

**EFFECT OF STORAGE PRE-TREATMENTS AND CONDITIONS ON THE DEHULLING
EFFICIENCY AND COOKING QUALITY OF RED LENTILS**

By

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LIST OF ABBREVIATIONS

DE	Dehulling efficiency
DL	Dehulling loss
MC	Moisture content
FR	Force ratio of the force-deformation curves
DR	Deformation ratio of the force-deformation curves

ABSTRACT

This study focuses on investigating the effect of post-harvest handling conditions and storage time on the dehulling efficiency and cooking quality of two varieties of red lentils, as well as optimizing dehulling conditions. Dehulling efficiency was studied with a Satake grain testing mill model TM05C. After the milling operation, the different fractions were separated and dehulling efficiency and dehulling losses were calculated. Dehulled samples were cooked and then tested with an Instron Universal Testing Machine equipped with an Ottawa texture cell fitted with an extrusion insert. Force-deformation diagrams were obtained and analyzed for slope of the curve, force ratio and deformation ratio. Slopes indicated the hardness of the sample while force and deformation ratios depicted if a sample was undercooked, overcooked or optimally cooked.

Response surface methodology was used to determine the effects of pre-milling moisture content, milling speed, and milling time. Dehulling efficiency and dehulling loss were the responses that were maximized and minimized, respectively, in order to optimize the milling operation.

The effects of storage time, storage moisture content and storage temperature, as well as the effect of different storage pre-treatments aiming to simulate post-harvest handling, were studied. Furthermore, for dehulling efficiency the effect of pre-milling treatment was included as well as the effect of cooking time in cooking quality tests.

Dehulling efficiency was mostly affected by the pre-milling moisture content, regardless of the storage conditions. Storage pre-treatments involving moisture content changes lowered the dehulling efficiency and increased the amount of broken and powder fractions of both varieties of red lentils, whereas freezing and thawing cycles had less of a negative effect on the dehulling characteristics. Drying temperature was a factor for the storage pre-treatment involving one drying cycle and it was found that higher temperature had less negative effect as compared to near-ambient temperatures, probably due to shorter drying times. Storage moisture content was only an important factor in the storage pre-treatments involving drying and rewetting cycles, while storage temperature had only minor effects on the dehulling efficiency or losses. Storage time affected the dehulling characteristics but its contribution is lower compared to pre-milling moisture content and storage pre-treatment.

Textural parameters were mostly affected by storage time; samples became harder after storage. Similar to dehulling efficiency results, moisture content during storage affected the storage pre-treatments involving changes in the moisture before storage. Storage pre-treatment was also implicated in the changes in textural parameters, especially pre-treatments involving moisture changes within the samples, which seemed to increase the textural parameters and therefore the hardness of cooked samples.

1. INTRODUCTION

Lentil is a bushy annual plant known for its lens-shaped seeds. It is a very important pulse crop and it is widely consumed in many Middle Eastern countries and India in soups, stews and many vegetarian dishes due to its high protein content and quality.

Among the world's pulse production, lentil production has been increasing during the past 10 years and the seeded area of lentils is expected to grow due to good returns and lower risks as compared to other pulse crops (Agriculture and Agri-Food Canada, 2010). Red lentils have grown to represent 30-35% of Canada's total export market, and this production is expected to grow. Agblor (2006) explained one of the objectives of Saskatchewan Pulse Growers was to increase the red lentil production and processing in Canada, since red lentils are globally the most consumed type of lentil.

Lentils can be green, red or brown, depending on the colour of the cotyledon. Red lentils are mostly consumed as dehulled split seeds and therefore the dehulling characteristics are very important for producers and processors. Dehulling efficiency is generally calculated as the percentage of dehulled whole and dehulled split seeds; in this study, dehulling efficiency also takes into account the percentage of unde-hulled seeds to give a more comprehensive measure of the efficiency of the dehulling process.

Knowledge of the behaviour of lentils after different storage conditions, and milling pre-treatments would bring opportunities to producers for red lentils to be processed

instead of being sold as a raw material, increasing the value of the product and thus helping the agricultural economy of Canada.

As stated before, red lentils are mostly consumed in soups and stews and therefore the cooking quality is an important parameter that must be considered as a quality parameter of the end product. Overall good quality, encompassing good dehulling efficiency and cooking quality, of red lentils is desired in order to be competitive in the global marketplace.

The main objective of this research is to evaluate the effect of different storage conditions (different temperatures, duration of storage, storage pre-treatments including tempering, drying or freezing, and final milling pre-treatment) on the post-harvest operations of red lentils, and generating a recommendation to producers and processors in terms of optimum conditions for red lentils to be handled, stored and processed.

Specific objectives include:

- Evaluation of the optimum dehulling operation conditions for two red lentil cultivars, using samples that have not undergone storage pre-treatments and evaluating the effect of storage time on the optimum conditions obtained.
- Determination of the effect of storage time, temperature and moisture content, as well as storage pre-treatment and pre-milling conditioning on the dehulling efficiency of red lentils.

- Evaluation of the effects of storage time, temperature, moisture content, pre-treatment and cooking time on textural quality parameters that translate to cooking quality.

2. LITERATURE REVIEW

2.1 Lentil

2.1.1 History

The history of the lentil is as old as Agriculture. Lentil (*Lens culinaris*) is indigenous to the near East and Central Asia, where the first evidence of cultivation was found (Sandhu & Singh, 2007) and it has been noted that some of the oldest remains of food plants are of lentils dated 7500-8500 BC (Smartt, 1990).

Lentil is a bushy annual plant grown for its lens-shaped seeds; it is a pulse (grain legume) crop. The lentil plant varies from 15 to 45 cm height and has many long ascending branches. The pods are broadly oblong, slightly inflated and contain two seeds, which have the shape of a doubly convex lens (Sandhu & Singh, 2007).

2.1.2 Uses

Lentils are mainly used for human consumption as a protein source in different products, including soups, stews, and vegetarian dishes (Oplinger et al., 1990). Lentil seeds are consumed either as whole grain or as dehulled *dhal* (dehulled split seeds) and it is used as a staple food in many Middle Eastern countries and India (Sandhu & Singh, 2007). *Dhal* is consumed in Southeast Asia as a thick slurry after cooking or boiling in water. Other popular products include *warri*, *varion*, canned lentil and lentil soup (Bhattacharya, 2005). It is said that combined with a cereal, lentils provide the

exact combination of essential amino acids required by the human body (Goodwin, 2003).

Pulses, including lentils, are being increasingly used in health-conscious diets to promote well-being and reduce the risk of illness (Yadav et al., 2007). Eating lentils might help lower blood cholesterol levels due to their high content of soluble fibre (Rani & Kawatra, 1994).

2.1.3 Composition

Lentil seeds have three main components: the seed coat, cotyledons and embryo, which constitute respectively 8, 90 and 2% of the total seed weight (Sokhansanj & Patil, 2003).

The chemical composition of raw lentils is provided in Table 2.1. In addition to these major components, lentils are also rich in calcium, phosphorus, iron, sodium, potassium, thiamine, riboflavin, and niacin (Adsule et al., 1989). Among the cool season legumes, lentils are rich in amino acids that are low in vegetarian diets (e.g. lysine, arginine, leucine, and sulphur containing amino acids (Yadav et al., 2007)).

Table 2.1 Chemical composition of raw lentil per 100 g of dry matter (Urbano et al., 2007)

	Range
Energy (kJ)	1483-2010
Total Nitrogen (g)	3.72-4.88
Protein (N 6.25) (g)	20.6-31.4
Non-protein Nitrogen (g)	0.49-1.049
Fat (g)	0.7-4.3
Carbohydrates (g)	43.4-69.9
Fibre (g)	5.0-26.9
Ash (g)	2.2-4.2

2.2 Red lentil

Red lentil varieties have brown, grey or pale green seed coats with an orange reddish cotyledon. The colour of the seed coat has some influence on the resistance of the seed to weathering damage; grey seed coats tend to bleach. Crimson varieties are considered “the old standard” (Roesler, 2008). CDC Impact is a 2006 cultivar produced using the CLEARFIELD® production system with similar seed traits to varieties with crimson and brown seed coat. CDC Redberry is a flatter, larger seed with grey seed coats that was released in 2004.

2.2.1 Red lentil production in Canada

Canada has become an important producer and exporter of lentils. Production in Canada is done in the Western provinces, cultivation in Manitoba and Saskatchewan was introduced during the grain surplus years of the early 1970’s (Bhatty, 1988).

Total lentil production in Canada has ranged from 734 kilo tonnes for the 2007-2008 crop to 1,510 kt for the 2010-2011 crop (Agriculture and Agri-food Canada, 2010). The area seeded is expected to increase due to good returns and lower risks compared to other pulse crops. Exports are expected to remain near the record level at 1.2 Mt. (Agriculture and Agri-Food Canada, 2010). Furthermore, the secondary processing capacity of red lentil within Canada has expanded recently (Saskatchewan Agriculture and Food, 2007) and therefore there is potential to increase the value of exports.

It is estimated that 75% of the total world lentil production is the red type, but until a few years ago, Canada had been primarily a green lentil producer. The red lentil market has grown to represent between 30-35% of Canada's total lentil export market. In 2002-2003, red lentils represented an export value of \$50 million (Agblor, 2006). With the exception of North America and Australia, most lentils are consumed in the region of production. Thus, the export market for red lentils is very important for North American and Australian producers. Commercial production of red lentils in Western Canada has increased to over 600,000 acres in 2006 (Vandenberg, 2007), and there is a potential for this production to increase. The problem that Canadian red lentil producers face is that the Western Canadian climate is very different from other lentil producing and importing countries. Consequently, when lentils are exported to these regions, they may undergo biochemical changes which adversely affect their end-use and dehulling properties (Wang, 2008).

Principal competitors in the production of red lentils are Turkey, Australia and India (Boersch, 2005). The limitations of the competitors for cropland, and the fact that Turkey's production and export of red lentils have trended lower (Vandenberg, 2007), might give Canada a big opportunity for increasing the production and export of red lentils if knowledge for optimum handling and storage conditions are created.

2.2.2 Red lentil processing

About 90-95% of all red lentils are consumed as dehulled seed either in a whole form (footballs) or split seeds; therefore, the dehulling process is one of the most important operations in post-harvest handling and the dehulling characteristics, milling yield and quality of lentils are very important parameters for potential customers.

It is generally recognized that red lentils should be stored at low moisture content (under 13% moisture is considered safe), otherwise splitting and dehulling processes become harder and the milling yield decreases (Saskatchewan Agriculture and Food, 2007). Information on the influence of different storage conditions and varieties on the dehulling process of red lentils is important for producers when they pick the variety to grow, as well as for processors trying to obtain the best dehulling yields.

It has been observed that storage pre-treatments of lentils affect the dehulling efficiency of red lentils (Erskine et al., 1991; Wang, 2005), and so the protein content, and variety of the red lentils (Wang, 2008). Agblor (2006) states that the factors that might affect the milling quality of red lentils include seed moisture content, seed

wrinkling, seed coat thickness and adherence, seed coat staining and seed coat damage.

The milling quality of Canadian red lentils has been found to be lower than that of the major competitors (Agblor, 2006). For this reason, studies of post-harvest operations that aim to develop a handling system that maintains the market and processing quality of red lentils is needed to maximize the value for producers and processors.

2.3 Dehulling operations

2.3.1 Introduction

Before cooking or other processing operations, it is often necessary to remove the seed coat of pulses. This step reduces the fibre content, improves the appearance, texture and palatability of pulses (Sokhansanj & Patil, 2003) as reflected in decreased cooking time. Dehulling is the most important operation during post-harvest handling of pulses, and hence plays an important role in processing and utilization (Singh, 1995). The dehulling process, also called primary processing, converts the whole seed of pulses into *dhal*, which can be consumed in various forms.

Historically, the dehulling of pulses in developing countries has been done at home by women (Singh, 1995). The process has evolved and important methods for industrial dehulling have been developed. Usually, the sequence in pulse dehulling is a pre-milling treatment, followed by dehulling and finally splitting, but several variations exist in these steps (Sokhansanj & Patil, 2003).

2.3.2 Dehulling pre-treatments

Pre-treatments before dehulling are usually employed to loosen the seed coats and therefore facilitate the ease of the dehulling operation. According to Singh (1995) there are two categories of pre-treatments for pulses: wet treatments and dry treatments.

Traditionally, in developing countries pulses are soaked in water for a short time before manual dehulling (Sokhansanj & Patil, 2003). This wet method has the advantage of preventing excessive breaking of the cotyledons while facilitating good dehulling (Singh, 1995; Sefa-Dedeh & Stanley, 1979a; Black et al., 1998; Mangaraj & Singh, 2009).

Chemical treatments are also used to promote the ease of dehulling. Singh & Sokhansanj (1984) used sodium bicarbonate and sodium chloride at different concentrations for dehulling of pigeonpea. Saxena et al. (1981) treated pigeonpea with aqueous solutions of calcium hydroxide, sodium hydroxide, and sodium carbonate. They determined sodium bicarbonate was the most effective pre-treatment.

Black et al. (1998) reported preconditioning treatments for dehulling of field peas involving vegetable oil and preheating. These methods are usually coupled with sun drying. Oil appears to penetrate thorough the hull to the cotyledons and releases its binding under the mild heat of the sun (Singh, 1995). Dry treatments involving addition of water to the seeds for later drying can help the milling process by expanding the

seed coat which helps in loosening the hull during drying (Sokhansanj & Patil, 2003). These methods produce *dhal* that cooks faster, but also result in high dehulling losses due to breakage and powdering (Singh, 1995).

2.3.3 Dehulling methods

Dehulling of pulses is preferably achieved by subjecting the grains to an abrasive force. It can be achieved mechanically with attrition-type dehullers (DeMan et al., 1973). Grains pass through a cylindrical head where a drum rubs the grains against a cylindrical metal screen (Reichert & Youngs, 1976).

Abrasive-type dehullers have also been used for dehulling of pulses (Reichert et al., 1984; Kurien & Parpia, 1968) especially for pulses with more tightly adhering seed coats (Kurien, 1984). This type of dehuller uses a carborundum or emery surface to gradually abrade the seed coat from the cotyledon (Reichert et al., 1984). In a continuous operation, grains are fed into the machine through a hopper located at one end and, after the action of the stones, are released through an overflow outlet (Reichert & Youngs, 1976).

One of the most widely used abrasive-type dehullers for research studies is the tangential abrasive dehulling device (TADD), which was developed in the Prairie Regional Laboratory (PRL) of the National Research Council of Canada in Saskatoon (Sokhansanj & Patil, 2003). The average results from the TADD are comparable to those of commercial *dhal* mills in India (Singh, 1995). Other designs include a Pulse

Processing Laboratory from the Central Institute of Agricultural Engineering, Bopal, India (Sahay & Bisht, 1988), a Schule design, used by European manufacturers, and a minimill dehuller from the Central Food Technological Research Institute, (CFTRI) in Mysore, India (Sokhansanj & Patil, 2003).

Wang (2005) found that a laboratory Satake testing mill was suitable for dehulling lentils with good reproducibility, and has used it for studies on the effects of preconditioning and varieties in the dehulling efficiency of red lentils. This testing mill works with an abrasive stone rotating at variable speeds. The stone, which is surrounded by a screen, crushes the lentils causing the hulls to break and the seeds to split. This mill has been used for red lentils (Wang, 2008), pigeonpeas (Goyal et al., 2008; Goyal et al., 2009), black gram (Tiwari et al., 2008) and field peas (Black et al., 1998).

2.3.4 Factors affecting dehulling of pulses

The outcome or yield after dehulling operations depends upon many factors. These can be either intrinsic seed characteristics, seed handling parameters, or the dehulling process itself.

Seed characteristics, including the nature of the seed coat, have an effect on the dehulling properties of pulses. If there is a higher content of seed coat, the cotyledon yield will be lower (Singh, 1995). The structure of the seed coat is another factor to consider. Sefa-Dedeh & Stanley (1979a) suggested that smooth seed coats dehull more

satisfactorily than those with thin, rough seed coats. Ehiwe & Reichert (1987) considered that the major factor responsible for good dehulling quality was how loosely the seed coat is bound to the cotyledon. The size of the seed also plays an important role in the dehulling behaviour. Erskine et al. (1991) found that large seeds have lower dehulling efficiencies due to increased broken and powder fractions. Finally, the variety, growing conditions and environment have also been related to changes in the dehulling properties of pulses (Wang, 2008; Ehiwe & Reichert, 1987).

The way in which pulses are handled and stored affects their dehulling yield. High seed moisture content has been shown to decrease the dehulling efficiency of pulses (Ehiwe et al., 1987; Mazza & Campbell, 1985; Wang, 2005). Another factor is the temperature at which pulses are stored. Limited studies have been performed assessing the effect of temperature on dehulling efficiency; Mazza & Campbell (1985) reported the dehulling of buckwheat to be unaffected by temperature. On the other hand, the pre-conditioning treatment before dehulling has been extensively studied as reflected in section 2.3.2. Most common pre-treatments that have been proven to aid in the loosening of seed coats and leading to increased dehulling yields include moisture content addition, soaking in chemical solutions or vegetable oils (Black et al., 1998; Tiwari et al., 2008; Goyal et al., 2008).

Finally, dehulling yield is influenced by the dehulling method used and the parameters involved in it. Operating conditions involved include the type of mill, the speed, and the dehulling time (Wang, 2005; Reichert & Youngs, 1975). Generally, increase in

dehulling time and speed of the motor used increase dehulling efficiency; nevertheless Wang (2005) found that even when the percentage of dehulled and split seeds increased, broken and powder fractions were also higher.

2.3.5 Methods for optimization of dehulling operations

Response surface technology (RSM) is a statistical and mathematical technique useful for developing, improving and optimizing processes. It is particularly useful in situations where several input variables potentially influence some quality characteristic of the product or process (Myers & Montgomery, 1995).

One of the key elements in analysis of problems with RSM is finding the relationship between the response and the independent factors, which can be done using a linear function or a polynomial of higher degree when there is a curvature in the system (Montgomery, 1991). In addition, this technique is designed to focus on the importance of factors and thus eliminate the unimportant ones (Myers & Montgomery, 1995). Once the important independent factors are identified, it is determined if the levels of the factors result in a value of the response that is near an optimum or target value. When more than one response is analyzed, the contour plots of the response surfaces can be overlapped in order to identify conditions that produce the responses that meet the predetermined desirable criteria.

RSM has been successfully used for optimization of dehulling of pigeonpea (Goyal et al., 2008; Mandgaraj & Singh, 2009) and red lentils (Wang, 2005). In these studies,

common factors included the moisture content of the seeds at the time of dehulling, speed of the dehuller and time of dehulling. All reported optimization studies used a second-order polynomial model.

2.4 Cooking quality of pulses

Cooking quality is one of the most important criteria for lentils because they are used in many culinary dishes (Bhatty, 1988). For determining cooking quality there is a need for parameters that can determine the point when it is properly cooked, and characterize the product at this point. Cooking of lentils is mostly done by heating in boiling water for a determined period of time; commonly red lentils are cooked until a soft, squishy texture is achieved. Iliadis (2001) reported that lentils presented a cooked texture when they become pasty when lightly compressed between the thumb and a finger.

2.4.1 Changes during cooking

During the cooking of pulses, two simultaneous processes occur inside and outside the cotyledon cells. Gelatinization of intracellular starch and denaturation of proteins are accompanied by softening of the seeds as a result of plasticization or partial solubilisation of the middle lamella, which leads to separation of individual cotyledon cells (Klamczynnska et al., 2001; Wang et al., 2003). Bhatty et al. (1984) reported that scanning electron microscopy (SEM) showed a complete loss of cellular structure in cooked lentils, while undercooked samples showed a lack of dissolution of the intercell

wall material, including pectin. Softening of cowpeas has been reported to occur in three phases. During the initial phase, the rate of softening is low; at this point the middle lamella exhibited a loss in structure which denotes the beginning of the softening process. During the second phase there is a rapid reduction in the hardness of the seeds corresponding to the breakdown of the middle lamella. During the third phase there is little change in the hardness, the water absorption components have reached the saturation point and thus the changes in texture are very slow (Sefa-Dedeh et al., 1978).

Problems that result in poor cooking quality are very common among pulses. The hard-to-cook phenomenon is a textural problem defined as the failure of the seeds to soften sufficiently during the normal cooking process. This phenomenon is produced because of reduced rate of cotyledon cell separation, which is due to either reduced middle lamella solubility or reduced water imbibition values leading to turgor pressure which is too low to force the cells apart (Vimala & Pushpamma, 1985). This defect has been shown to appear in samples stored at high humidity and temperature (Sefa-Dedeh et al., 1979). The hard shell or seed coat defect appears to be more physical in nature and it is the failure of seed coats to imbibe sufficient amounts of water prior to cooking (Stanley & Aguilera, 1985). The structural element for this defect is the testa, but more specifically, the palisade layer contained within the seed coat, the hilum, the strophiose, and various waterproofing substances (Antunes & Sgarbieri, 1979).

2.4.2 Methods for cooking quality measurement

Analysis of the cooking quality of pulses has seen very different approaches. One of the most common ways to determine this important parameter has been with subjective methods, but the conditions are very difficult to reproduce (Bhatty, 1988). The time to reach a cooked texture has been used as an indicator of the cooking quality in lentils (Erskine et al., 1985) and chickpeas (Williams et al., 1983). In these studies, individual seeds were taken from the boiling process and pressed between the thumb and a finger; optimum cooking time was determined by the time when most seeds appear to have a soft texture. Other studies on legumes (Singh et al., 1988) and rough rice (Meullenet et al., 2000) have focused on sensory evaluation of samples cooked at different times.

Objective methods include penetration studies of individual kernels. Iliadis (2001) has used a penetrometer coupled with subjective evaluation to determine hardness of lentils. Anzaldua-Morales et al. (1996) also used the puncture force of 40 seeds to determine force vs. cooking time curves of six different legumes. Furthermore, a cooker was developed by Mattson (1946) for yellow peas; this apparatus is a series of vertical plungers with a determined weight that penetrate individual seeds when the kernel is sufficiently tender. Samples are considered cooked when the plungers have penetrated a predetermined percentage of seeds. This method has been adapted to measure cooking times of dry beans by Burr et al. (1968) and later an automated

version has been used for yellow peas, lentils, chickpeas, navy beans (Wang & Daun, 2005) and field peas (Wang et al., 2010).

The Mattson cooker has the disadvantage of measuring only cooking time and not the way in which texture changes. Wang et al. (2010) have coupled cooking time measurements with the determination of firmness by shear compression tests. These types of compression tests where textural characteristics are related to cooking quality rather than only cooking time seem to give a more comprehensive approach to the measurement of this quality parameter.

