.1		0.64	1.3		0.32	0.6	
LSD V x T	n=2	2.35	4.7		1.52	3.1		1.80	3.6		0.91	1.8	
T-VALUE=2.01													

LSD - Least Significant Differnce, SE - Standard Error, CV - Coefficient of Variation

Appendix VI: Analysis of Variance for Percent Football Recovery: Satake & Turkish Mills

			2005			2005			2006			2006	
Location	DF		**Floral**			**Rouleau**			**Floral**			**Rouleau**	
Total	95	MS	F-value	p	MS	F-value	p	MS	F	p	MS	F	p
Rep	1	391.23	10.7	*	26.36	2.19	NS	171.05	9.76	*	6.20	0.36	NS
Variety (V)	7	908.40	24.85	**	3649.75	302.74	**	3806.90	217.29	**	4551.27	264.73	**
Treatment (T)	5	2835.30	77.55	**	214.51	17.79	**	51.98	2.97	*	10.20	0.59	NS
V x T	35	46.79	1.28	NS	22.36	1.86	*	27.40	1.56	NS	16.71	0.97	NS
Error	47	36.56			12.06			17.52			17.19		
		SE	LSD .05		SE	LSD .05		SE	LSD .05		SE	LSD .05	
LSD (V)	n=12	2.47	5.0		1.42	2.9		1.71	3.4		2.93	5.9	
LSD (T)	n=16	2.14	4.3		1.23	2.5		1.48	3.0		2.39	4.8	
LSD V x T	n=2	6.05	12.2		3.47	7.0		4.19	8.4		0.85	1.7	
T-value = 2.02		CV	23.89			7.34			6.74			5.89	

LSD - Least Significant Difference, SE - Standard Error, CV - Coefficient of Variation

Appendix VII: Analysis of Variance for Percent Dehulling Efficiency: Satake & Turkish Mills

		2005			2005			2006			2006		
Location	DF		**Floral**			**Rouleau**			**Floral**			**Rouleau**	
Total	95	MS	F-value	p	MS	F-value	p	MS	F-value	p	MS	F-value	p
Rep	1	10.08	0.76	NS	0.80	4.48	*	15.76	4.46	*	0.07	0.4	NS
Variety (V)	7	72.82	5.53	**	0.22	1.23	NS	14.02	3.96	*	0.60	3.65	*
Treatment (T)	5	129.36	9.82	**	0.08	0.44	NS	3.42	0.97	NS	0.21	1.3	NS
V x T	35	34.17	2.59	*	0.19	1.06	NS	2.96	0.84	NS	0.07	0.41	NS
Error	47	13.18			0.18			3.54			0.16		
		SE	LSD .05		SE	LSD .05		SE	LSD .05		SE	LSD .05	
LSD (V)	n=12	1.48	3.0		0.17	0.3		0.77	1.5		0.29	0.8	
LSD (T)	n=16	1.28	2.6		0.15	0.3		0.66	1.3		0.23	0.7	
LSD V x T	n=2	3.63	7.3		0.42	0.9		1.88	3.8		0.08	0.2	
T-value = 2.02		CV	3.80			0.43			1.92			0.41	

Analysis of Variance for Percent Dehulling Efficiency: Turkish Mill

		2005			2005			2006			2006		
Location			**Floral**			**Rouleau**			**Floral**			**Rouleau**	
Total	95	MS	F-value	p	MS	F-value	p	MS	F-value	p	MS	F-value	p
Rep	1	46.573	0.75	NS	124.898	18.15	**	73.675	1.19	NS	1.787	0.64	NS
Variety (V)	7	879.298	14.24	**	92.412	13.43	**	536.2	8.64	**	59.009	21.2	**
Treatment (T)	5	711.433	11.52	**	11.273	1.64	NS	60.008	0.97	NS	3.232	1.16	NS
V x T	35	98.56	1.6	NS	7.317	1.06	NS	55.007	0.89	NS	3.037	1.09	NS
Error	47	61.758			6.879			62.075			2.783		
		SE	LSD .05		SE	LSD .05		SE	LSD .05		SE	LSD .05	
LSD (V)	n=12	3.21	6.5		1.07	2.2		3.22	6.5		1.18	3.4	
LSD (T)	n=16	2.78	5.6		0.93	ns		2.79	ns		0.96	ns	
LSD V x T	n=2	7.86	ns		2.62	ns		7.88	ns		0.34	ns	
T-value = 2.02		CV	11.89			2.87			10.07			1.77	