Tests applying uniaxial compression have been performed on chickpeas, wrinkled and smooth peas (Klamczynska et al., 2001) and on beans (Buckle & Sambudi, 1990) by compressing samples to a certain height, determining the peak force required and relating it to hardness. These tests apply force in one direction and the sample is allowed to expand in the other two directions until it breaks or is completely crushed (Lu & Abbott, 2004).

Measurement of shear force has also been used to assess cooking quality in lentils. Generally, cooked samples are passed through by a multi-blade shear compression cell. Bhatti (1983) related the force required to shear cooked lentil samples to sensory methods and determined the point where noticeable differences separated good- (lower than 4.0 kgf per gram of sample) from poor-cooking lentils. This method was later used for determining factors affecting cooking quality of lentils (Bhatti & Slinkard, 1989; Bhatti, 1995; Bhatti et al., 1984) and beans (Rockland & Metzler,

1967). Quast & Da Silva (1977) also employed a Kramer shear press to compress and measure the force needed to shear beans and peas.

Compression-extrusion tests apply force through a plunger that compresses the sample in a test cell until it is crushed and flows through the extrusion grid (Lu & Abbott, 2004). The Ottawa Texture Measuring System (OTMS) (Voisey, 1971) is popularly used for measuring texture of solid foods. Maximum force required to compress and extrude samples has been used as an indicator of cooking quality in lentils (Arntfield et al., 2001; Varoquaux et al., 1995), cowpeas (Sefa-Dedeh et al., 1979) and dry beans (Voisey & Larmond, 1971). The OTMS can be used either with a wire-extrusion grid or with a plate-extrusion grid with holes in the bottom.

Since red lentils are mostly dehulled before consumption, they tend to decompose and create a paste after cooked. To successfully evaluate the degree of cooking of the samples it would be useful to create a simulation of the chewing process, which is basically a reduction of particle size before the food is transported to the back of the tongue (Wilkinson et al., 2000). During extrusion tests, the structure of the food product is disrupted as it would be on the mouth of consumers, and these types of tests give a good measure of textural quality of viscous liquids and gels (Bourne & Moyer, 1968). A positive correlation was found by Scanlon et al. (1998) between peak force to extrude lentil samples and sensory measurements of hardness, chewiness, and particle size. Furthermore, Ametek, Inc. (2001) indicated that an OTMS was ideally suited for testing cooked pulses.

2.4.3 Factors affecting cooking quality of pulses

Several factors have been reported to influence the cooking quality of pulses. The cultivar has been shown to affect the cooking quality in lentils (Bhatty, 1995; Bhatty et al., 1984) and field peas (Wang, 2010). Differences in quality have also been attributed to the growing location and environment (Gubbels et al., 1985; Gubbels & Ali-Khan, 1991) as well as the time of harvesting (Iliadis, 2001).

The effects of structure and composition of the seeds on cooking quality have been extensively studied. Structural features responsible for water absorption have been found to influence the textural parameters. Peas with higher hydration capacity showed shorter cooking times (Wang et al., 2003), and legumes with thinner seed coats presented a softer texture as they absorb water more rapidly (Sefa-Dedeh & Stanley, 1979b; Stanley & Aguilera, 1985). Sefa-Dedeh & Stanley (1979b) reported that seed thickness and hilum size of cowpeas influenced water absorption during the initial stage of soaking. The seed size has also been proven to affect the cooking quality of chickpeas; varieties with greater grain size lead to increases in cooking time (Williams et al., 1983). This was also proven in lentils (Bhatty, 1995).

Some pre-treatment procedures are designed to reduce the cooking time of pulses, such as soaking in water or sodium bicarbonate (Singh et al., 1988). Taiwo et al. (1998) reported cooked cowpea samples that had been presoaked were softer in texture than unsoaked samples. Scanlon et al. (1998) used different solutions of salts or acids and determined that soaking in the mentioned solutions decreased the time to optimally

cook lentils as compared to soaking in water. Other pre-treatments include micronization, which is an operation where the grains are heated under infrared heat; Arntfield et al. (2001) have successfully reduced the force to compress samples after cooking with this technique.

Methods and conditions during storage of pulses are also factors involved in their cooking quality. Vimala & Pushpamma (1985) reported a decrease in water uptake of pulses after they were stored for one year, which reduces their cooking quality. Increasing storage temperature, moisture content also had a detrimental effect on the texture of cowpeas (Sefa-Dedeh et al., 1979) and dry beans (Burr et al., 1968) since these conditions promoted the hard-to-cook defect.

Phytic acid content has long been implicated in influencing the cooking quality of legumes (Bhatty & Slinkard, 1989; Bhatty, 1995). Phytic acid chelates divalent cations (Ca^{2+} , Mg^{2+}) and prevents their cross linking with pectin, thereby facilitating the cell wall dissolution during the cooking process (Stanley & Aguilera, 1985). It is therefore desirable to increase the levels of phytic acid in lentils, which can be done by ensuring adequate levels of P during the growing season (Bhatty & Slinkard, 1989).

Dehulling efficiency is an important quality parameter for pulses. In red lentils specifically, it is a key indicator of the quality of the product since almost all red lentils are consumed dehulled. Cooking quality is another parameter that is very important for red lentils. There have been many efforts to understand the factors affecting both quality parameters but there is still a dearth of information regarding the effects of

post-harvest handling systems on the final dehulling efficiency and cooking quality of red lentils. More research is needed in order to determine the post-harvest conditions that affect these parameters with the purpose of generating a handling system that aims to keep the quality of red lentils.

3. MATERIALS AND METHODS

3.1 Materials

Two cultivars of red lentils (CDC Impact and CDC Redberry) were used; both were bought as clean seeds for two consecutive years (2007 and 2008 crop). Lentils from the 2007 crop were purchased from Barry Reinser (Impact) and Ken Hundebly (Redberry) and transported to the University of Manitoba in polyethylene bags in January 2008; Impact lentils from the 2008 crop year were purchased from Bradley Barlow and Redberry lentils from 2008 from Craswell Seeds Ltd. Both were received in November 2008 in similar conditions to those of the 2007 crop. All lentils were produced in Saskatchewan, Canada. Figure 3.1 shows fresh red lentil samples as well as dehulled split seeds.



Figure 3.1 Fresh and dehulled split red lentils

3.2 Methods

3.2.1 Storage pre-treatments

To study the effects of post-harvest handling operations on the dehulling efficiency and cooking quality of red lentils, storage pre-treatments (A-D) were created for simulating conditions in which red lentils would be stored. A summary of storage pre-treatments is shown in Figure 3.2.

Storage pre-treatment A studied the effect of moisture content and temperature of storage; 3 moisture contents (10, 11.5 and 13%), and 2 storage temperatures (5 and 25°C) were studied. In addition, 3 storage times (0, 6 and 12 months) for 2007 red lentils and 2 storage times (0 and 6 months) for 2008 crop were included as factors.

To determine the effect of drying temperature on dehulling characteristics, lentils were tempered to 13% moisture and after two days of equilibration they were tempered to 18% moisture (the first conditioning to 13% was made in order to prevent excessive water addition that could create greater moisture gradients within a batch). Lentils were then subjected to drying. Two drying temperatures (40 and 80°C), 2 final moisture contents (10, 13%), 2 storage temperatures (5 and 25°C) and 3 storage times (1, 6, 12 months) for 2007, 2 storage times for 2008 (1 and 6 months) were used. This batch was labeled pre-treatment B and sub-divided into B40 and B80 according to the drying temperature.

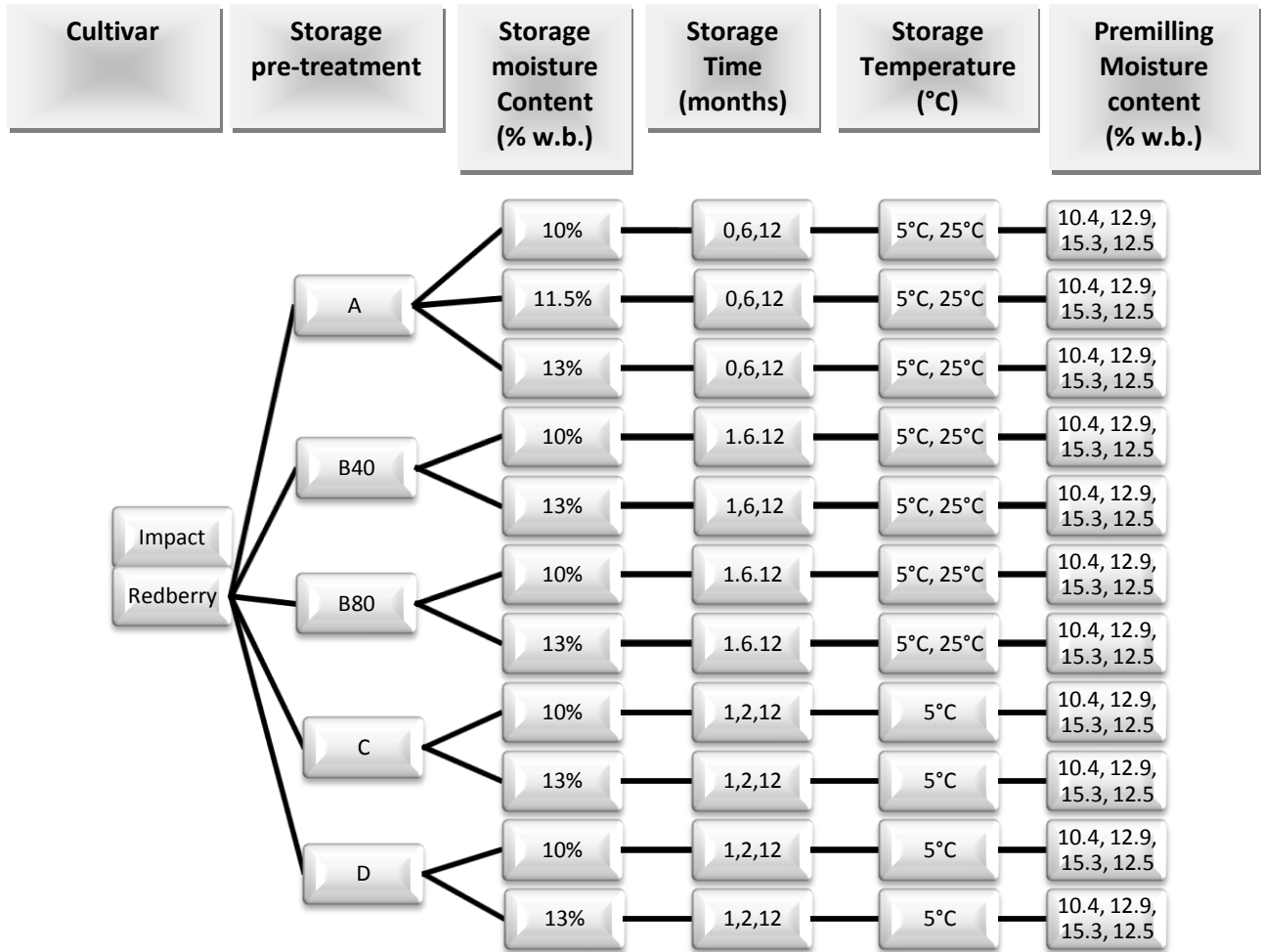


Figure 3.2 Diagram of treatments for red lentils
 A- Moisture tempering, B- Drying from high moisture,
 C-Drying/rewetting cycles, D- freezing/thawing cycles

Temperature changes between day and night generate a moisture gradient within the storage bin and thus moisture in the grain fluctuates. Storage pre-treatment C is designed to simulate this moisture changes within the grains. Lentils were exposed to drying and rewetting cycles during 9 days. One set of samples used moisture ranging from 11-15% for lentils with a final moisture content of 13%, while a second set used moisture ranging from 8-12% with a final moisture content of 10%. After a month of

storage, samples for which the total storage time was 6 and 12 months were subjected to a second drying and rewetting cycle of 9 days and stored after that. Drying of lentils for this storage pre-treatment was done at 80°C. Two storage moisture contents (10 and 13%) and 3 storage times (1, 2, and 12 months) were analyzed for 2007, and two times (1 and 2 months) for 2008. Drying methodology for storage pre-treatments B and C is further explained in section 3.2.4 of this chapter.

Treatment D was designed to evaluate storage conditions under cold climates, using freezing and thawing cycles. Two storage moisture contents (10 and 13%) and 3 storage times were analyzed for 2007 (1, 2, and 12 months), as well as two storage times for 2008 lentils (1 and 2 months). Methodology of the freezing and thawing of lentils is explained in section 3.2.5 of this chapter.

For all above storage pre-treatments, the effect of pre-milling moisture content conditioning was evaluated with 4 levels (10.4, 12.9, 15.3 and 12.5%).

3.2.2 Moisture content conditioning

Lentils were tempered to the desired moisture content by adding the amount of water necessary to reach the required level of moisture and then mixed carefully by shaking until even absorption of water (no visible free water) was obtained and then placed in zip-locked polyethylene bags. The amount of water needed is given by the next relationship.

$$\text{g H}_2\text{O needed} = \frac{(TW) * (FM^a - IM^a)}{(1 - FM^a)} \quad (\text{Eq. 1})$$

Where: TW- total grams of sample, g

FM- final moisture (w.b)

IM- initial moisture content (w.b)

^a-Moisture content should be placed as a fraction (e.g. 0.8 as 80% w.b.)

3.2.3 Moisture content measurement

Moisture content was monitored in fresh lentils, lentils that had been stored for determined period of times and before milling. A method developed by Tang & Sokhansanj (1991) was used. This method involves drying 16 g of lentil sample under 130°C for 20h in a forced convection oven (Precision Thelco Laboratory Oven, Thermo Fischer Scientific, Waltham, MA). This method was also confirmed by using a DICKEY-John® mini GAC Plus Grain Moisture Tester. Lentil samples were mixed before testing to avoid moisture gradients within each bag.

3.2.4 Dried samples

For lentils that needed to undergo drying cycles, a drying oven (Blue M Oven, model EM-243F, Blue Island, IL) was used and set up either at 40 or 80°C. Five hundred grams of samples were placed on a baking tray in the oven and allowed to dry to the desired moisture content. Moisture was monitored every 30 min. After the drying process, lentils were placed in polyethylene air-tight bags.

3.2.5 Freeze-thawed samples

For treatments simulating natural freezing and thawing cycles in storage bins, lentils were placed in a freezer at -15°C in polyethylene sealed bags containing 1.5 kg of sample, the internal temperature of the lentil bag was monitored with a HOBO data logger (Onset Computer Corporation, Pocasset, MA) and it was determined by preliminary trials that 16 hours in the freezer and 8 hours at room temperature was enough to reach -5°C in the center of the bag when freezeed and 5°C when thawed. Two freezing/thawing cycles were performed on lentils before storage at 5°C .

3.2.6 Pre-milling conditioning

Prior to starting the dehulling procedure, red lentils were conditioned to the different moisture contents as explained in section 3.2.1. Samples that had been stored for certain amount of time were analyzed for moisture content and then adjusted to different levels (10.4, 12.5, 12.9 and 15.3% w.b.) two days before dehulling, this time was required to allow for equilibration of moisture within the seeds. For samples whose original moisture was higher than the pre-milling moisture, drying was done at ambient temperature in baking trays containing 500 g of sample.

3.2.7 Dehulling procedure

Conditioned samples were separated to maintain homogenous seed size using different size sieves (Carter Day International Inc., Minneapolis, MN). Preliminary experiments were conducted to identify the range representing 90% of the seeds. For

the 2007 crop lentils, Redberry cultivar seeds with diameters between 4.37 and 5.16 mm and Impact cultivar seeds with diameters between 3.97 and 4.76 mm were used. For the 2008 crop, a shift in size was noted for the Impact variety and therefore the size range was broadened to 3.97 to 5.16 mm.

Dehulling of samples was done with a laboratory scale Satake grain test mill model TM05C (Satake Engineering Co., Hiroshima, Japan) equipped with a 36 mesh abrasive wheel. The test mill is shown in Figure 3.3. For optimization experiments, 5 speeds (800, 900, 1100, 1300, 1400 rpm) were used. For determining the effect of storage times and pre-treatments on the dehulling efficiency, 1100 rpm was utilized as recommended by Wang (2005). Thirty grams of sample were poured on the hopper and the mill was stopped after the required dehulling time. For the optimization study, 5 time levels were considered (10, 22, 40, 58, 70 s), the rest of the samples was milled for 40 s.

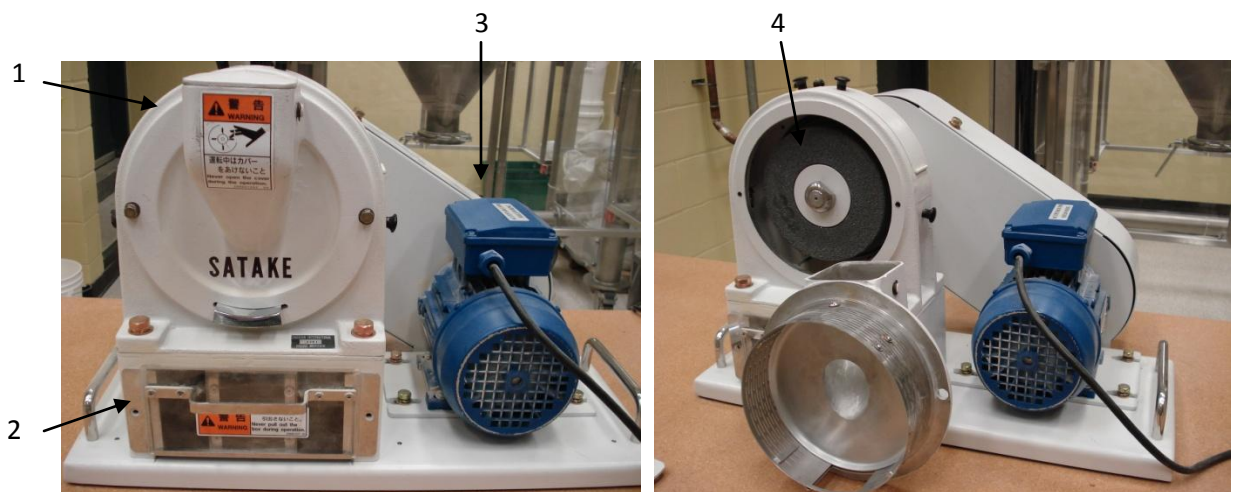


Figure 3.3 Satake grain test mill TM05C
1-hopper, 2-outlet, 3-motor, 4-abrasive wheel

After the dehulling process, a separation of the different fractions of the milled samples was done. Powder fraction (P) was collected with a US standard No. 20 sieve (850 μm). The leftover fraction was passed through an aspiration unit that separated the hull portion (H). Another sieve was used for separating broken seeds (US standard No. 8). The rest of the lentils, without powder and brokens, were separated into whole seeds and split seeds using a No. 4.5 (1.79 x 12.7 mm) slotted sieve (Carter Day International Inc., Minneapolis, MN), each fraction (whole or splits) was further classified manually into their respective dehulled and unde-hulled parts.

Dehulling efficiency (DE) and dehulling loss (DL) were used for evaluating the dehulling characteristics. The relationships used were based on the work of Goyal et al. (2008) and are shown in the equations 2 and 3.

$$DE (\%) = \left[\left(1 - \frac{UDW + UDS}{TW} \right) \times \left(\frac{DW + DS}{DW + DS + P + B} \right) \right] \times 100 \quad (\text{Eq. 2})$$

$$DL (\%) = \left(\frac{P + B}{TW} \right) \times 100 \quad (\text{Eq. 3})$$

Where:

DE: Dehulling Efficiency (%)

DW: Dehulled whole seeds (g)

DL: Dehulling Loss (%)

DS: Dehulled split seeds (g)

UDW: Undehulled whole seeds (g)

P: Powder fraction (g)

UDS: Undehulled split seeds (g)

B: Broken fraction (g)

TW: Total weight of sample (g)

3.2.8 Optimization of dehulling conditions

For optimization of milling process conditions, RSM was used. RSM is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response (Montgomery, 1991). Three factors were analyzed and 5 levels of each factor were used, these values are shown in Table 3.1.

Table 3.1 Coded and uncoded levels for independent variables used for optimization of the dehulling procedure

Independent variable	Coded level				
	$-\alpha$	-1	0	1	α
Pre-milling moisture content (% w.b.), X_1	8.7	10.4	12.9	15.3	17
Milling Speed (rpm), X_2	800	900	1100	1300	1400
Milling time (s), X_3	10	22	40	58	70

Response surfaces were obtained using $\alpha=1.68$

Experimental data for dehulling efficiency (DE) and dehulling loss (DL) were analyzed by RSM to fit the following second-order polynomial equations (Myers & Montgomery, 1995).

$$DE = \beta_0 + \sum_1^3 \beta_i X_i + \sum_1^3 \beta_i X_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^3 \beta_{ij} X_i X_j \quad (\text{Eq. 4})$$

$$DL = \beta_0 + \sum_1^3 \beta_i X_i + \sum_1^3 \beta_i X_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^3 \beta_{ij} X_i X_j \quad (\text{Eq. 5})$$

Where:

DE, DL: predicted responses

β_{ii} : quadratic terms

β_0 : Intercept coefficient

β_i : linear terms

X_i and X_j : coded independent variables

A central composite RSM design was used to evaluate the three variables. The experimental design was made with 5 central points, 1 replicate axial point (α) and 1 replicate factorial point (1, -1). Optimization was carried out using Design Expert 7.1 software, which overlaps the factors and generates a shaded area representing optimum regions based on prefixed conditions. For this study, central points (12.9%, 1100 rpm and 40 s) were selected based on criteria found by Wang (2005). Lower and upper limits for the two responses (DE and DL) were selected based on preliminary tests to ensure all experiments included some of the optimum region. Table 3.2 summarizes the conditions used for optimization of dehulling operations.

Table 3.2 Conditions for optimization of dehulling conditions for red lentils

Factors	Conditions	Lower limit	Upper limit	Importance
Pre-milling moisture content (% w.b.), X_1	In range	10.4	15.3	+++
Milling speed (rpm), X_2	In range	900	1300	+++
Milling time (s) X_3	In range	22	58	+++
Dehulling efficiency (%)	Maximize	88	99	+++++
Dehulling loss (%)	Minimize	0	5	+

Analysis of second-order polynomial regression included: 1) fitting a full second order response surface; 2) analyzing the properties of the fit surface; and 3) calculating the optimum response.

3.2.9 Cooking procedure

For cooking tests, 6 batches of lentils (30 g each) were dehulled as stated previously. After the dehulling process, powder and hull fractions were removed and dehulled samples (as a mixture of whole and split fractions) were cooked as follows. A beaker containing 500 mL of water was placed on a heating plate (Figure 3.4); when boiling, 50 grams of lentils were added and kept boiling with occasional stirring. After a determined cooking time (either 10 or 12.5 minutes), samples were drained using a 1 mm USA Standard test sieve No. 18, placed in polyethylene zip-locked bags and left to cool down for an hour at room temperature before testing.

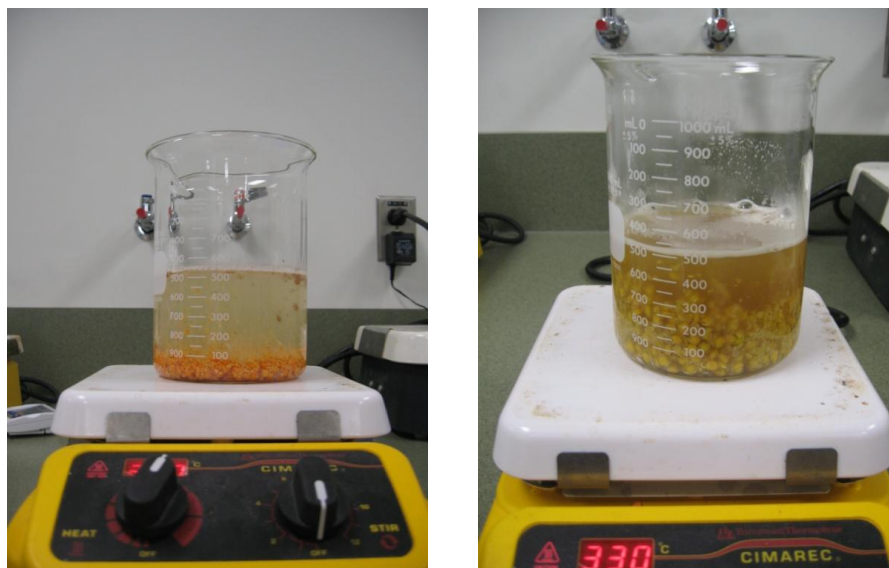


Figure 3.4 Cooking process showing fresh and cooked lentils

The ratio of whole to split seeds prior to cooking was recorded after separating fractions using a 4.5 mm slotted sieve (Carter Day International Inc., Minneapolis, MN). However, before cooking both whole and split fractions were mixed thoroughly.

3.2.10 Cooking evaluation

Texture of cooked lentils was evaluated using an Instron universal testing machine (model 3366, Instron, Norwood, MA) with a 2000 N load cell. The device was equipped with an Ottawa texture cell (model S4427 A) fitted with an extrusion insert (model S5404 A) containing 52 holes, each with a 3 mm diameter. The experimental setup is shown in Figure 3.5. Thirty grams of cooked sample were placed in the texture cell; the plunger was set at a crosshead speed of 60 mm/min and sample was compressed to within 5 mm from the base of the cell.

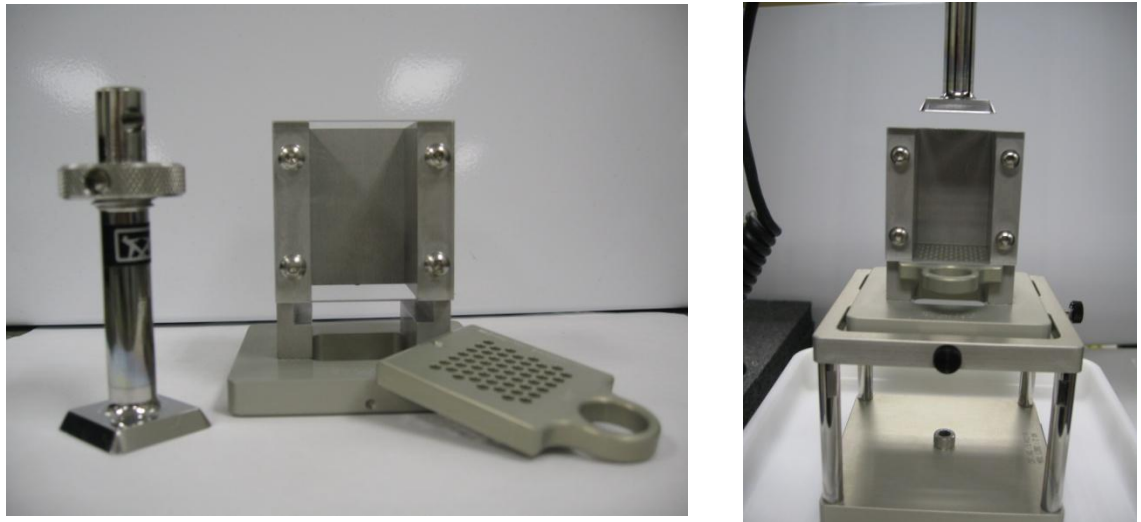


Figure 3.5 Ottawa texture cell showing the plunger and extrusion insert, and experimental setup

Data was collected using Instron Bluehill® Software (Instron, Norwood, MA). The test was considered to start when it reached a load of 1 N; nevertheless, raw data was collected from the beginning and thus data for deformation had to be normalized to 0 mm when the compressive load reached 1 N.

Raw data was analyzed for every replicate according to the method reported by Ross et al. (2009), visually identifying the inflection point and the following parameters were obtained: inflection force, inflection deformation, slope, plateau force, deformation ratio and force ratio. Inflection point was defined and visually observed as the point where the curve changes from concave upwards to concave downwards and both coordinates (force and deformation) at this point were recorded. Slope was calculated from points 1 mm prior to the inflection point (1 mm of deformation before the inflection point to the deformation at inflection). Plateau force was obtained visually and defined as the force value in the force-deformation curve where both slope and force values seem to achieve a constant value. Deformation ratio was defined as the deformation at the inflection point divided by the total crosshead travel (45 mm) and force ratio was the value obtained by dividing force at inflection by plateau force. Ross et al. (2009) reported that force ratio values higher than 0.5 described undercooked samples whereas deformation ratios lower than 0.35 depicted a sample that had an overcooked texture. These parameters were used in interpreting the force-deformation curves obtained.

3.2.11 Statistical analysis

3.2.11.1 Optimization of dehulling operations

As previously stated in section 3.2.8, optimization of conditions during the dehulling operation was carried out using RSM with a Central Composite Design. Results were analyzed with Design Expert 7.1 software.

3.2.11.2 Factorial experiments

Analysis of factorial experiments for determining the effect of storage conditions on dehulling efficiency and cooking quality of red lentils was carried out using JMP IN Version 4.0.4 (SAS Institute, Inc., North Carolina, USA). Multi-factorial analyses of variance (ANOVA) were performed and significance was accepted at $p < 0.05$.

In preliminary tests and analysis it was noted that when analyzing all data for both Redberry and Impact varieties, the cultivar effect was the most significant in all experiments and thus the other factor effects were difficult to assess since all seemed to have little impact when compared to cultivar effect. To increase the ability to evaluate other factors, all data was analyzed separately for each cultivar.

For assessing the effect of storage pre-treatments along with other factors, a “general factorial” experiment was created for common points within all analyzed samples. For the 2007 crop, samples included in the experiment were stored at 5°C. The factors evaluated were: storage pre-treatment (A, B40, B80, C, D); storage time (initial and 12 month storage); storage moisture content (10 and 13%); and either pre-milling

moisture content for dehulling (10.4, 12.9, 15.3 and 12.5%) or cooking time in texture analysis (10 or 12.5 minutes). For the 2008 crop, only initial storage data was available, therefore storage time was not a factor.

Separately, a factorial experiment was evaluated for each storage pre-treatment. For the 2007 crop the factors in each pre-treatment were as follows:

- Storage pre-treatment A, factors: Storage time (0, 6, and 12 months), storage moisture content (10, 11.5, and 13%), storage temperature (5, and 25°C); and pre-milling moisture content (10.4, 12.9, 15.3 and 12.5%) or cooking time (10 and 12.5 min);
- Storage pre-treatment B, factors: Drying temperature (40 and 80°C), storage time (1, 6, and 12 months), storage temperature (5 and 25°C), storage moisture content (10% and 13%); and pre-milling moisture content (10.4, 12.9, 15.3 and 12.5%) or cooking time (10 and 12.5 min);
- Storage pre-treatment C and D, factors: Storage time (1, 2, and 12 months), storage moisture content (10 and 13%); and pre-milling moisture content (10.4, 12.9, 15.3 and 12.5%) or cooking time (10 and 12.5 min);

The 2008 crop had the same factors as 2007, but it was only evaluated until 6 month storage and therefore the 12 month level was not included in factorial experiments.

The sum of squares represents the contribution of every factor and/or interaction of factors on a selected response. Graphs of percentage contribution of every factor and

two-way interactions on the total sum of squares (SS) were used to show their significance and factors with lower than 5% sum of squares input were taken as not contributing. This approach was selected in order to assess the magnitude of the contribution of each factor rather than only explaining which factor is significant.

Separately, least square means were obtained from JMPIN software and plotted in order to show the interactions between two factors. Lines between least square mean points were included to guide the eye of the reader only and do not show a continuous function.

3.2.11.3 Comparisons with Reference (untreated) samples

Comparisons of mean values against Reference samples (which had not undergone any storage pre-treatment) were done using SigmaStat Version 3.5 (Systat Software, Inc., Chicago, IL) with a one-factor ANOVA and Holm-Sidak method of multiple comparisons against a control group ($p < 0.05$).

4. RESULTS AND DISCUSSION

4.1 Optimization of dehulling operation conditions

The first objective of this work was to optimize the milling conditions of lentils that had not undergone any pre-treatment in order to maximize the dehulling efficiency (DE), while minimizing the dehulling losses (DL) represented by powder and broken seeds. Response surface methodology (RSM) with a central composite design was used to optimize the factors involved, which are the seed moisture content before milling, milling speed and milling time (Wang, 2005).

To obtain proper models for the optimization of milling conditions, the experimental data was used and fitted to the second order polynomial equation reported by Myers & Montgomery (1995). Coefficients of the full model were evaluated and tested for significance with the ANOVA test for each response (dehulling efficiency and dehulling loss). The insignificant terms were removed from the model using a stepwise elimination with an alpha exit level of $p \leq 0.1$. Results of ANOVA and statistical values are shown in Tables 4.1 and 4.2 for 2007 red lentils and Table 4.3 for those of 2008. It can be noted that for both Impact and Redberry 2007, all main factors significantly affected the response. For the 2008 red lentils, pre-milling moisture content was not significant for most responses, while milling time and speed showed statistical significance.

For the majority of the models for both DE and DL, the second order term involving moisture content (X_1^2) was not significant, as well as interaction between moisture and time (X_1X_3).

Table 4.1 Analysis of variance for responses for Redberry 2007 crop (after stepwise elimination: alpha exit =0.1)

Source	0 months		6 months		12 months	
	DE	DL	DE	DL	DE	DL
Model	<0.0001	<0.0001	0.0012	<0.0001	0.0002	<0.0001
X₁, moisture	0.0088	0.0017	0.0036	<0.0001	0.0444	<0.0001
X₂, speed	0.0088	0.0005	0.0098	<0.0001	0.0012	<0.0001
X₃, time	<0.0001	0.0007	0.0065	<0.0001	0.0002	<0.0001
X₁²	NS	NS	0.0329	NS	NS	NS
X₂²	0.0138	NS	NS	NS	0.0206	0.0001
X₃²	0.0005	NS	0.0900	NS	0.0026	NS
X₁X₂	0.0307	NS	NS	0.0167	0.0116	0.0005
X₁X₃	0.0352	NS	NS	0.0999	0.0366	NS
X₂X₃	0.0048	NS	NS	0.0040	0.0026	<0.0001
Lack of fit	<0.0001	NS	<0.0001	0.0029	<0.0001	0.3831
Coefficient of variation	6.78	34.16	16.58	16.59	4.88	9.06
R²	0.9335	0.7784	0.7551	0.9567	0.9167	0.9837
Adjusted R²	0.8804	0.7341	0.6609	0.9350	0.8500	0.9755

DE- dehulling efficiency
DL- dehulling loss
NS- represent non significant factor

Table 4.2 Analysis of variance for responses for Impact 2007 crop (after stepwise elimination: alpha exit =0.1)

IMPACT	0 months		6 months		12 months	
Source	DE	DL	DE	DL	DE	DL
Model	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
X₁, moisture	0.0007	<0.0001	0.0003	0.0008	0.0012	0.0008
X₂, speed	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
X₃, time	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	0.0031
X₁²	NS	NS	NS	NS	NS	NS
X₂²	0.0015	NS	0.0012	NS	0.0011	NS
X₃²	0.0004	0.0084	0.0005	NS	0.0003	NS
X₁X₂	0.0348	NS	0.0396	NS	0.0146	NS
X₁X₃	NS	NS	NS	NS	NS	NS
X₂X₃	0.0035	NS	0.0022	NS	0.0016	NS
Lack of fit	0.0001	NS	0.0006	0.0361	0.0002	NS
Coefficient of variation	10.71	15.86	10.83	31.51	7.55	30.84
R²	0.9507	0.9366	0.9564	0.8450	0.9515	0.8200
Adjusted R²	0.9194	0.9185	0.9286	0.8140	0.9207	0.7840

DE- dehulling efficiency

DL- dehulling loss

NS- represent non significant factor

Table 4.3 Analysis of variance for responses for Redberry and Impact red lentils 2008 crop (after stepwise elimination: alpha exit =0.1)

Source	Redberry				Impact			
	0 months		6 months		0 months		6 months	
	DE	DL	DE	DL	DE	DL	DE	DL
Model	0.0006	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
X₁,moisture	0.4064	0.0279	0.4608	<0.0001	NS	0.1023	0.0176	<0.0001
X₂, speed	0.0600	<0.0001	0.0454	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
X₃, time	0.0003	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
X₁²	NS	NS	NS	NS	NS	NS	NS	NS
X₂²	0.0275	0.0255	NS	NS	0.0001	0.0121	0.0043	0.0019
X₃²	0.0042	NS	0.0004	NS	<0.0001	NS	0.0008	NS
X₁X₂	0.0940	NS	0.0245	0.0010	NS	0.0203	0.0275	0.0069
X₁X₃	NS	NS	0.0238	NS	NS	NS	NS	NS
X₂X₃	0.0033	0.0192	0.0013	0.0066	<0.0001	0.0159	0.0048	NS
Lack of fit	0.0261	0.0226	0.0060	0.0698	0.0371	NS	0.0199	NS
Coefficient of variation	2.91	17.03	2.50	8.26	4.59	9.46	4.85	7.78
R²	0.8589	0.9133	0.8973	0.9757	0.9596	0.9686	0.9490	0.9755
Adjusted R²	0.7692	0.8800	0.8319	0.9664	0.9441	0.9529	0.9166	0.9661

DE- dehulling efficiency
DL- dehulling loss
NS- represent non significant factor

Most of the models generated for dehulling loss (DL) were close to linear, and therefore the main factors had the majority of the impact on the responses while quadratic terms and two-way interactions were not significant. Goyal et al. (2008) and Goyal et al. (2009) also observed non significant interactions and quadratic terms for dehulling loss of pigeon pea. The regression coefficients for these models are presented for the 2007 and 2008 lentils in Tables 4.4 and 4.5 respectively.

Lack-of-fit tests are used to measure how satisfactory the model represents the experimental points (Myers & Montgomery, 1995). A significant lack of fit indicates that the variation of the replicates from their mean values is smaller than the variation of the design points from their predicted values. The R^2 value is a measure of the amount of variation around the mean explained by the model (Madamba, 2002). Both of these parameters were used to assess the adequacy of the generated models. In most cases, lack-of-fit was significant, but all of the R^2 values were higher than 0.75, showing lower values in DE of Redberry 2007 at 6 months storage. Madamba and Yabes (2005) indicated that significant second order polynomial models tend to have higher correlation values despite a significant lack of fit. Goyal et al. (2009) and Goyal et al. (2008) also found significant F values in their lack-of-fit tests and concluded that the models were valid. Therefore, a reasonably high proportion of the variability was explained with the response surface models of DE and DL which is an indication that the models developed for these responses were adequate.

Table 4.4 Regression coefficients in terms of coded factors for the responses for 2007 red lentils

Response Variable	Regression Coefficients									
	β_0	β_1	β_2	β_3	β_{11}	β_{22}	β_{33}	β_{12}	β_{13}	β_{23}
Redberry 0 months										
DE	96.38	-5.16	7.91	11.22	-	5.6	-8.10	5.24	5.07	-7.50
DL	2.19	-0.77	0.94	0.87	-	-	-	-	-	-
Redberry 6 months										
DE	92.75	-12.94	11.58	11.91	-8.55	-	-6.74	-	-	-
DL	2.25	-0.74	1.23	0.72	-	-	-	-0.37	-0.23	0.47
Redberry 12 months										
DE	95.39	-2.71	5.53	6.62	-	-3.82	-4.71	4.76	3.72	-6.13
DL	2.67	-0.70	1.50	0.90	-	0.47	-	-0.45	-	0.55
Impact 0 months										
DE	91.86	-10.26	19.73	16.99	-	-10.99	-11.24	6.97	-	-10.70
DL	2.14	-0.46	0.99	0.52	-	-	-0.26	-	-	-
Impact 6 months										
DE	87.46	-10.85	20.81	17.55	-	-10.86	-10.39	6.50	-	-11.08
DL	2.43	-0.86	1.37	1.01	-	-	-	-	-	-
Impact 12 months										
DE	90.01	-6.97	13.95	12.53	-	-8.30	-8.18	6.08	-	-8.73
DL	3.22	-1.12	1.74	0.95	-	-	-	-	-	-

DE, dehulling efficiency; DL, dehulling loss

- = indicates coefficient does not significantly contribute to the model:

$$Response = \beta_0 + \sum_1^2 \beta_i X_i + \sum_1^3 \beta_i X_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^3 \beta_{ij} X_i X_j$$

Table 4.5 Regression coefficients in terms of coded factors for the responses for 2008 red lentils

Response Variable	Regression Coefficients									
	β_0	β_1	β_2	β_3	β_{11}	β_{22}	β_{33}	β_{12}	β_{13}	β_{23}
Redberry 0 months										
DE	89.68	-0.59	1.50	3.52	-	-2.04	-2.45	1.63	-	-3.34
DL	5.01	-0.62	2.44	1.44	-	-	0.88	-	0.75	-
Redberry 6 months										
DE	90.87	-0.46	1.41	3.46	-	-	-2.98	2.04	2.05	-3.36
DL	5.19	-0.93	1.91	1.56	-	-	-	-0.64	-	0.49
Impact 0 months										
DE	84.98	-	10.75	9.94	-	6.0	-5.42	-	-	-7.03
DL	4.14	-0.2	1.74	1.27	-	0.39	-	-0.39	-	0.41
Impact 6 months										
DE	85.12	-2.88	8.28	9.73	-	-4.37	-4.74	3.43	-	-4.75
DL	4.13	-0.52	1.65	1.22	-	0.42	-	-0.39	-	-

DE, dehulling efficiency; DL, dehulling loss

- = indicates coefficient does not significantly contribute to the model:

$$Response = \beta_0 + \sum_1^2 \beta_i X_i + \sum_1^3 \beta_i X_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^3 \beta_{ij} X_i X_j$$

Figures 4.1-4.4 depict overlay plots showing the optimum regions (shaded) obtained by superimposing contour plots of DE and DL. These regions meet the criteria that DE values must be between 88 and 99% while $DL \leq 5\%$. For Redberry 2007 (Figure 4.1), the level 0 of each factor (12.9% pre-milling moisture content, 1100 rpm and 40 s) was

within the optimum regions for all storage time points, which was in accordance to results reported by Wang (2005). The shaded area was reduced after 6 months and increased at 12 months.

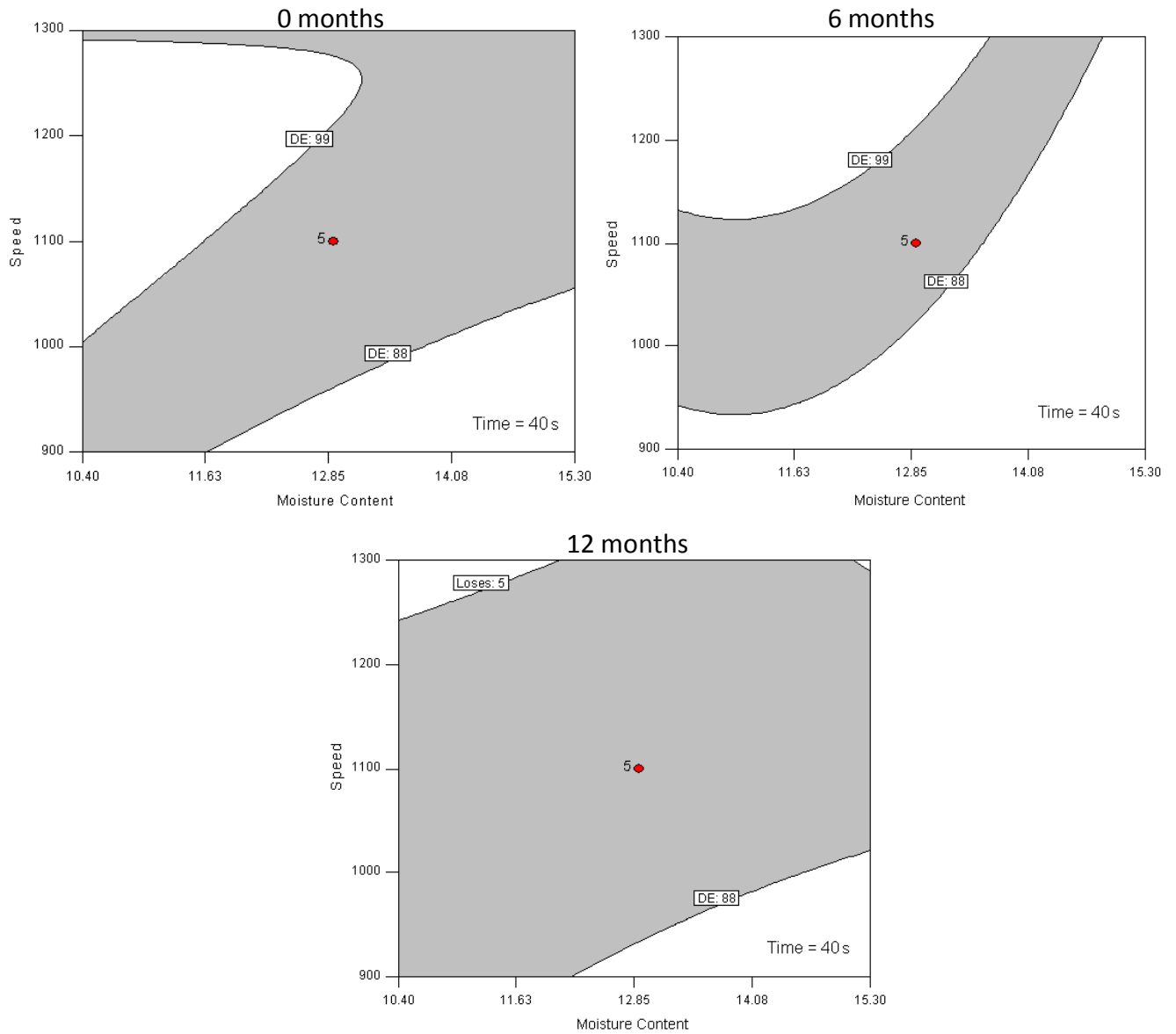


Figure 4.1 Overlay plots showing optimum regions for Redberry 2007

Overlay plots for Impact 2007 (Figure 4.2) show smaller optimum area than Redberry 2007. Also at 6 months storage, a shift towards higher milling speed is noticeable. Similarly to Redberry 2007, the optimum area increased after 12 months, which might be an indicator of samples stabilizing over time.