LSD - Least Significant Difference, SE - Standard Error, CV - Coefficient of Variation

Appendix VIII: Climate summary data for Rouleau 2005 and 2006 (Moose Jaw Environment Canada weather station)

Monthly Data Report for 2005								
Month	Mean Max Temp °C	Mean Temp °C	Mean Min Temp °C	Extr Max Temp °C	Extr Min Temp °C	Total Rain mm	Total Snow cm	Total Precip mm
May	17.2	9.6	1.9	25.7	-10.6	39.4	0	39.4
Jun	21.8	15.9	10	34.7	4.7	113.8	0	113.8
Jul	26.1	18.6	11.1	36.7	4.3S	91.2	0	91.2
Aug	25.1	17.1	9.1	37.2	3.5	113	0	113
Sep	20.9	12.8	4.7	34.1	-5.8	71.2	0	71.2
Oct	13.5	5.8	-1.9	20.8	-9.2	11	0	11
Sum						**439.6**	**0**	**439.6**
Avg	**20.8**	**13.3**	**5.8**					
Xtrm				**31.5**	**-3.5**			

Monthly Data Report for 2006								
Month	Mean Max Temp °C	Mean Temp °C	Mean Min Temp °C	Extr Max Temp °C	Extr Min Temp °C	Total Rain mm	Total Snow cm	Total Precip mm
May	19.5	12.4	5.2	33.8	-3.5	60.4	0	60.4
Jun	22.6	16.2	9.8	33	4.2	125	0	125
Jul	27	19.5	12	33.6	7	87.8	0	87.8
Aug	27.8	18.9	9.9	35.2	4.2	15.6	0	15.6
Sep	19.4	12.3	5.2	32.1	-4.2	84.2	0	84.2
Oct	8.2	2.1	-4.1	23.1	-11.5	23	1.1	24.1
Sum						**396**	**1.1**	**397.1**
Avg	**20.8**	**13.6**	**6.3**					
Xtrm				**31.8**	**-0.6**			

Appendix IX: Climate summary data for Floral 2005 and 2006 (Saskatoon Environment Canada weather station)

Monthly Data Report for 2005								
Month	Mean Max Temp °C	Mean Temp °C	Mean Min Temp °C	Extr Max Temp °C	Extr Min Temp °C	Total Rain mm	Total Snow cm	Total Precip mm
May	17	10.2	3.4	25.1	-9.6	27.5	0	27.5
Jun	19.5	14.4	9.2	30	5.8	160.5	0	160.5
Jul	24.1	17.5	10.8	31.8	3.3	53.5	0	53.5
Aug	22.2	15.4	8.5	31	2	53.5	0	53.5
Sep	18	11.3	4.5	28.7	-4.2	74	0	74
Oct	11.9	5.2	-1.5	18.3	-9.4	18	0	18
Sum						**387**	**0**	**387**
Avg	**18.8**	**12.3**	**5.8**					
Xtrm				**27.5**	**-2.0**			

Monthly Data Report for 2006								
Month	Mean Max Temp °C	Mean Temp °C	Mean Min Temp °C	Extr Max Temp °C	Extr Min Temp °C	Total Rain mm	Total Snow cm	Total Precip mm
May	17.9	11.7	5.4	31.1	-5.8	39.8	0	39.8
Jun	22.2	16.2	10.1	32.3	4.5	108	0	108
Jul	27.1	20	12.9	32.7	8.4	32	0	32
Aug	26.1	18	9.8	33.9	3.1	30	0	30
Sep	18.7	12.2	5.7	31	-2.3	118	0	118
Oct	6.9	1.6	-3.8	21.2	-11.1	31	1.5	32.5
Sum						**358.8**	**1.5**	**360.3**
Avg	**19.8**	**13.3**	**6.7**					