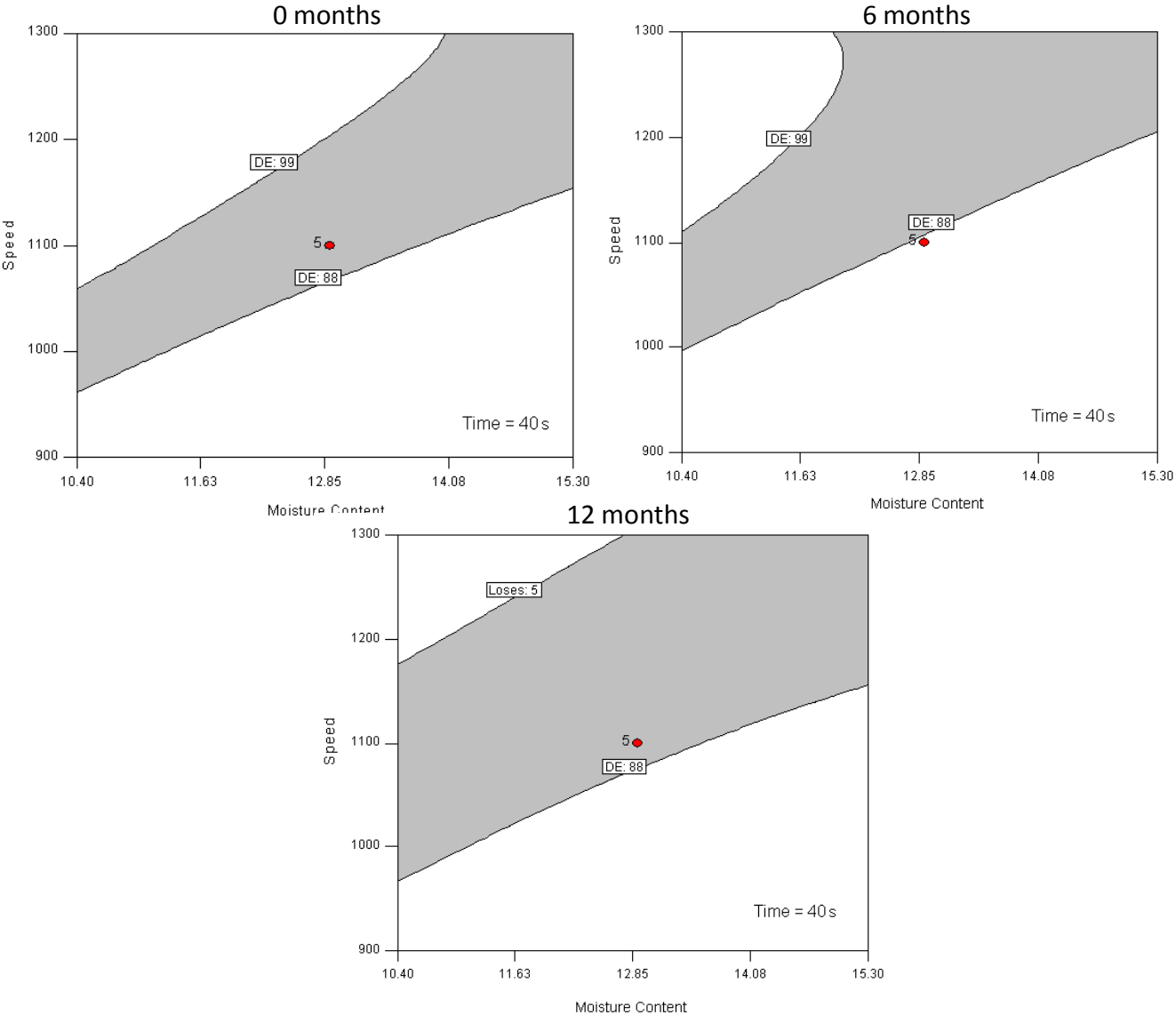


Figure 4.2 Overlay plots showing optimum regions for Impact 2007

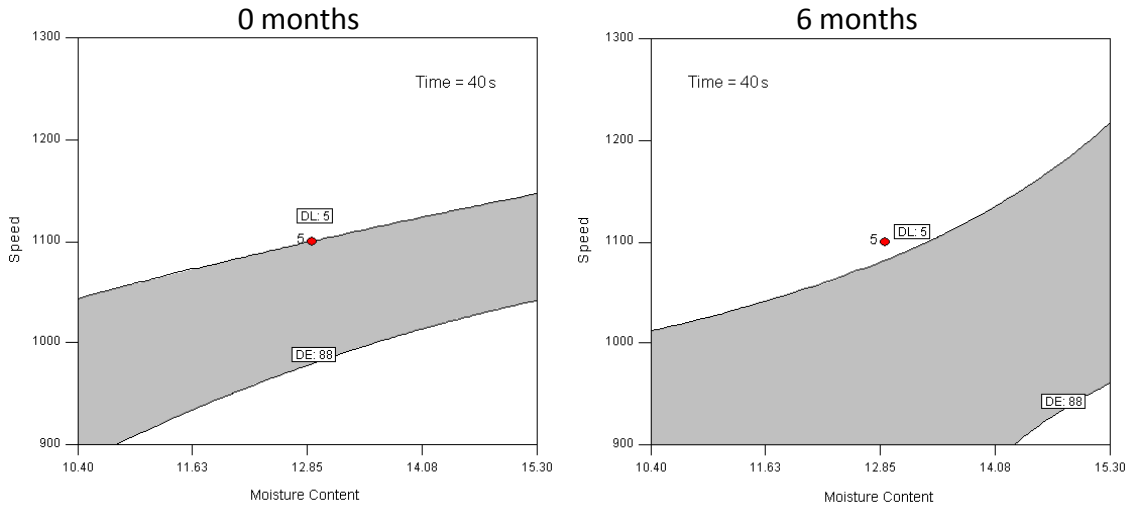


Figure 4.3 Overlay plots showing optimum regions for Redberry 2008

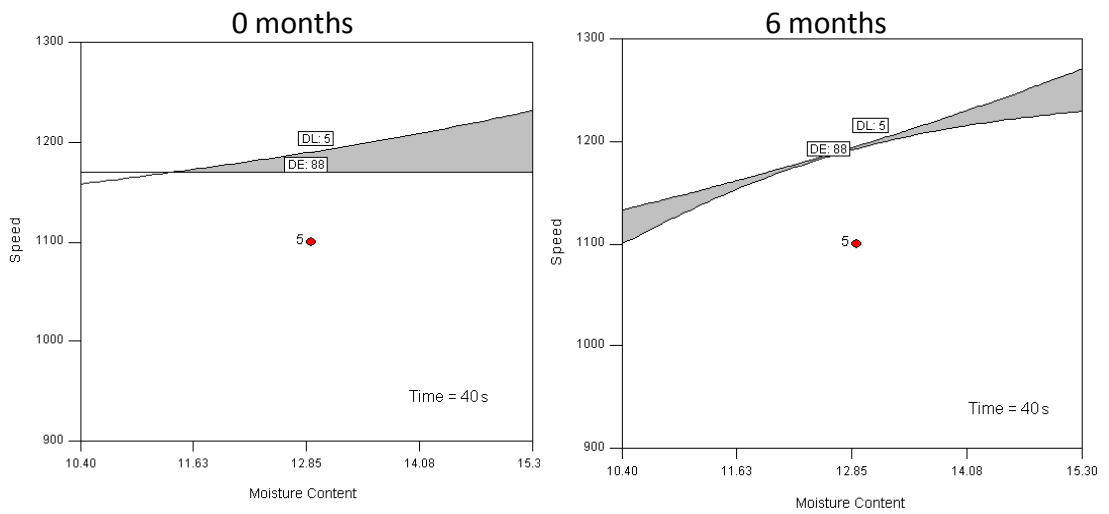


Figure 4.4 Overlay plots showing optimum regions for Impact 2008

Figure 4.3 displays the overlay plots of Redberry 2008 red lentils, stored for 0 and 6 months. Optimum region at 0 months is found at lower dehulling speeds as compared to 2007 samples. After 6 months storage, this trend becomes more noticeable and center point is no longer within the shaded area.

Impact 2008 overlay plots are shown in Figure 4.4. It is visible that shaded areas are very small when compared to Redberry 2008 and center points are far from these optimum areas. It should be noted that the displayed overlay plots are set with the third factor (milling time) as 40 seconds, and for Impact 2008 the optimum regions were significantly wider when increased milling times were examined.

Tables 4.6 and 4.7 show the results of the numerical optimization performed in Design Expert 7 software after maximizing DE (importance of 5) while minimizing DL (importance of 1). Displayed combination of values of pre-milling moisture content (moisture), milling speed (speed) and milling time (time) depict the solution with the highest desirability.

Generally, lower moisture contents were chosen for maximizing DE, with the exception of Redberry 2007 at 0 months, Impact 2007 at 12 months and Impact 2008 at 0 months. All milling times were higher than 40 seconds, and selected milling speeds range from 900 to 1274 rpm. It should be noted that although higher milling speeds (1300 and 1400 rpm) generate a higher percentage of dehulled seeds, damage in the cotyledons is visible and reflected in the powder and broken fractions, which increase the DL. Oomah et al. (1996) reported higher dehulling of flaxseeds with higher milling

speeds but after a certain speed, dehulling was less successful. Mangaraj and Singh (2009) found similar trends when optimizing milling speeds for dehulling of pigeon pea.

Table 4.6 Optimum values obtained by numerical optimization for 2007 red lentils

Optimum values					
Sample	DE	DL	Moisture	Speed	Time
Redberry 0 months	98.2	1.9	15.3	1122	49
Impact 0 months	96.4	1.9	10.4	913	58
Redberry 6 months	96.7	2.4	11.7	1020	50
Impact 6 months	94.8	2.9	10.4	996	46
Redberry 12 months	96.6	2.1	10.4	900	48
Impact 12 months	92.8	3.2	15.3	1215	43

For Redberry 2007 (Table 4.6) the optimum pre-milling moisture content and milling speed decreased with storage time, while milling times are close to the values for 0 months. For Impact 2007 an optimum milling time after 6 months of storage decreased and optimum milling speed after 12 months increased. This demonstrates the variety-dependent effects of storage time.

For 2008 red lentils (Table 4.7), Redberry needed less milling time to achieve similar DE and DL values at 6 month storage, while for Impact more milling time, and lower milling moisture and speeds were necessary.

Overall, the Redberry cultivar exhibited higher DE and lower DL than Impact. For Impact, DE decreased and DL increased over time, while Redberry red lentils had a lower DE after 6 months but it stabilizes after that.

Table 4.7 Optimum values obtained by numerical optimization for 2008 red lentils

Sample	Optimum values				
	DE	DL	MC	Speed	Time
Redberry 0 months	92.8	4.5	10.4	900	58
Impact 0 months	89.8	4.9	15.3	1154	47
Redberry 6 months	93.7	4.2	10.4	900	50
Impact 6 months	91.4	4.8	10.4	999	56

In order to validate the selected models, experimental data of samples milled at 12.5% pre-milling moisture content, 1100 rpm and 38 s was used (Wang, 2005). Tables 4.8-4.10 show the predicted and experimental values for response variables at the chosen optimum dehulling conditions. The experimental values were the average of two replicates. Experimental values were relatively close to the predicted values in all cases, indicating that the generated models were acceptable.

Table 4.8 Predicted and actual values^a for response variables^b at dehulling conditions in optimum region (12.5%, 1100 rpm, and 38 s) at 0 months of storage of Reference samples (2007 and 2008 crops).

	DE (%)		DL (%)	
	2007	2008	2007	2008
Impact Reference				
Predicted value	91.3	83.8	2.1	4.0
Actual value \pm SD	94.7 \pm 0.0	86.1 \pm 0.7	1.8 \pm 0.1	4.1 \pm 0.1
Redberry Reference				
Predicted value	95.9	89.3	2.2	4.9
Actual value \pm SD	97.4 \pm 0.1	90.1 \pm 0.3	2.0 \pm 0.5	5.1 \pm 0.0

^an=2; SD – standard deviation.

^bDE – dehulling efficiency; DL – dehulling loss.

Table 4.9 Predicted and actual values^a for response variables^b at dehulling conditions in optimum region (12.5%, 1100 rpm, 38 s) at 6 months of storage of Reference samples (2007 and 2008 crops).

	DE (%)		DL (%)	
	2007	2008	2007	2008
Impact Reference				
Predicted value	86.9	84.4	2.4	4.1
Actual value \pm SD	91.1 \pm 1.3	85.9 \pm 0.5	2.4 \pm 0.2	4.2 \pm 0.1
Redberry Reference				
Predicted value	93.0	90.6	2.3	5.2
Actual value \pm SD	95.7 \pm 0.5	92.9 \pm 0.4	2.3 \pm 0.0	5.1 \pm 0.3

^an=2; SD – standard deviation.

^bDE – dehulling efficiency; DL – dehulling loss.

Table 4.10 Predicted and actual values^a for response variables^b at dehulling conditions in optimum region (12.5%, 1100 rpm, 38 s) at 12 months of storage of Reference samples (2007 crop).

	DE (%)	DL (%)
Impact Reference		
Predicted value	89.5	3.3
Actual value \pm SD	91.8 \pm 0.6	2.8 \pm 0.2
Redberry Reference		
Predicted value	95.0	2.7
Actual value \pm SD	95.2 \pm 0.4	3.0 \pm 0.4

^an=2; SD – standard deviation.

^bDE – dehulling efficiency; DL – dehulling loss.

4.2 Effect of storage pre-treatments and storage time on dehulling efficiency of red lentils

4.2.1 Dehulling efficiency results for 2007 crop analyzed with a general factorial design

Figures 4.5-4.8 show in detail the significance of every factor and interaction of factors on both DE and DL in terms of percentage of the total sum of squares. Since the criterion was to eliminate factors or interactions with lower than 5% of total sum of squares, Tables 4.11 and 4.12 show the selected significant terms on the dehulling efficiency for Redberry and Impact cultivars, respectively, for the general factorial analysis on 2007 crop year. Storage pre-treatment was the main factor affecting the dehulling efficiency and dehulling loss for the Impact cultivar, as well as dehulling efficiency for Redberry cultivar, and it also was the second most significant factor for Redberry dehulling loss (Table 4.11). For Redberry, pre-milling moisture content had the highest significance in dehulling loss, while it was the fourth significant factor in dehulling efficiency. For Impact variety, pre-milling moisture content is the second significant factor for both dehulling efficiency and loss (Table 4.12). Storage time showed significance only when interacting with storage pre-treatment and storage moisture content and was therefore only a concern for pre-treatment C and 10% moisture content. Storage moisture content was significant in a minor way on the dehulling loss for Impact variety but for Redberry (DE) its influence was dependent on the storage pre-treatments, and storage time.

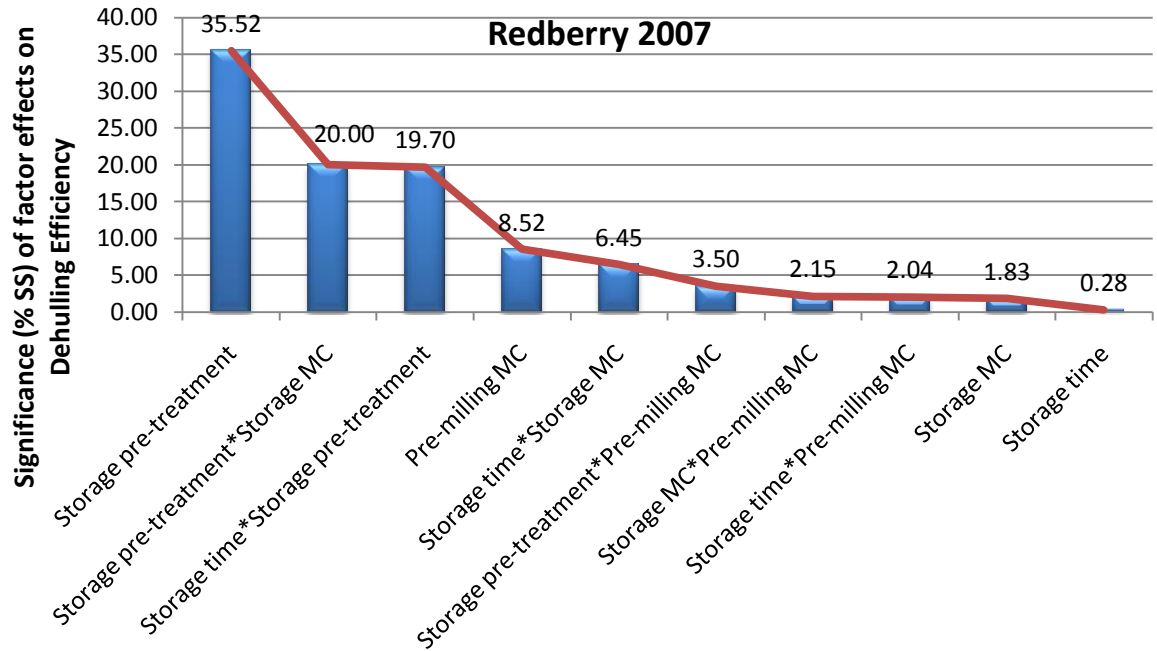


Figure 4.5 Significance of factor effects on dehulling efficiency for Redberry 2007 red lentils stored at 5°C

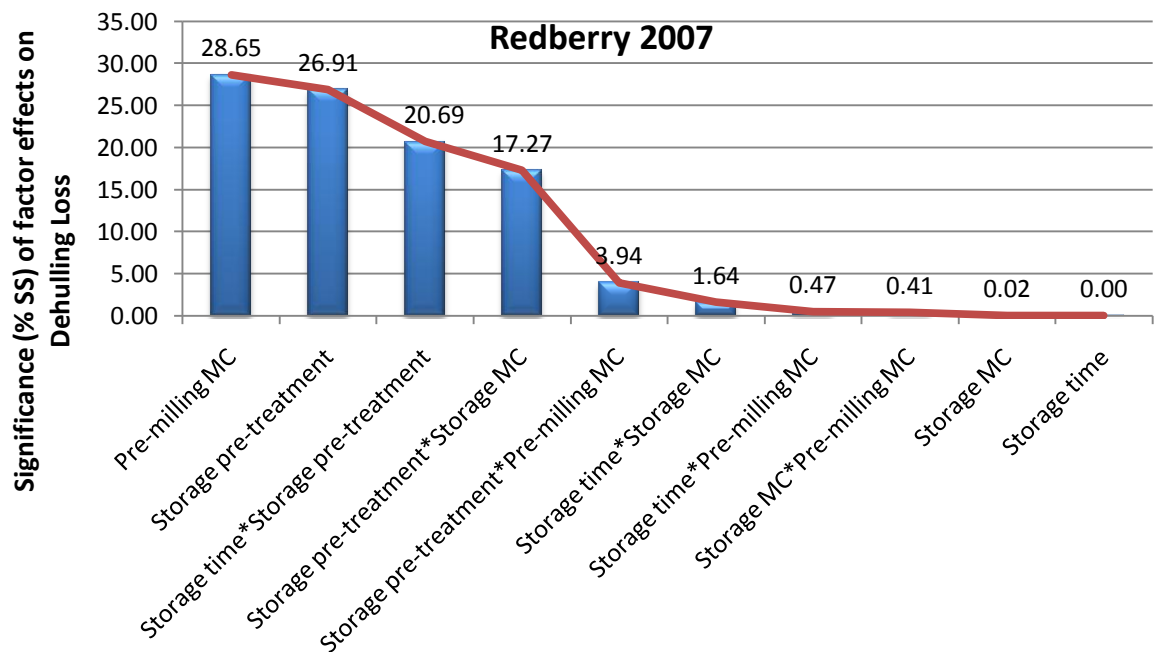


Figure 4.6 Significance of factor effects on dehulling loss for Redberry 2007 red lentils stored at 5°C

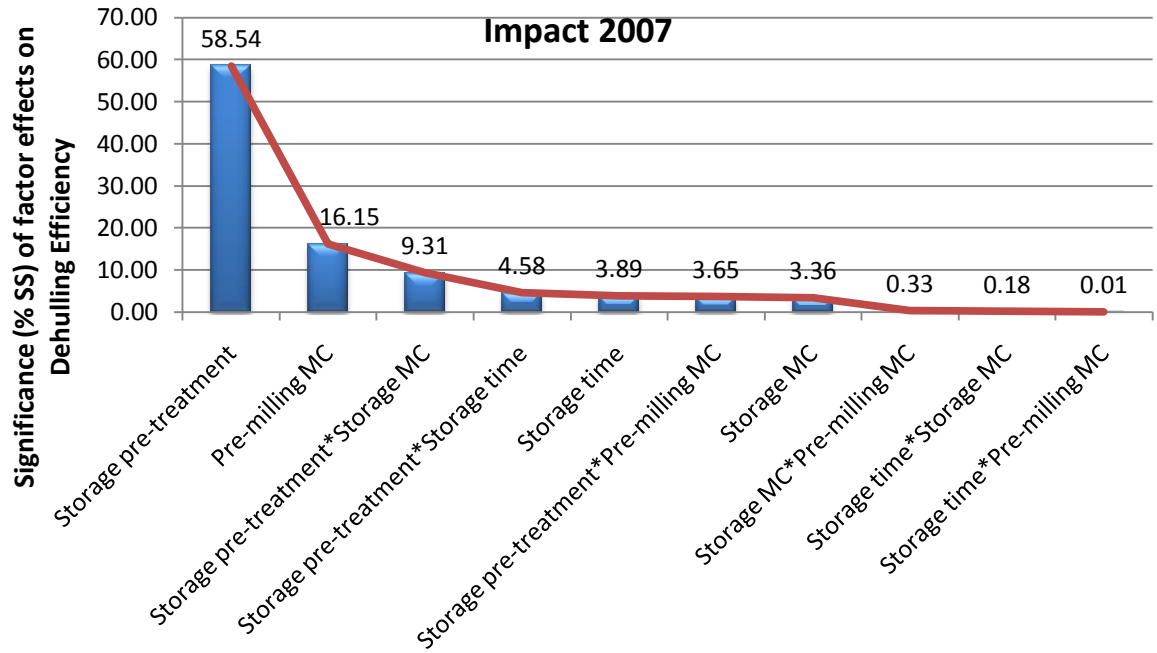


Figure 4.7 Significance of factor effects on dehulling efficiency for Impact 2007 red lentils stored at 5°C

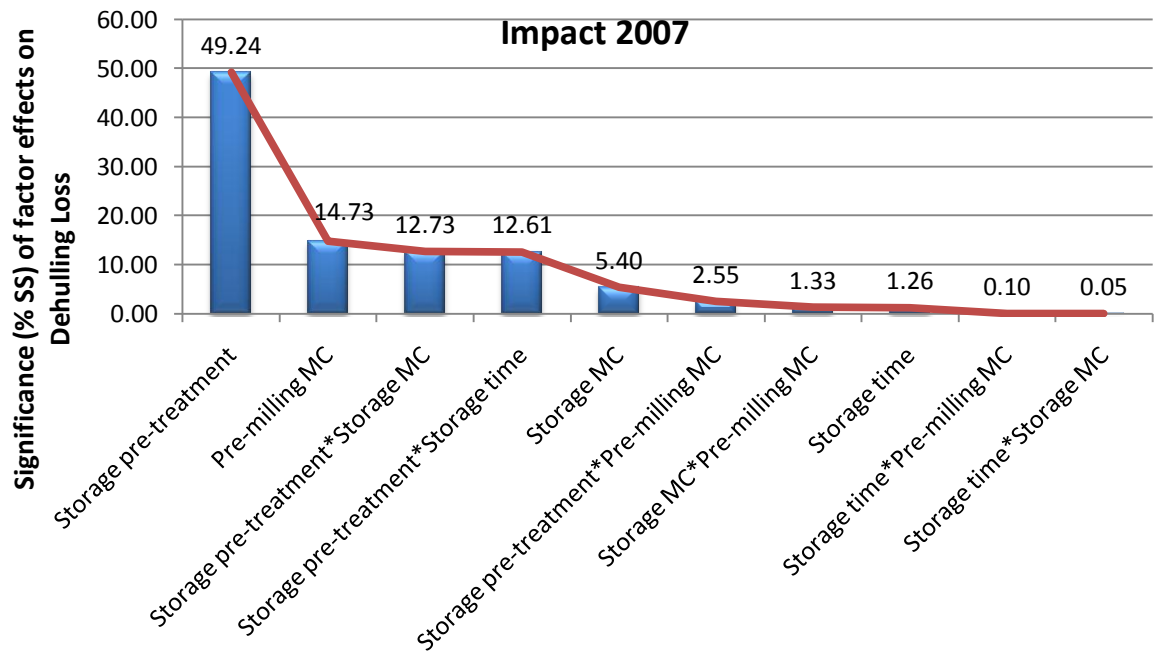


Figure 4.8 Significance of factor effects on dehulling loss for Impact 2007 red lentils stored at 5°C

Table 4.11 Significant factors affecting dehulling efficiency (DE) and dehulling loss (DL) for Redberry cultivar red lentils 2007 crop year

Parameter	Significant factors for Redberry 2007	% SS ^a
DE	Storage pre-treatment	35.52
	Storage pre-treatment*Storage MC	20.00
	Storage time*Storage pre-treatment	19.70
	Pre-milling MC	8.52
	Storage time*Storage MC	6.45
DL	Pre-milling MC	28.65
	Storage pre-treatment	26.91
	Storage time*Storage pre-treatment	20.69
	Storage pre-treatment*Storage MC	17.27

^a percentage of the total sum of squares
DE- dehulling efficiency DL- dehulling loss MC- moisture content

Table 4.12 Significant factors affecting dehulling efficiency (DE) and dehulling loss (DL) for Impact cultivar red lentils 2007crop year

Parameter	Significant factors for Impact 2007	% SS ^a
DE	Storage pre-treatment	58.54
	Pre-milling MC	16.15
	Storage pre-treatment*Storage MC	9.31
DL	Storage pre-treatment	49.24
	Pre-milling MC	14.73
	Storage pre-treatment*Storage MC	12.73
	Storage pre-treatment*Storage time	12.61
	Storage MC	5.40

^a percentage of the total sum of squares
DE- dehulling efficiency DL- dehulling loss MC- moisture content

Interactions between storage pre-treatment and storage moisture content were significant for both DE and DL for Redberry and Impact cultivars. This is an indication of the high co-dependency of these factors. For the Impact cultivar (Figure 4.9), dehulling

efficiency was higher at 10% moisture content for storage pre-treatment A, while higher at 13% moisture for pre-treatments B40, B80, C and D. Redberry cultivar (Figure 4.10) storage pre-treatments B40 and C presented higher values of DE with higher moisture content (13%) and showed opposite trends on pre-treatments A, B80 and D with much higher DE values when stored at 10% moisture content.

Storage pre-treatment also showed interactions with storage time that were significant for DE and DL for Redberry and for DL for Impact. This interaction can be further observed in Figure 4.11. It can be noted that B pre-treatments show the most drastic interaction, especially in B80 with much higher DE after 12 month storage as compared with initial storage, while pre-treatments A, C and D decreased DE values with storage time. The higher values in DE after storage for pre-treatment B can be a reflection of very low DE at 1 month storage and not necessarily an increase after 12 months, this could be an indication of the negative impact of drying on dehulling efficiency. Sachan et al. (1993) reported lower milling yields and higher milling losses for soybeans dried at 65°C in an oven as compared to dry heat roasting.

The only significant interaction not including storage pre-treatment was between storage time and storage moisture content, which proved to be slightly significant for Redberry DE. Totally opposite trends were observed between red lentils stored at 10% and at 13%. When stored at 10%, DE decreased after storage while when stored at 13%, DE increased after 12 months (Figure 4.12).

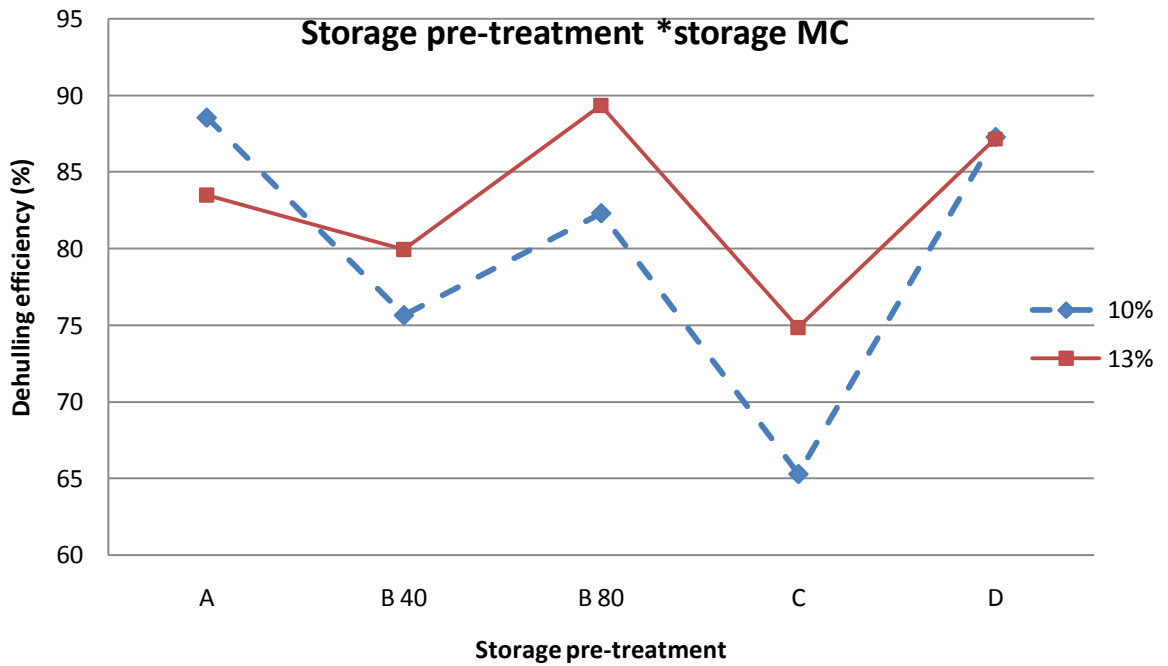


Figure 4.9 Least square means plot showing interaction between storage time and storage moisture content for Impact 2007 general factorial for dehulling efficiency results

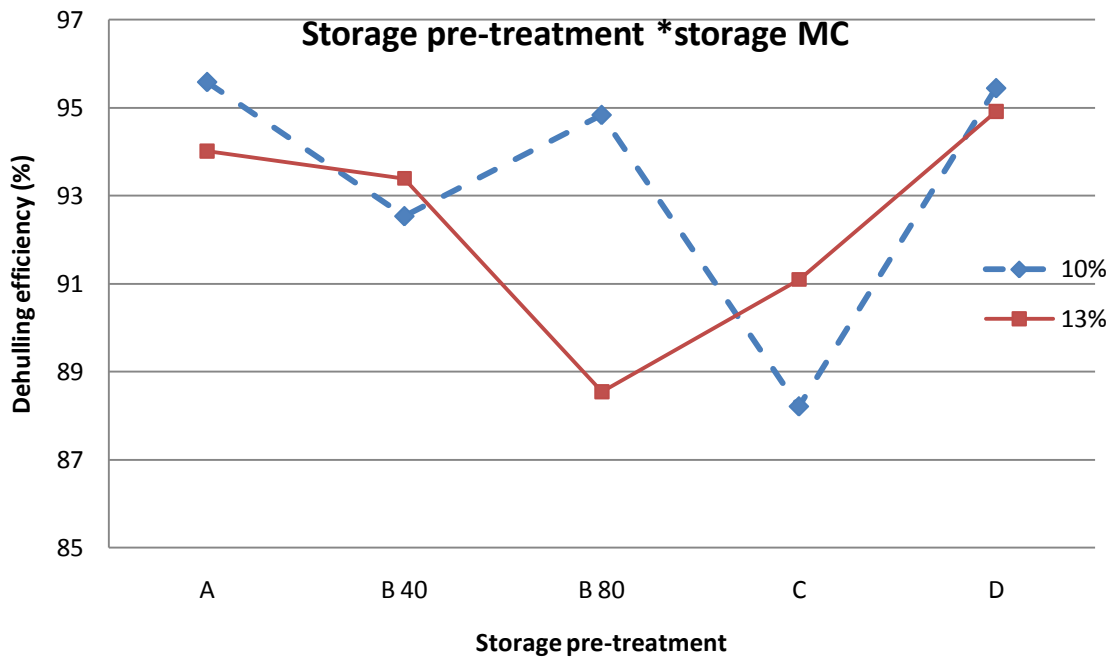


Figure 4.10 Least square means plot showing interaction between storage pre-treatment and storage moisture content for Redberry 2007 general factorial for the dehulling efficiency results

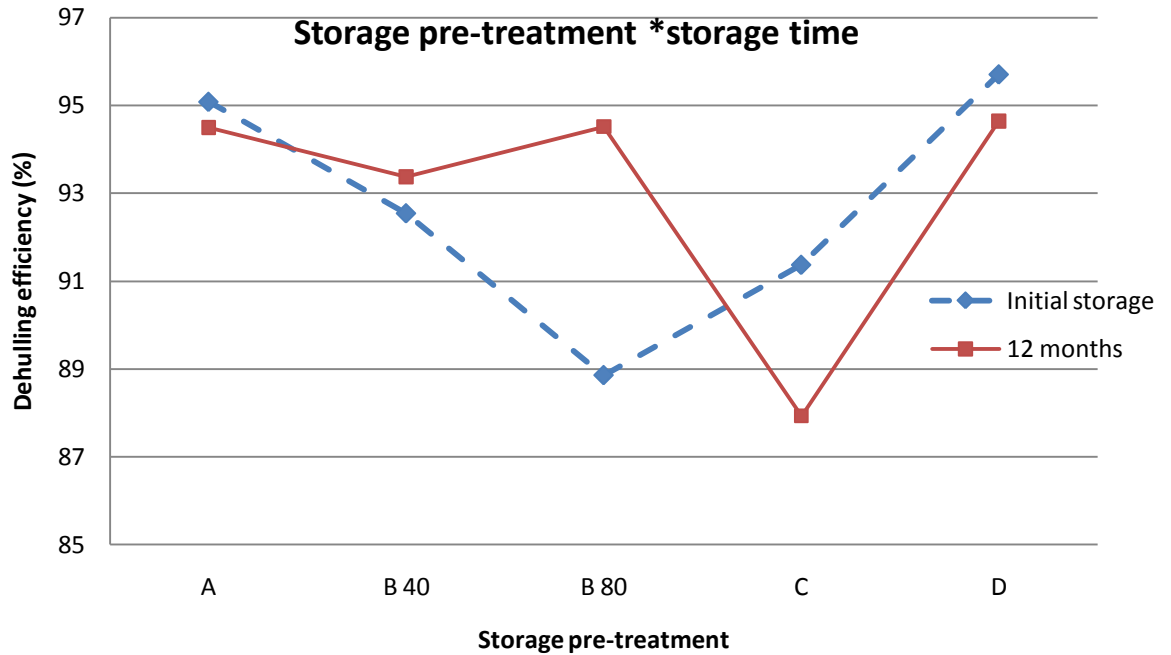


Figure 4.11 Least square means plot showing interaction between storage pre-treatment and storage time for Redberry 2007 general factorial on dehulling efficiency results

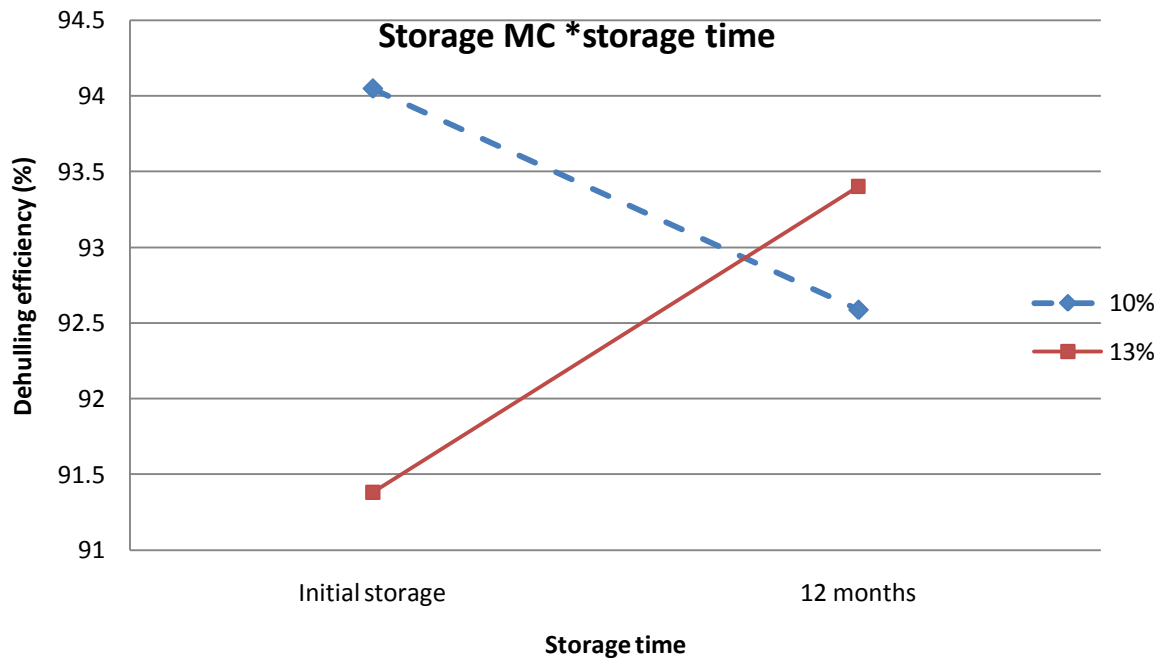


Figure 4.12 Least square means plot showing interaction between storage time and storage moisture content for Redberry 2007 general factorial for dehulling efficiency results

Figures 4.13 and 4.14 are plots showing the predictions of the main trends for all the levels of each factor on the two responses (DE and DL) for Redberry and Impact cultivars, respectively. Storage time showed a slight decrease in dehulling efficiency and increase in dehulling loss after 12 month storage. Storage pre-treatments B40 and C appear to have the lowest DE and highest DL values, while A and D pre-treatments produced the highest DE and lowest DL. Higher moisture content during storage decreased DE and increased DL in a minor fashion, whereas the decrease was evident in both DE and DL for the 15.3% pre-milling moisture content.

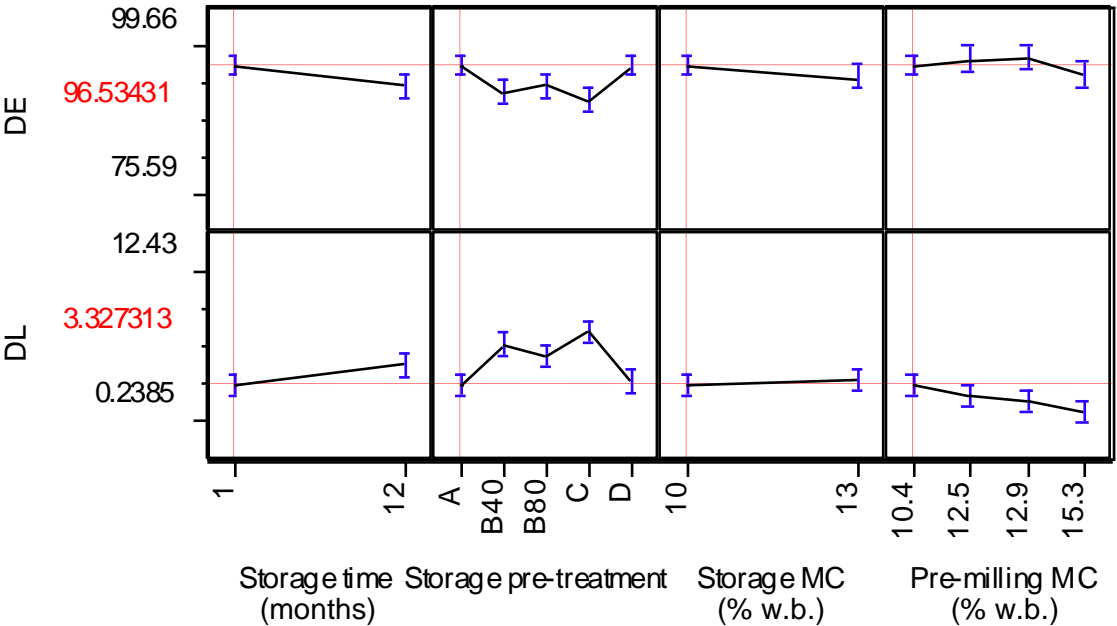


Figure 4.13 Prediction profiler for factors affecting DE and DL of the general factorial for Redberry 2007 red lentils

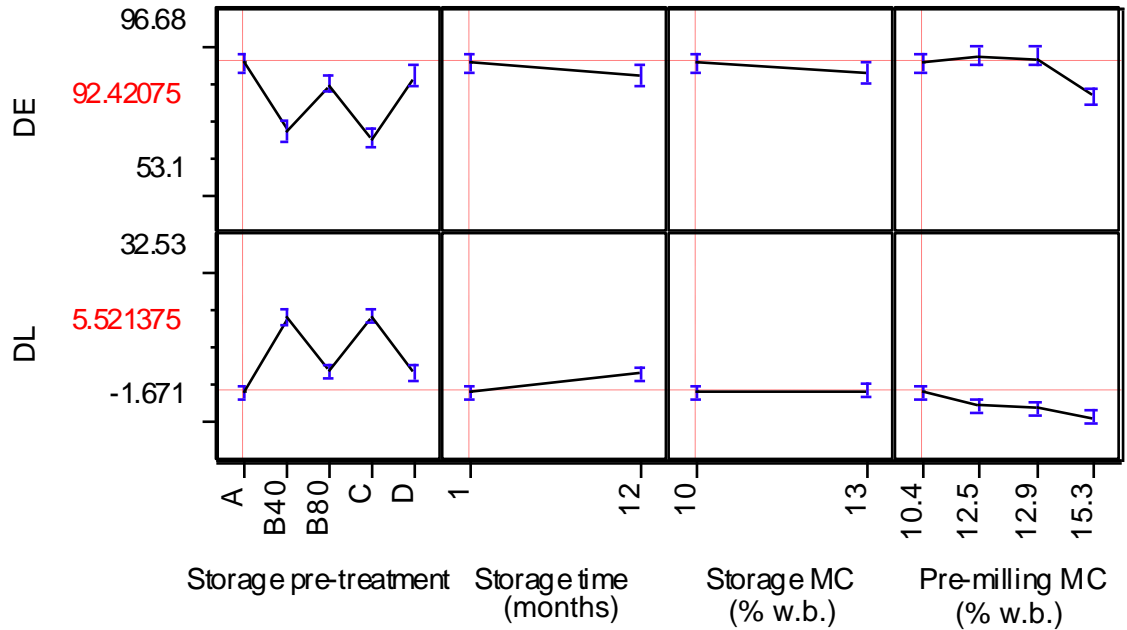


Figure 4.14 Prediction profiler for factors affecting DE and DL of the general factorial for Impact 2007 red lentils

4.2.2 Dehulling efficiency results as affected by storage pre-treatment for

2007 crop year

4.2.2.1 Dehulling efficiency

4.2.2.1.1 Redberry cultivar

Table 4.13 shows the significant terms (higher than 5% of the total sum of squares) contributing to the dehulling efficiency for Redberry cultivar 2007 crop year. The pre-milling moisture content is the most significant factor in terms of the dehulling efficiency for all storage pre-treatments with the percent of contribution ranging from 21.6 to 48.1%. For all storage pre-treatments, the lowest DE was found at 15.3%, regardless of storage conditions.

Storage time had a significant effect in DE, although the contribution was low (11.3-18.8 %) for B, C and D pre-treatments. The contribution of this factor might be significant for Redberry because of a lack of overall variation between replicates and therefore smaller limits to declare significance, since most samples show similar DE values over time, even for storage pre-treatment C (up to 4% variation in DE).

Storage moisture content affected significantly all pre-treatments except B, whereas storage temperature did not show significant effects on the dehulling efficiency for any of the storage pre-treatments. The effect of drying temperature as a main factor in storage pre-treatment B was not significant, nevertheless, the variation in drying temperature used in pre-treatment B showed significant effects when interacting with storage time and storage moisture content. Opposite trends were visible between both drying temperatures at 1 and 6 months, with lower DE for 80°C at 1 month but higher at 6 months. Graphs with all significant interactions for Redberry 2007 are displayed in Appendices 1-9.

Storage time also had significant interactions with pre-milling moisture content for all storage pre-treatments, while storage time interacting with storage moisture content were significant for B, C, and D pre-treatments. In addition, interactions between storage moisture content and pre-milling moisture content were significant for storage pre-treatment A.

Table 4.13 Significant factors affecting dehulling efficiency (DE) for Redberry cultivar red lentils 2007 crop year

Storage Pre-treatment	Significant factors on Dehulling Efficiency	%SS^a
A	Pre-milling MC	48.1
	Storage time*Pre-milling MC	17.9
	Storage MC	14.4
	Storage MC*Pre-milling MC	11.7
B	Pre-milling MC	21.6
	Storage time*Storage MC	20.9
	Storage time*drying temperature	15.7
	Storage MC*drying temperature	15.4
	Storage time	11.3
	Storage time*Pre-milling MC	8.3
C	Pre-milling MC	29.7
	Storage MC	29.0
	Storage time	18.8
	Storage time*Pre-milling MC	10.1
	Storage time*Storage MC	9.5
D	Pre-milling MC	43.2
	Storage time*Pre-milling MC	23.5
	Storage time	16.6
	Storage MC	7.5
	Storage time*Storage MC	5.7

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

4.2.2.1.2 Impact cultivar

Similar to the Redberry results, dehulling efficiency of the Impact cultivar for all storage pre-treatments is mainly affected by pre-milling moisture content, with contributions ranging from 25.8 to 78.2% (Table 4.14). Again, a pre-milling moisture of 15.3% resulted in the lowest DE for all cases. All storage pre-treatments were also affected by storage time, although with reduced contributions. Generally, samples showed slightly lower DE after storage at 6 months, but after 12 months DE either increased or did not decrease much further.

Storage moisture content significantly affected storage pre-treatments A and B in a minor way, but made a major contribution in pre-treatment C, which is an indication that moisture content during storage is accentuated when having drying/rewetting cycles. Storage temperature had less of an effect for all storage pre-treatments and was not involved in any interactions.

Drying temperature in B pre-treatment proved to be highly significant (25.5%) for the Impact cultivar and its influence was also dependent on storage time. At 1 month storage, DE was much higher for lentils dried at 80°C compared to those dried at 40°C, while after 6 and 12 months, DE values were similar for both drying temperatures.

Storage time also had significant interactions with pre-milling moisture content for A and D pre-treatments, as well as drying temperature and storage moisture content for B pre-treatment.

Table 4.14 Significant factors affecting dehulling efficiency (DE) for Impact cultivar red lentils 2007 crop year

Storage Pre-treatment	Significant factors on Dehulling Efficiency	%SS^a
A	Pre-milling MC	61.1
	Storage MC	12.5
	Storage time*Pre-milling MC	12.4
	Storage time	8.6
B	Drying temperature	25.5
	Pre-milling MC	24.8
	Drying temperature*Storage time	21.5
	Storage time*Storage MC	7.8
	Storage time	6.8
C	Pre-milling MC	42.1
	Storage MC	39.5
	Storage time	8.8
D	Pre-milling MC	78.2
	Storage time	8.4
	Storage time*Pre-milling MC	6.1

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture, C-drying/rewetting cycles, D-freezing/thawing cycles

4.2.2.2 Dehulling loss

4.2.2.2.1 Redberry cultivar

Pre-milling moisture content was the main factor (highest significance as % of sum of squares) affecting Redberry 2007 for all storage pre-treatments (Table 4.15). Storage time made a significant contribution for pre-treatments A, B and C but not for pre-treatment D.

Storage moisture content showed a significant effect only for pre-treatment C. These results confirm that moisture content is a very important factor in terms of the breakage and damage of red lentils when having drying and rewetting cycles.

Storage temperature had no significant effect on dehulling losses on any of the storage pre-treatments.

Significant interactions were found between storage time and storage moisture content for dehulling loss of Redberry with A and B pre-treatments. These interactions can be observed in Appendices 18 and 19. In post-harvest treatment A the biggest difference was at 10% storage moisture content, where DL at 0 months was higher than at 6 months. Storage pre-treatment B showed higher dehulling losses for 10% moisture content after 6 and 12 month storage but not after 1 month of storage.

In addition, interactions of storage time and storage moisture with drying temperature were significant for B pre-treatment. Redberry 2007 dehulling losses were also slightly affected by an interaction between storage moisture content and pre-milling moisture content for storage pre-treatment D. Table 4.15 is a summary of the significant terms for Redberry cultivar.

Table 4.15 Significant factors affecting dehulling loss (DL) for Redberry cultivar red lentils 2007 crop year

Storage Pre-treatment	Significant factors on Dehulling Loss	%SS^a
A	Pre-milling MC	50.5
	Storage time	37.6
	Storage time*Storage MC	6.1
B	Pre-milling MC	39.5
	Storage time	25.5
	Storage time*Storage MC	14.2
	Storage MC*drying temperature	8.4
	Storage time*drying temperature	8.4
C	Pre-milling MC	37.1
	Storage MC	30.4
	Storage time	24.2
	Storage MC*Pre-milling MC	5.8
D	Pre-milling MC	89.0

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

4.2.2.2.2 Impact cultivar

Table 4.16 shows a summary of the significant terms of the dehulling loss for the Impact cultivar 2007 crop year. Pre-milling moisture content was the most significant factor affecting the DL of pre-treatments B and D and the second most significant for A and C.

Storage time was the most significant factor for pre-treatment A and it was also significant for C but not significant for B and D, which indicates better stability and less broken and powder fractions on samples stored after these pre-treatments.

The significance of storage moisture content is visible, although its contribution is lower. Storage moisture had a minor effect for the A and B pre-treatments and, similar to Redberry behaviour, was the main factor contribution to dehulling losses for samples stored after C pre-treatment.

Significant interactions were found between storage time and storage moisture content for dehulling loss of A, C and D pre-treatments.

Values for DL were higher after 2 months for C and D samples, indicating a negative effect of the second drying and rewetting cycle. For storage pre-treatment A, a clear trend of increased DL values with increasing time was evident, but at 0 months the effect of moisture content had much less impact on DL than at 12 month storage.

Table 4.16 Significant factors affecting dehulling loss (DL) for Impact cultivar red lentils
2007 crop year

Storage Pre-treatment	Significant factors on Dehulling Loss	%SS^a
A	Storage time	51.3
	Pre-milling MC	22.9
	Storage MC	12.4
	Storage time*Storage MC	8.8
B	Pre-milling MC	39.9
	Drying temperature	26.7
	Drying temperature*Storage time	15.1
	Storage MC	8.3
C	Storage MC	52.6
	Pre-milling MC	20.2
	Storage time	16.8
	Storage time*Storage MC	5.1
D	Pre-milling MC	80.1
	Storage time*Storage MC	11.2

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

4.2.3 Dehulling efficiency results for 2008 crop analyzed with a general factorial

Figures 4.15 and 4.16 show the percentages of the total contribution of every factor and interaction involved in the general factorial design for Redberry 2008 for DE and DL, respectively. It is important to mention that storage moisture content made negligible contributions to both DE and DL. Impact cultivar in 2008 (Figures 4.17 and 4.18) showed similar results to Redberry.

Table 4.17 shows the significant factors and interactions affecting the DE and DL for the Redberry cultivar in the 2008 crop year based on percentage of the total sum of squares when results from all pre-treatments are combined and compared (general factorial). Storage pre-treatment was the most significant factor for both DE and DL, while pre-milling moisture content was the second most significant. Storage moisture content did not significantly affect the DE or the DL of Redberry samples.

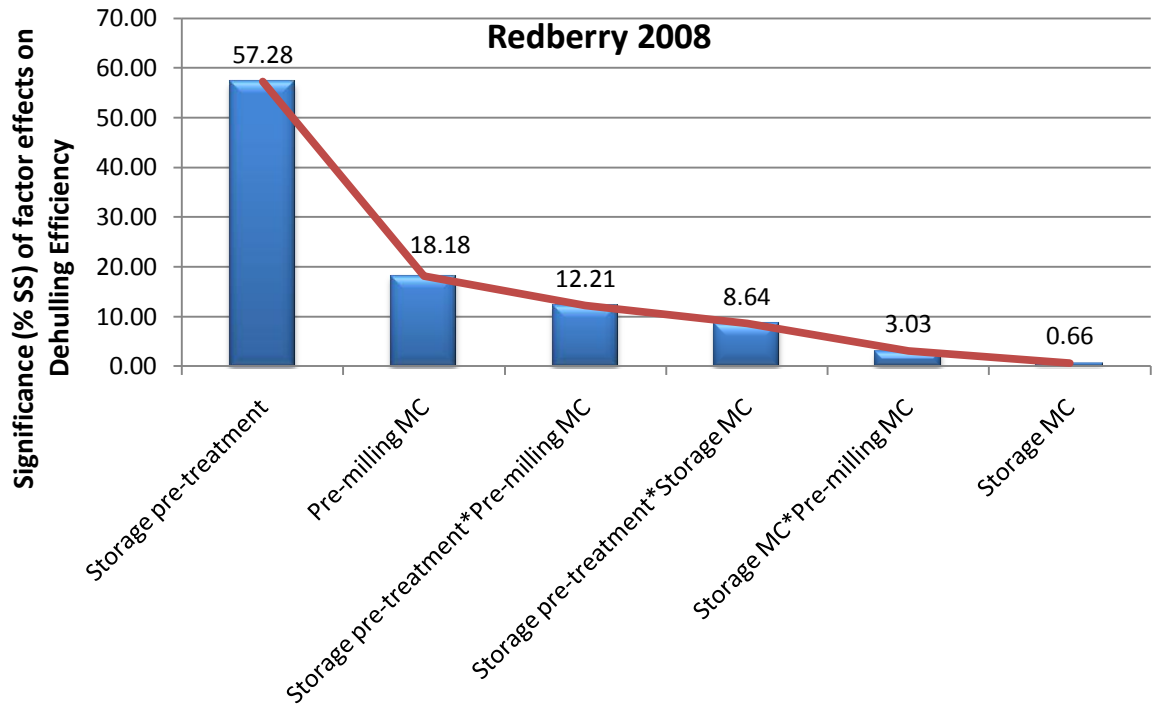


Figure 4.15 Significance of factor effects on dehulling efficiency for Redberry 2008 red lentils stored at 5°C

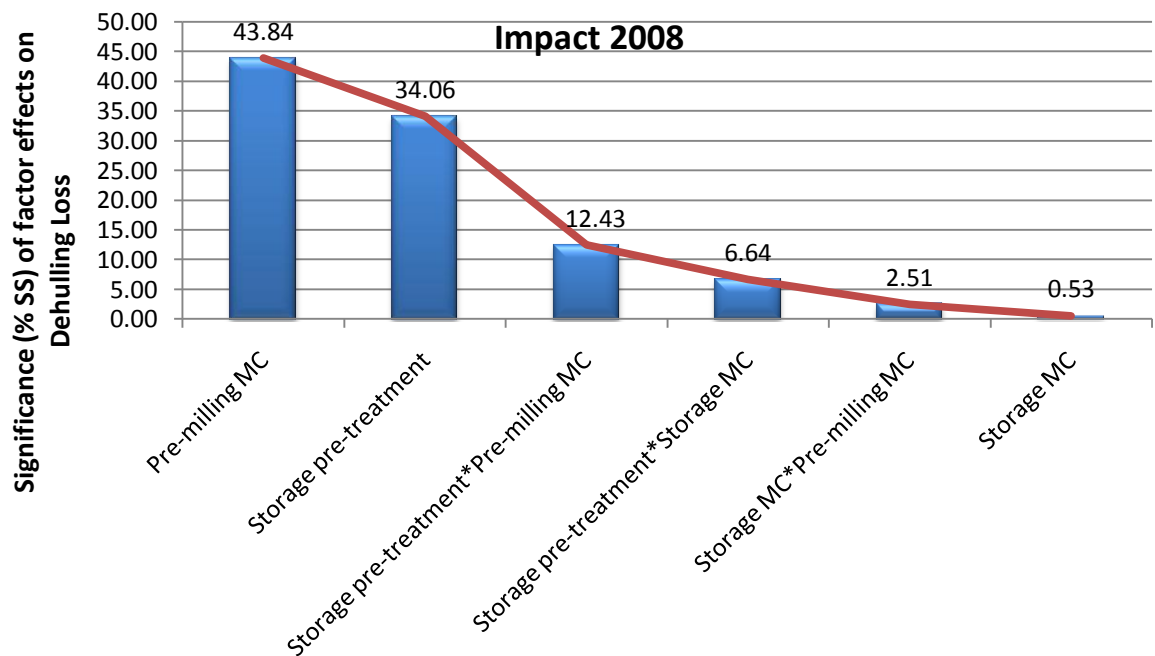


Figure 4.16 Significance of factor effects on dehulling efficiency for Impact 2008 red lentils stored at 5°C

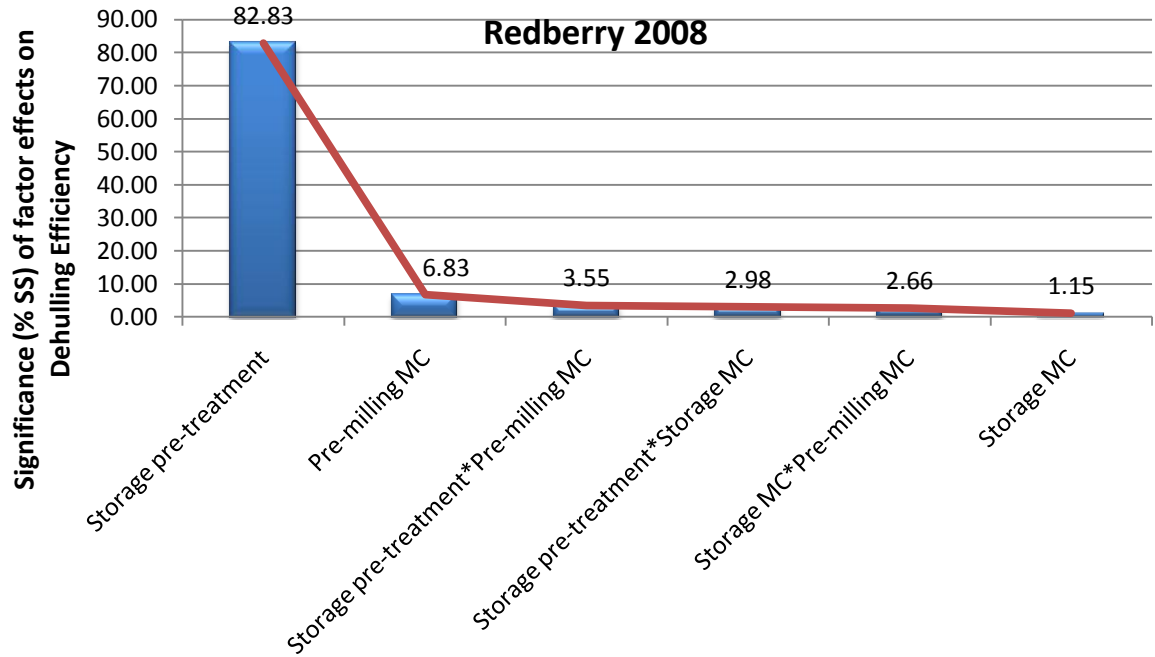


Figure 4.17 Significance of factor effects on dehulling loss for Redberry 2008 red lentils stored at 5°C

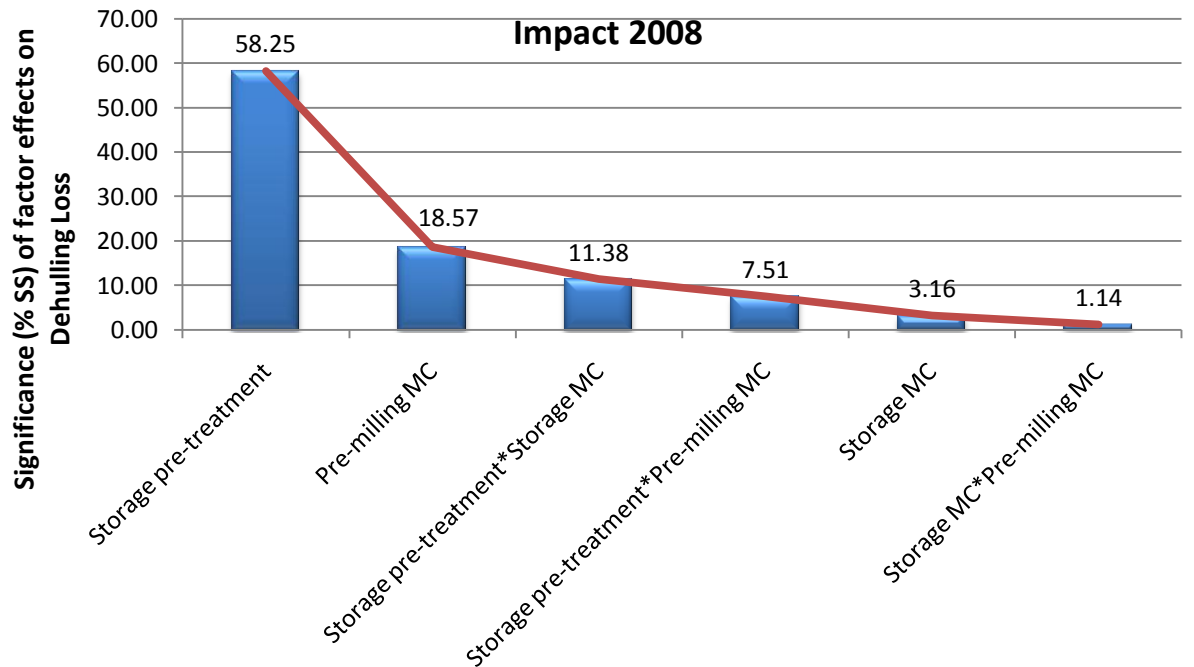


Figure 4.18 Significance of factor effects on dehulling loss for Impact 2008 red lentils stored at 5°C

Two interactions significantly affected the dehulling efficiency of Redberry cultivar, both involving storage pre-treatment and another factor, either pre-milling moisture content or storage moisture content. For all pre-milling and storage moisture contents, DE seems to achieve maximum values at storage pre-treatment B dried at 80°C while they show minimum DE in pre-treatment C, interaction plots are shown in Appendices 27 and 28). Pre-milling moisture content 15.3% showed the lowest DE values in A, B40, C and D pre-treatments but for B80 it had similar DE values than other pre-milling moisture levels. Higher moisture content during storage results in lower DE for storage pre-treatment A, but higher DE for pre-treatments C and D. DE does not seem to be affected by storage moisture content in pre-treatments B40 and B80. It is important to emphasize that no interactions were significant for dehulling loss of Redberry cultivar analyzed on the general factorial.

Table 4.17 Significant factors affecting dehulling efficiency (DE) and dehulling loss (DL) for Redberry cultivar red lentils 2008 crop year

Parameter	Significant factors for Redberry 2008	% SS ^a
DE	Storage pre-treatment	57.3
	Pre-milling MC	18.2
	Storage pre-treatment*Pre-milling MC	12.2
	Storage pre-treatment*Storage MC	8.6
DL	Storage pre-treatment	82.8
	Pre-milling MC	6.8

^a percentage of the total sum of squares

DE- dehulling efficiency DL- dehulling loss MC- moisture content

As can be seen in Table 4.18, DE of the Impact cultivar in the 2008 crop was mainly affected by pre-milling moisture content, followed by storage pre-treatment, while the order is reversed for dehulling loss. Similar to results for Redberry, Impact cultivar red lentils were not affected by storage moisture content as its contribution as a main factor is lower than 5% of the total sum of squares. Nevertheless, storage moisture content showed significance when interacting with other factors.

Interactions between storage pre-treatment and either storage or pre-milling moisture content were the other terms significantly affecting both DE (6.6 to 12.4%) and DL (7.5 to 11.4%) of Impact samples. DE appeared to be higher in storage pre-treatment B80 regardless of the storage or pre-milling moisture content. In contrast to the trends presented for Redberry DE results, Impact had the lowest DE in storage pre-treatment A and although pre-treatment C had lower DE than B80, it was higher than B40. On the other hand, DL was visibly higher in pre-treatment C, and this was accentuated in samples stored at 10% moisture content and conditioned at 10.4% before milling. Singh (1995) also reported higher breakage and powder fractions when milling at lower moisture contents.

Table 4.18 Significant factors affecting dehulling efficiency (DE) and dehulling loss (DL) for Impact cultivar red lentils 2008 crop year

Parameter	Significant factors for Impact 2008	% SS ^a
DE	Pre-milling MC	43.8
	Storage pre-treatment	34.1
	Storage pre-treatment*Pre-milling MC	12.4
	Storage pre-treatment*Storage MC	6.6
DL	Storage pre-treatment	58.3
	Pre-milling MC	18.6
	Storage pre-treatment*Storage MC	11.4
	Storage pre-treatment*Pre-milling MC	7.5

^a percentage of the total sum of squares

DE- dehulling efficiency DL- dehulling loss MC- moisture content

Figures 4.19 and 4.20 are reflections of point predictions based on the ANOVA model and show the trends of dehulling efficiency and dehulling loss as affected by the main factors involved in the general factorial. The most drastic changes in DE and DL were produced by the different storage pre-treatments. Pre-treatment C shows the lowest DE and the highest DL for Redberry while Impact pre-treatment A had the lowest DE while samples with pre-treatment C still had the highest losses. Increasing storage moisture content to 13% seemed to decrease slightly both DE and DL whereas increasing pre-milling moisture content increased DE but decreased DL. Pre-milling moisture content affected each cultivar differently. For Redberry, 15.3% moisture appears to produce the highest DE while for Impact it resulted in the lowest DE value. Therefore Impact was more affected by the differences in pre-milling moisture content.

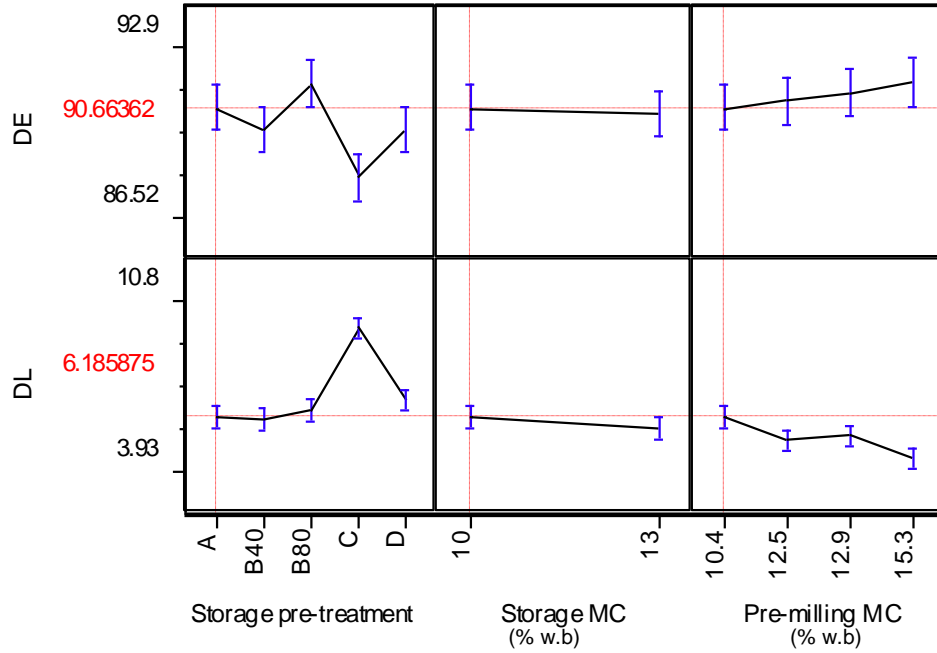


Figure 4.19 Prediction profiler for every factor of the general factorial for Redberry 2008 red lentils

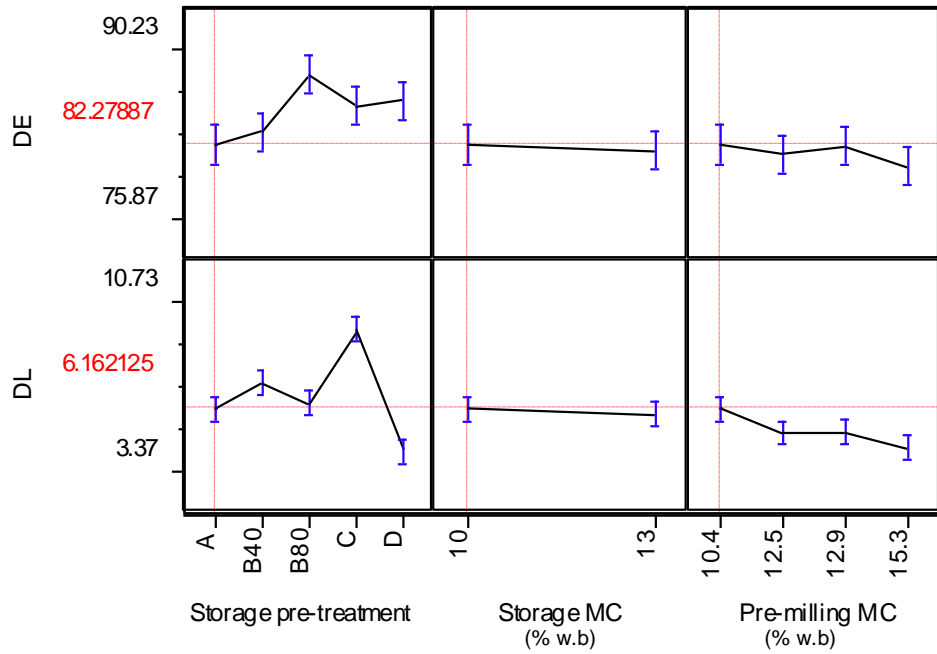


Figure 4.20 Prediction profiler for every factor of the general factorial for Impact 2008 red lentils

4.2.4 Dehulling efficiency results as affected by storage pre-treatment for 2008 crop year

4.2.4.1 Dehulling efficiency

4.2.4.1.1 Redberry cultivar

A summary of the significant terms for DE of Redberry cultivar is shown in Table 4.19. Storage pre-treatment A was affected principally by storage time and storage moisture content, and minimally (lower than 10%) by two-way interactions between either storage time or storage temperature with pre-milling moisture content, as well as pre-milling moisture content itself. Generally, DE values were higher at 6 months compared to 0 months. The interaction with pre-milling moisture content showed that samples stored for 6 months tended to have lower DE at 15.3% pre-milling moisture whereas samples at the beginning of storage presented higher DE at the same pre-milling moisture level. Samples stored at 13% moisture content showed similar DE regardless of the pre-milling moisture, while samples at 10% had increased DE with increasing moisture before milling.

Pre-treatment B was highly affected by pre-milling moisture content, followed by drying temperature and by storage time. Storage moisture content and temperature, on their own, did not affect the DE of Redberry B samples, but there were three significant interactions, two of them involving storage temperature. Lentils stored at 5°C were affected more by drying temperature than those stored at 25°C. The

opposite trend was observed for storage time, where the DE of Redberry lentils stored at 25°C changed more over time than lentils stored at 5°C. Samples dried at 80°C had higher DE after 6 month storage while samples dried at 40°C did not seem to be strongly affected by storage. Although these three interactions were significant, the real differences between DE values from the factors involved in the interactions were not higher than 1.5%; moreover, the biggest difference in DE within all B combinations was 5%.

Pre-milling moisture content was also the most significant factor affecting storage pre-treatment C for Redberry, followed closely by the contribution of storage moisture content. Three interactions were found to significantly affect the DE: number of cycles with storage moisture content; storage and pre-milling moisture; and the number of cycles with pre-milling moisture content. After the second application of drying/rewetting cycles, samples were more affected by storage moisture content (lower DE at 10% moisture). Lower DE values were also found after the second application of drying/rewetting cycles for all pre-milling moisture contents except at 15.3%. Samples stored at 10% moisture content presented lower DE and were more affected by pre-milling moisture content than samples stored at 13%.

Table 4.19 Significant factors affecting dehulling efficiency (DE) for Redberry cultivar red lentils 2008 crop year

Storage pre-treatment	Significant factors on Dehulling Efficiency	% SS ^a
A	Storage time	41.2
	Storage MC	31.4
	Storage time*Pre-milling MC	8.6
	Storage MC*Pre-milling MC	7.7
	Pre-milling MC	6.3
B	Pre-milling MC	22.6
	Drying temperature	19.0
	Storage time	14.7
	Drying temperature*Storage temperature	11.4
	Storage time*Drying temperature	8.8
	Storage time*Storage temperature	6.3
C	Pre-milling MC	32.1
	Storage MC	31.5
	Number of cycles*Storage MC	14.9
	Storage MC*Pre-milling MC	13.0
	Number of cycles*Pre-milling MC	6.4

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

4.2.4.1.2 Impact cultivar

The significant factors affecting DE of Impact red lentils for 2008 are given in Table 4.20. Storage pre-treatment A for Impact cultivar was mainly affected by storage time and pre-milling moisture content, although the significance of storage time was due to an increase in DE after 6 months storage. A pre-milling moisture level of 15.3% is again, responsible for the lowest DE.

Two-way interactions between storage time and storage moisture content, as well as between storage moisture content and pre-milling moisture content were also significant for pre-treatment A. DE values increased at 13% storage moisture content for samples stored for 6 months while for the initial storage, 13% presented the lowest DE. Samples stored at 13 and 11.5% moisture content presented higher DE values when subjected to lower pre-milling moisture contents, while samples stored at 10% had higher DE when preconditioned at 12.9%.

For storage pre-treatment B, three main factors were responsible for the changes in DE. Drying temperature accounted for the highest contribution (75.6%), since higher DE were found after drying at 80°C. Minimal contributions were found from pre-milling moisture content and storage moisture content. Storage time, temperature and all two-way interactions did not significantly affect the DE of Impact B samples.

Pre-milling and storage moisture contents as well as their interaction were responsible for the majority of the changes for samples that underwent drying/rewetting cycles

(storage pre-treatment C). An interaction between the number of applications of the treatment and storage moisture content was also significant. Interactions resulted from the fact that samples stored at 13% had higher DE values for most pre-milling moisture contents, but when milled at 15.3%, the differences between 10 and 13% were much lower.

Table 4.20 Significant factors affecting dehulling efficiency (DE) for Impact red lentils 2008 crop year

Storage pre-treatment	Significant factors on Dehulling Efficiency	% SS^a
A	Storage time	34.5
	Pre-milling MC	29.5
	Storage time*Storage MC	20.1
	Storage MC*Pre-milling MC	6.7
B	Drying temperature	75.6
	Pre-milling MC	7.2
	Storage MC	6.2
C	Pre-milling MC	39.1
	Storage MC	26.8
	Storage MC*Pre-milling MC	20.7
	Number of cycles*Storage MC	8.0

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

4.2.4.2 Dehulling loss

4.2.4.2.1 Redberry cultivar

Pre-milling moisture content was the major factor affecting the dehulling loss of the 2008 Redberry cultivar contributing more than 50% of the total sum of squares in all storage pre-treatments. The summary of significant terms can be observed in Table 4.21.

Pre-treatment A was also affected by interactions between pre-milling moisture content and either storage time or moisture content. After 6 month storage, Redberry red lentils seemed more susceptible to the effects of pre-milling moisture content.

Storage time was also a significant factor affecting minimally the DL of B samples while DL for storage pre-treatment C was affected by storage moisture content and interactions between storage moisture content and either pre-milling moisture or the number of applications of the treatment. Samples stored at 10% moisture content were more affected by lower pre-milling moisture contents, resulting in increase in the amount of broken seeds and therefore the DL value. A combination of 2 applications of the C pre-treatment with lower storage moisture content also increased the dehulling loss of Impact red lentils.

Table 4.21 Significant factors affecting dehulling loss (DL) for Redberry cultivar red lentils 2008 crop year

Storage pre-treatment	Significant factors on Dehulling Loss	% SS ^a
A	Pre-milling MC	80.9
	Storage time	8.5
	Storage time*Pre-milling MC	5.3
B	Pre-milling MC	81.8
	Storage time	6.6
C	Pre-milling MC	52.5
	Storage MC	22.3
	Storage MC*Pre-milling MC	13.6
	Number of cycles*Storage MC	5.5

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

4.2.4.2.2 Impact cultivar

The factors affecting the dehulling losses for Impact cultivar are summarized in Table 4.22 for all storage pre-treatments. Pre-milling moisture content contributed greatly to DL for all pre-treatments (A, B and C), ranging from 35.2 to 49.7% of the total contribution. Storage moisture content significantly affected the DL of pre-treatments A and C. Drying temperature was also an important factor in the dehulling losses of Impact B samples representing 34% of the total contribution. The number of times the treatment was applied for storage pre-treatment C also made a significant contribution to DL for pre-treatment C.

For pre-treatment A, storage moisture content affected the DL of samples stored at 6 months more than samples tested at the beginning of storage, which resulted in a significant two-factor interaction. Higher losses and a greater effect of pre-milling moisture content were also observed in samples stored at 10% compared to samples stored at 13%.

Table 4.22 Significant factors affecting dehulling loss (DL) for Impact cultivar red lentils 2008 crop year

Storage pre-treatment	Significant factors on Dehulling Loss	% SS ^a
A	Pre-milling MC	49.7
	Storage MC	20.8
	Storage time*Storage MC	13.7
B	Pre-milling MC	44.8
	Drying temperature	34.0
C	Storage MC	36.9
	Pre-milling MC	35.2
	Number of cycles	16.0
	Storage MC*Pre-milling MC	10.1

^apercentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

4.2.5 General discussion of dehulling efficiency

As mentioned before, the cultivar had the most significant effect on the dehulling characteristics of red lentils. For this reason, an individual analysis for each cultivar was performed. Impact presented, in general, lower DE and higher DL values compared to Redberry. Wang (2008) also reported a variety effect on the dehulling properties of red

lentils as did Ehiwe and Reichert (1987), who reported major differences in the resistance to seed splitting contributed to dehulling efficiencies and dehulling losses for different cultivars of cowpea. Differences between cultivars might be due to differences in the structure of the seed coats. Sefa-Dedeh & Stanley (1979a) noticed that cowpeas with thick seed coats are favoured for dry-dehulling methods as thin seed coat varieties cannot withstand the shearing forces and therefore perform better under wet conditions.

It should be noted that the red lentil cultivars used in this study had different average seed sizes, therefore the mechanical separation used a different range of sieves to get representative samples from each cultivar (see Chapter 2). Redberry has larger, flatter seeds than Impact. According to Erskine et al. (1991), large lentil seeds generate higher broken fractions but also higher splits, which might explain the higher DE of Redberry red lentils. Reichert et al. (1984) and Oomah et al. (1996) also correlated the seed size to the dehulling characteristics of legumes and flaxseed, respectively.

Overall, pre-milling moisture content generated the majority of the changes in both dehulling efficiency and dehulling losses for both Impact and Redberry cultivars in both years. Mazza & Campbell (1985) noticed a decrease in dehulling yield of buckwheat as water activity of samples increased, which is in accordance with the results of this study. They attributed the increase in dehulling yield to the brittleness of the seeds which caused the detachment of seed coats from the cotyledons.

Storage pre-treatments involving drying and rewetting of samples exhibited lower dehulling efficiencies and higher dehulling losses (as high as 30%), demonstrating the detrimental effect of the moisture gradients. Erskine et al. (1991) reported lower dehulling efficiencies for lentils with higher moisture contents due to immersion of the seeds in water. In his study of methods for dehulling pulses, Singh (1995) showed that dry methods produced more broken seeds while wet methods tended to have lower percentage of losses. Tiwari et al. (2008) also reported high breakage of pigeon pea (up to 18%) when applying moisture to the sample and then drying it to 9.5%. Ehiwe et al. (1987) noticed the high seed breakage at low moisture contents within field peas and attributed it to either changes in tissue elasticity, or the binding between inner seed coat surface and the cotyledon. When tissues begin to lose moisture, there is an increase in brittleness caused by either an increase in crystallization or a change in cellulosic orientation; the loss of elasticity results in susceptibility to breakage. Storage moisture content was highly significant for storage pre-treatments involving drying and rewetting cycles and minimally for the other storage pre-treatments.

Drying temperature showed a significant effect on the dehulling characteristics of red lentils. Interestingly, drying at higher temperatures (80°C) resulted in much less damage and higher dehulling efficiencies than drying at 40°C. This might be attributed to longer drying times to reach the desired moisture content when using lower temperatures. The results are in accordance with Phirke et al. (1995) whose research showed a high tendency to dehulling and splitting of pigeon peas when treated with heat.

Storage time did have a significant effect in most cases, but contributions to the total changes were relatively minor. Storage temperature had no impact in most cases. Similar results where DE was unaffected by temperature were found by Mazza & Campbell (1985).

4.2.6 Comparison of dehulling efficiency and loss with Reference samples

4.2.6.1 Redberry cultivar 2007 crop

In order to assess the magnitude of the changes of individual DE and DL values, means of samples from each condition were compared to untreated (References) which were kept at 5°C. Each sample was compared to the Reference sample at their closest time point (e.g. samples stored for 1 and 2 months were compared to Reference at 0 months and were denominated as samples at initial storage).

It can be observed in Table 4.23 that at the beginning of storage (up to 2 months), samples stored after pre-treatments A and D had similar DE and DL values to the Reference sample, whereas storage pre-treatments B dried at 40°C (B40) and pre-treatment C resulted in lower DE and higher DL. Samples stored for 1 month after storage pre-treatment B dried at 80°C (B80) and stored at 13% moisture content presented lower DE than the Reference sample, but samples stored at 10% did not significantly differ from the Reference.

After 6 months of storage, Redberry samples stored after pre-treatments A, B40 and B80 did not significantly differ in DE and DL values from the Reference sample (Table 4.24) with the exception of samples using a pre-milling moisture content of 15.3%.

Redberry samples stored for 12 months (Table 4.25) and storage pre-treatments A and D presented similar DE and DL values to the Reference (untreated) sample with a few exceptions from samples with pre-milling moisture content of 15.3%. Samples with storage pre-treatment B40, stored at 10% moisture and 25°C showed lower DE values than the Reference sample, while the rest of the B40 and B40 samples did not significantly differ from the Reference, regardless of pre-milling moisture content. Storage pre-treatment C resulted in lower DE (as low as 83%) and higher DL (as high as 12.2%) values after 12 months.

4.2.5.2 Impact cultivar 2007 crop

At the initial storage point (0, 1, and 2 months), Impact samples that followed storage pre-treatments B40, C and D presented lower DE and higher DL values when compared to the Reference samples, regardless of pre-milling moisture content (Table 4.23). In contrast, samples following pre-treatment A had similar DE and DL to those of the Reference, with the exception of two samples using 15.3% pre-milling moisture, which reflects the impact of the pre-milling treatment. Samples with storage pre-treatment B dried at 80°C (B80) had less of a negative effect than those dried at 40°C since only the B80 samples with storage moisture content of 10% presented lower DE than the Reference whereas DE was lower than the Reference for all B40 samples. The lowest

DE (58.4 and 58.5%) were found in storage pre-treatment C after one and two treatment rounds, respectively, at a pre-milling moisture content of 15.3%. This demonstrates the negative effect of moisture gradients and high pre-milling moisture contents. It should be noted that results were similar to Redberry, with the exception of storage pre-treatment D, which negatively affected the DE of Impact lentils but not Redberry.

Impact samples stored for 6 months following pre-treatment A presented lower DE only when pre-conditioned at 15.3% moisture content before milling. Samples stored at 13% had also lower DE at pre-milling moisture content of 12.5 and 12.9%. Storage pre-treatments B40 and B80 resulted in samples with lower DE and higher DL than those of Reference samples stored for 6 months, regardless of temperature and moisture content.

After 12 months storage, the Impact cultivar samples stored after pre-treatment A were still severely affected by high storage moisture contents as all samples stored at 13% presented lower DE than the Reference for that storage time. The DE value of freeze/thawed (pre-treatment D) samples did not show the same effects as earlier as the only samples that were negatively affected were when pre-milling moisture content was 15.3%. Storage pre-treatments B40, B80 and C continued to have significantly lower DE and higher DL than the Reference sample. Similar to samples tested at the initial storage point, the lowest DE (53.1%) was found in storage pre-

treatment C with pre-milling moisture of 15.3%; the same pre-treatment with 10.4% pre-milling moisture generated the highest DL (31.5%).

As can be observed in Tables 4.23, 4.24 and 4.25, despite the statistically significant differences between the Reference and pre-treated samples for Redberry red lentils the actual values were not as dramatically different from the Reference as they were for the Impact cultivar. Nevertheless, the same factors seemed to affect both cultivars although to a different extent. Moisture content gradients were the leading cause of damage resulting in lower dehulling efficiencies and higher dehulling losses. It should also be noted that higher drying temperatures had less of a negative impact on the DE and DL of red lentil samples than the fluctuation in moisture.

4.2.5.3 Redberry cultivar 2008 crop

Table 4.26 shows the DE and DL values for Impact and Redberry cultivar red lentils at the initiation of storage for 2008. The Redberry cultivar did not show significant differences compared to the Reference sample at 0 months in any of the storage pre-treatment. Most DE values were above 87% which is close to the Reference value of 90.1%. Dehulling losses were similar to the Reference value of 5.1%. The only storage pre-treatments that showed significant differences were the ones involving drying/rewetting cycles (pre-treatment C) where DE as low as 82.2% and DL values as high as 14.4% were obtained.

After 6 months storage, DE of the Reference sample was slightly higher than the Reference at 0 months, but still none of the storage pre-treatments resulted in statistically different values when compared to the Reference. For DL, significant differences were found in most storage pre-treatments when using pre-milling moisture content of 10.4 or 15.3% (samples at 15.3% showed lower DL than the Reference while samples milled at 10.4% had higher DL values).

4.2.5.4 Impact cultivar 2008 crop

The DE values of Impact cultivar red lentils at the initiation of storage and pre-treatment A were generally lower than that of the Reference, with almost 10% reduction for samples with a pre-milling moisture content of 15.3%. Storage pre-treatments B40 and B80 generally resulted in similar values to the Reference. Exceptions for the B40 pre-treatment were two samples with a pre-milling moisture content of 15.3% that produced low DE values. For B80 at 10% storage moisture and 25°C, significantly higher values than those of the Reference were achieved. In general, storage pre-treatments C and D did not differ significantly in DE values from the Reference. For A and B80 pre-treatments, samples milled at 10.4% had higher DL than the Reference, while all B40 and C samples presented significantly higher DL levels. Storage pre-treatment D was the only set that had statistically DL values that were similar to the Reference.

After 6 months storage time, Impact samples stored after pre-treatments A and B40 showed lower DE values than the Reference only when milled at 15.3% moisture.

Interestingly, samples in storage pre-treatment B80 presented significantly higher values than the Reference, which confirms that drying at high temperatures produces less of a negative effect for Impact red lentils. As for dehulling losses, only pre-treatment B40 showed higher values than the Reference, although no DE value was higher than 9% (Reference value of 4.2%).

Table 4.23 Dehulling parameters^a obtained for Redberry and Impact samples (2007 crop) after 0, 1, and 2 months of storage

Storage Pre-Treatment	Storage MC (% wb)	Storage Temperature (°C)	Storage Time months)	Pre-Milling MC (% wb)	DE (%)		DL (%)	
					Redberry	Impact	Redberry	Impact
Reference	as is	as is	0	12.5	97.4	94.7	2.0	1.8
A	10	as is	0	10.4	94.9	91.8	4.0*	5.4*
				12.9	96.6	92.1	2.4	3.5
				15.3	95.4	82.2*	2.1	2.3
				12.5	96.0	93.1	3.1	3.9
	11.5	as is	0	10.4	95.4	93.8	3.7*	4.1
				12.9	95.9	89.2*	2.8	3.5
				15.3	91.3*	80.8*	1.7	2.1
				12.5	95.9	92.8	3.1	2.9
	13	as is	0	10.4	96.3	93.8	3.1	4.1
				12.9	95.9	90.3	2.6	4.6
				15.3	89.3*	73.8*	1.5	2.3
				12.5	96.3	90.0	2.7	4.5
B40	10	5	1	10.4	90.7*	68.6*	7.7*	25.1*
				12.9	93.0*	76.2*	4.8*	16.2*
				15.3	90.8*	76.5*	2.6	9.9*
				12.5	93.1*	75.7*	5.0*	16.1*
	13	5	1	10.4	92.7*	77.7*	6.0*	15.9*
				12.9	93.9*	81.3*	4.0*	11.6*
				15.3	91.9*	77.5*	2.2	5.6*
				12.5	94.2*	79.7*	4.4*	11.9*
	10	25	1	10.4	93.0*	75.2*	5.9*	19.5*
				12.9	93.4*	77.6*	4.4*	16.0*
				15.3	90.1*	76.5*	2.6	8.8*
				12.5	93.6*	78.4*	4.4*	14.4*
13	25	1	10.4	94.0*	79.6*	5.1*	13.9*	
			12.9	94.5	77.1*	3.8*	13.4*	
			15.3	90.7*	71.3*	2.5	7.7*	
			12.5	94.4	77.6*	3.3	13.4*	

^aDE – dehulling efficiency, DL – dehulling loss; n=2.

*Indicates significant difference (P<0.05) from the Reference (using the Holm-Sidak multiple comparison method).

Table 4.23 cont'd.

Storage Pre-Treatment	Storage MC (% <i>, wb</i>)	Storage Temperature (°C)	Storage Time months)	Pre-Milling MC (% <i>, wb</i>)	DE (%)		DL (%)	
					Redberry	Impact	Redberry	Impact
Reference	as is	as is	0	12.5	97.4	94.7	2.0	1.8
B80	10	5	1	10.4	94.8	87.0*	4.5*	9.4*
				12.9	95.8	86.8*	3.4*	7.0*
				15.3	95.1	75.5*	1.8	3.6
				12.5	95.3	86.1*	3.6*	6.6*
	13	5	1	10.4	87.5*	95.1	8.9*	3.9
				12.9	82.9*	95.7	9.6*	3.0
				15.3	76.1*	94.5	5.7*	2.2
				12.5	83.4*	94.8	9.9*	3.5
	10	25	1	10.4	94.7	87.6*	4.6*	8.3*
				12.9	96.1	86.2*	2.9	6.1*
				15.3	93.6*	75.0*	2.0	3.5
				12.5	95.3	86.6*	3.5*	6.5*
13	25	1	10.4	87.7*	95.0	7.9*	3.9	
			12.9	81.7*	95.1	8.8*	3.3	
			15.3	75.0*	95.3	5.8*	2.2	
			12.5	83.2*	95.0	9.2*	3.5	
C	10	5	1	10.4	91.4*	71.7*	7.4*	24.1*
				12.9	93.2*	75.0*	5.5*	15.6*
				15.3	87.3*	58.4*	2.8	9.7*
				12.5	92.2*	76.2*	6.6*	16.8*
	13	5	1	10.4	94.4	82.4*	4.7*	12.3*
				12.9	93.7*	79.8*	3.6*	11.5*
				15.3	84.6*	63.3*	2.2	6.2*
				12.5	94.1*	77.4*	3.4*	11.5*

Table 4.23 cont'd.

Storage Pre-Treatment	Storage MC (%, wb)	Storage Temperature (°C)	Storage Time (months)	Pre-Milling MC (%, wb)	DE (%)		DL (%)	
					Redberry	Impact	Redberry	Impact
Reference	as is	as is	0	12.5	97.4	94.7	2.0	1.8
C	10	5	2	10.4	86.3*	62.7*	12.3*	32.9*
				12.9	89.7*	67.3*	8.3*	27.1*
				15.3	84.7*	58.5*	6.7*	20.1*
				12.5	90.3*	66.4*	8.0*	28.1*
				10.4	92.5*	79.5*	6.6*	15.2*
				12.9	92.3*	77.9*	6.1*	13.8*
	13	5	2	15.3	92.5*	65.5*	3.9*	8.9*
				12.5	93.1*	78.2*	5.4*	13.8*
				10.4	96.0	89.4*	3.4*	8.4*
				12.9	96.3	90.1	3.2	5.3
				15.3	96.7	81.6*	2.2	3.1
				12.5	96.2	90.7	2.9	5.4*
D	10	5	1	10.4	94.6	87.2*	4.5*	10.9*
				12.9	95.6	88.9*	3.4*	8.9*
				15.3	94.6	88.4*	2.2	5.1
				12.5	95.6	89.9*	3.2	8.1*
				10.4	94.3	85.9*	4.6*	11.2*
				12.9	96.1	88.5*	2.9	6.5*
	13	5	1	15.3	93.8*	81.6*	1.9	3.9
				12.5	95.8	88.6*	3.0	6.8*
				10.4	94.5	88.7*	4.2*	8.7*
				12.9	95.6	89.6*	2.7	6.3*
				15.3	89.2*	83.2*	2.0	3.4
				12.5	95.6	89.7*	3.1	6.3*

Table 4.24 Dehulling parameters^a obtained for Redberry and Impact samples 2007 crop after 6 months of storage

Storage Pre-Treatment	Storage MC (% wb)	Storage Temperature (°C)	Storage Time (months)	Pre-Milling MC (% wb)	DE (%)		DL (%)	
					Redberry	Impact	Redberry	Impact
Reference	as is	5	6	12.5	95.7	91.1	2.3	2.4
A	10	5	6	10.4	96.4	92.0	2.8	5.7*
				12.9	96.0	91.1	2.7	4.0
				15.3	94.2	71.2*	1.5	2.0
				12.5	96.5	91.6	2.3	4.0
	11.5	5	6	10.4	95.4	90.4	3.3	6.8*
				12.9	96.0	90.4	2.6	3.7
				15.3	90.6*	63.9*	2.0	2.0
				12.5	95.9	90.2	3.0	3.5
				10.4	94.4	90.3	3.9*	5.4*
				12.9	95.3	83.9*	2.8	5.9*
				15.3	92.4*	60.1*	2.0	2.9
				12.5	95.4	81.1*	2.8	5.8*
	10	25	6	10.4	96.5	93.1	2.7	5.2*
				12.9	96.9	91.6	2.1	3.8
				15.3	93.7*	79.3*	1.8	2.5
				12.5	97.0	90.0	2.3	4.2
				10.4	96.1	90.5	3.3	6.6*
				12.9	96.6	90.6	2.7	4.7*
				15.3	93.1*	75.3*	2.2	2.4
				12.5	96.2	87.9	3.0	4.9*
	13	25	6	10.4	95.7	87.6	3.0	8.3*
				12.9	96.1	83.3*	2.8	6.7*
				15.3	91.8*	61.8*	2.0	4.3*
				10.4	93.3*	80.7*	5.6*	14.1*
B40	10	5	6	12.9	93.7*	81.5*	3.5*	10.7*
				15.3	84.6*	67.9*	2.0	4.4*
				12.5	93.7*	80.3*	3.6*	10.9*

^aDE – dehulling efficiency, DL – dehulling loss; n=2.

*Indicates significant difference (P<0.05) from the Reference (using the Holm-Sidak multiple comparison method).

Table 4.24 cont'd.

Storage Pre-Treatment	Storage MC (%, wb)	Storage Temperature (°C)	Storage Time months)	Pre-Milling MC (%, wb)	DE (%)		DL (%)	
					Redberry	Impact	Redberry	Impact
Reference	as is	5	6	12.5	95.7	91.1	2.3	2.4
B40	13	5	6	10.4	95.0	84.3*	4.2*	10.0*
				12.9	94.8	82.3*	3.0	8.3*
				15.3	87.2*	70.4*	1.5	4.0
				12.5	94.8	81.8*	2.9	9.0*
	10	25	6	10.4	93.4*	77.6*	4.6*	16.8*
				12.9	94.2	80.5*	3.6*	9.7*
				15.3	73.2*	77.3*	1.2	4.2
				12.5	94.8	82.0*	3.6*	10.6*
	13	25	6	10.4	94.3	79.8*	4.5*	14.6*
				12.9	94.8	81.8*	2.8	9.4*
				15.3	89.9*	79.3*	1.7	4.0
				12.5	94.5	81.5*	3.0	10.2*
B80	10	5	6	10.4	94.6	84.1*	3.9*	12.0*
				12.9	95.5	85.2*	2.8	8.1*
				15.3	92.2*	73.1*	1.5	2.8
				12.5	95.6	85.1*	2.5	6.8*
	13	5	6	10.4	95.3	86.5*	3.6*	7.9*
				12.9	94.7	84.4*	3.0	8.1*
				15.3	91.5*	71.0*	1.5	3.4
				12.5	95.4	82.0*	2.1	8.0*
	10	25	6	10.4	94.3	81.0*	5.0*	14.6*
				12.9	94.9	83.8*	3.9*	10.7*
				15.3	93.3*	79.2*	2.1	3.9
				12.5	94.7	83.1*	3.0	7.9*
13	25	6	10.4	94.6	82.8*	4.2*	11.7*	
			12.9	95.5	82.1*	2.8	10.7*	
			15.3	90.7*	70.5*	1.2	5.6*	
			12.5	96.1	81.0*	1.7	9.1*	

Table 4.25 Dehulling parameters^a obtained for Redberry and Impact samples 2007 crop after 12 months of storage

Storage Pre-Treatment	Storage MC (% wb)	Storage Temperature (°C)	Storage Time (months)	Pre-Milling MC (% wb)	DE (%)		DL (%)	
					Redberry	Impact	Redberry	Impact
Reference	as is	5	12	12.5	95.2	91.8	3.0	2.8
A	10	5	12	10.4	95.0	87.9	3.9*	8.4*
				12.9	95.9	90.4	3.0	5.1
11.5	5	12	15.3	95.6	81.5*	2.3	4.8	
			12.5	95.2	89.5	3.1	6.1*	
			10.4	93.9	85.9*	4.9*	11.3*	
			12.9	93.9	86.3*	4.1*	8.6*	
			15.3	93.5	79.0*	2.8	6.1*	
			12.5	93.9	86.2*	4.1*	8.3*	
13	5	12	10.4	93.1*	81.0*	5.6*	13.4*	
			12.9	94.1	82.6*	4.2*	9.9*	
			15.3	92.8*	74.6*	3.4	8.9*	
			12.5	94.3	81.7*	4.0*	11.0*	
			10.4	94.7	89.8	4.3*	7.0*	
			12.9	95.3	88.3	3.7	6.0*	
10	25	12	15.3	95.6	82.6*	2.7	4.1	
			12.5	94.8	89.6	4.0*	5.1	
			10.4	94.5	88.3	4.2*	8.8*	
			12.9	95.4	87.4	3.4	7.7*	
			15.3	94.9	83.7*	2.5	3.6	
			12.5	94.7	88.6	3.8*	7.7*	
11.5	25	12	10.4	94.5	88.3	4.2*	8.8*	
			12.9	95.4	87.4	3.4	7.7*	
			15.3	94.9	83.7*	2.5	3.6	
			12.5	94.7	88.6	3.8*	7.7*	
			10.4	93.6	80.5*	4.7*	13.7*	
			12.9	93.9	82.7*	3.8	9.9*	
13	25	12	15.3	91.9*	77.4*	3.0	6.6*	
			12.5	93.4*	81.7*	3.9*	10.9*	

^aDE – dehulling efficiency, DL – dehulling loss; n=2.

*Indicates significant difference (P<0.05) from the Reference (using the Holm-Sidak multiple comparison method).

Table 4.25 cont'd.

Storage Pre-Treatment	Storage MC (%, wb)	Storage Temperature (°C)	Storage Time (months)	Pre-Milling MC (%, wb)	DE (%)		DL (%)	
					Redberry	Impact	Redberry	Impact
Reference	as is	5	12	12.5	95.2	91.8	3.0	2.8
B40	10	5	12	10.4	93.7	80.1*	5.0*	13.7*
				12.9	92.8*	78.7*	4.9*	11.5*
				15.3	93.2*	72.4*	2.5	6.5*
				12.5	94.6	80.2*	3.8*	10.1*
	13	5	12	10.4	94.2	82.4*	4.5*	9.9*
				12.9	94.2	84.7*	2.8	5.7*
				15.3	93.5	77.4*	1.9*	3.5
				12.5	94.1	81.9*	3.2	6.2*
	10	25	12	10.4	92.0*	79.7*	6.2*	13.8*
				12.9	92.7*	78.5*	4.7*	13.6*
				15.3	90.2*	73.5*	2.7	8.4*
				12.5	92.4*	78.5*	5.4*	13.7*
13	25	12	10.4	91.9*	77.0*	5.8*	14.7*	
			12.9	93.1*	80.5*	4.4*	10.6*	
			15.3	92.6*	75.2*	2.5	6.5*	
			12.5	93.5	78.6*	4.6*	9.1*	
B80	10	5	12	10.4	93.9	80.8*	4.9*	12.8*
				12.9	94.8	83.0*	3.7	9.4*
				15.3	94.8	75.4*	2.5	5.1
				12.5	94.1	83.9*	3.7	8.8*
	13	5	12	10.4	93.9	84.8*	4.5*	6.7*
				12.9	95.3	85.6*	2.9	4.7
				15.3	94.3	77.7*	1.9*	3.0
				12.5	95.0	86.5*	2.9	4.6
	10	25	12	10.4	93.6	87.6	4.3*	11.1*
				12.9	93.4*	86.2*	3.4	5.9*
				15.3	90.1*	75.0*	2.3	3.7
				12.5	94.1	86.6*	4.1*	8.0*

Table 4.25 cont'd.

Storage Pre-Treatment	Storage MC (%, wb)	Storage Temperature (°C)	Storage Time months)	Pre-Milling MC (%, wb)	DE (%)		DL (%)	
					Redberry	Impact	Redberry	Impact
Reference	as is	5	12	12.5	95.2	91.8	3.0	2.8
B80	13	25	12	10.4	93.2*	73.8*	5.2*	12.5*
				12.9	95.4	82.6*	2.6	5.0
				15.3	93.1*	71.2*	2.0*	3.2
				12.5	94.6	80.7*	2.6	4.9
C	10	5	12	10.4	84.2*	62.3*	12.2*	31.5*
				12.9	87.0*	61.3*	7.9*	27.9*
				15.3	83.3*	53.1*	5.0*	17.9*
				12.5	87.0*	64.3*	8.1*	25.1*
	13	5	12	10.4	91.2*	77.7*	6.8*	13.8*
				12.9	91.2*	76.6*	5.9*	14.1*
				15.3	88.7*	65.7*	4.1*	11.9*
				12.5	90.8*	75.9*	5.7*	15.7*
D	10	5	12	10.4	95.0	87.3	4.1*	9.7*
				12.9	95.5	89.9	3.0	5.0
				15.3	92.1*	81.7*	1.9*	3.0
				12.5	95.6	87.8	3.0	6.6*
	13	5	12	10.4	95.0	88.7	4.0*	7.9*
				12.9	95.2	88.0	3.5	6.8*
				15.3	93.8	79.8*	2.8	4.5
				12.5	94.9	86.4*	3.4	6.7*

Table 4.26 Dehulling parameters^a obtained for Redberry and Impact samples 2008 crop year at initial storage (0, 1, and 2 months)

Storage Pre-Treatment	Storage MC (%, wb)	Storage Temperature (°C)	Storage Time (months)	Pre-Milling MC (%, wb)	DE (%)		DL (%)	
					Redberry	Impact	Redberry	Impact
Reference	as is	as is	0	12.5	90.1	86.1	5.1	4.1
A	10	as is	0	10.4	90.4	81.1*	6.0	5.8*
			0	12.9	90.9	83.2	5.7	5.2
			0	15.3	92.3	81.0*	4.4	4.6
			0	12.5	90.8	81.1*	5.3	5.2
			0	10.4	88.9	84.9	6.2	5.4*
			0	12.9	89.2	82.8	6.0	5.0
	11.5	as is	0	15.3	90.4	79.2*	4.7	4.6
			0	12.5	90.0	84.2	5.8	4.9
			0	10.4	90.7	83.0	6.0	6.3*
			0	12.9	90.5	79.5*	5.6	4.7
			0	15.3	90.2	76.6*	5.0	4.6
			0	12.5	90.1	80.5*	5.4	4.6
B40	10	5	1	10.4	90.4	83.2	5.9	6.9*
			1	12.9	91.5	83.7	5.1	6.7*
			1	15.3	91.0	84.4	4.6	5.6*
			1	12.5	91.2	84.0	4.9	7.1*
			1	10.4	90.0	83.4	6.2	7.5*
			1	12.9	91.1	83.7	5.8	6.4*
	13	5	1	15.3	91.7	79.5*	4.9	5.8*
			1	12.5	91.3	83.2	5.6	6.1*
			1	10.4	89.5	84.9	6.4*	7.0*
			1	12.9	92.1	85.0	5.1	6.0*
			1	15.3	92.2	81.7*	4.3	5.6*
			1	12.5	91.4	87.0	5.1	6.5*
10	25	1	10.4	89.5	84.9	6.4*	7.0*	
		1	12.9	92.1	85.0	5.1	6.0*	
		1	15.3	92.2	81.7*	4.3	5.6*	
		1	12.5	91.4	87.0	5.1	6.5*	
		1	10.4	89.5	84.9	6.4*	7.0*	
		1	12.9	92.1	85.0	5.1	6.0*	

^aDE – dehulling efficiency, DL – dehulling loss; n=2.

*Indicates significant difference (P<0.05) from the Reference (using the Holm-Sidak multiple comparison method).

Table 4.26 cont'd.

Storage Pre-Treatment	Storage MC (%, wb)	Storage Temperature (°C)	Storage Time (months)	Pre-Milling MC (%, wb)	DE (%)		DL (%)	
					Redberry	Impact	Redberry	Impact
Reference	as is	as is	0	12.5	90.1	86.1	5.1	4.1
B40	13	25	1	10.4	91.9	83.6	5.5	7.5*
			1	12.9	92.8*	84.7	5.0	6.8*
			1	15.3	91.7	83.3	4.3	4.7
			1	12.5	91.9	83.4	5.2	6.6*
B80	10	5	1	10.4	91.7	88.9	6.3*	6.3*
			1	12.9	92.4	89.2	5.2	6.6*
			1	15.3	92.3	89.2	4.3	5.1
			1	12.5	92.1	90.0	5.2	5.8*
			1	10.4	92.0	87.2	5.7	6.6*
			1	12.9	92.0	87.6	5.1	6.2*
	13	5	1	15.3	92.4	87.9	4.0	5.3
			1	12.5	92.6	88.3	5.0	6.4*
			1	10.4	91.3	90.1*	6.6*	6.3*
			1	12.9	91.7	90.3*	5.5	5.1
			1	15.3	91.1	90.3*	4.6	4.2
			1	12.5	90.8	89.6	6.5*	5.0
C	10	25	1	10.4	89.3	89.0	7.5*	6.5*
			1	12.9	90.9	89.7	6.2	5.4
			1	15.3	91.6	88.1	4.7	4.5
			1	12.5	90.3	89.5	6.6*	5.5*
			1	10.4	87.4*	85.4	10.5*	10.4*
	13	5	1	12.9	91.2	87.9	6.6*	8.2*
			1	15.3	90.1	86.7	5.0	5.9*
			1	12.5	89.6	87.1	7.8*	8.3*
			1	10.4	90.1	87.8	7.4*	6.6*
			1	12.9	90.9	89.2	6.1	6.2*
			1	15.3	91.0	84.2	5.0	5.0
			1	12.5	89.6	89.2	6.7*	6.4*

Table 4.26 cont'd.

Storage Pre-Treatment	Storage MC (%, wb)	Storage Temperature (°C)	Storage Time (months)	Pre-Milling MC (%, wb)	DE (%)		DL (%)	
					Redberry	Impact	Redberry	Impact
Reference	as is	as is	2	12.5	90.1	86.1	5.1	4.1
C	10	5	2	10.4	82.2*	83.3	14.4*	13.7*
			2	12.9	88.4	87.8	8.4*	9.4*
			2	15.3	90.6	84.4	5.3	7.6*
			2	12.5	87.1*	84.9	10.2*	10.5*
			2	10.4	90.4	88.0	7.3*	8.1*
			2	12.9	91.8	87.8	6.3*	7.7*
	13	5	2	15.3	92.1	86.6	4.7	6.2*
			2	12.5	91.8	89.3	6.3*	7.5*
			2	10.4	90.2	87.0	6.7*	4.2
			1	12.9	90.4	86.3	5.9	4.8
			1	15.3	91.0	83.6	4.8	3.5
			1	12.5	91.0	87.8	6.0	5.0
D	10	25	1	10.4	90.7	86.8	6.5*	4.3
			1	12.9	91.2	87.3	6.1	4.6
			1	15.3	92.2	85.2	4.8	4.1
			1	12.5	90.8	87.2	6.2	4.6
			1	10.4	91.1	88.7	6.5*	4.4
			2	12.9	92.2	87.5	5.2	4.2
	13	5	2	15.3	90.5	83.7	4.6	3.6
			2	12.5	91.7	88.5	5.3	4.1
			2	10.4	91.2	86.0	6.0	5.2
			2	12.9	91.2	83.1	5.4	4.8
			2	15.3	90.5	76.3*	4.3	4.0
			2	12.5	90.3	85.0	5.4	4.3

Table 4.27 Dehulling parameters^a obtained for Redberry and Impact samples 2008 crop year after 6 months of storage

Storage Pre-treatment	Storage MC (%, wb)	Storage Temperature (°C)	Storage Time months)	Pre-Milling MC (%, wb)	DE (%)		DL (%)	
					Redberry	Impact	Redberry	Impact
Reference	as is	5	6	12.5	92.9	85.9	5.1	4.2
A	10	5	6	10.4	91.4	81.9*	6.1*	6.4*
			6	12.9	91.5	84.4	5.0	6.2*
			6	15.3	92.1	80.4*	4.0*	5.0
			6	12.5	92.2	83.4	5.2	5.8*
			6	10.4	90.3	86.2	6.3*	6.2*
			6	12.9	91.2	85.9	5.0	5.3
	11.5	5	6	15.3	90.4	79.5*	4.0*	4.4
			6	12.5	91.7	84.4	5.1	5.5
			6	10.4	91.6	91.1*	6.3*	4.3
			6	12.9	92.2	87.4	4.9	4.5
			6	15.3	91.7	83.0	4.1*	3.4
			6	12.5	91.8	89.4	5.4	4.4
	13	5	6	10.4	91.2	84.4	5.8	6.1*
			6	12.9	92.1	84.8	5.0	5.2
			6	15.3	91.5	79.9*	4.1*	4.0
			6	12.5	91.8	86.3	5.3	5.0
			6	10.4	90.9	87.9	6.4*	5.4
			6	12.9	91.9	87.4	5.2	4.9
	10	25	6	15.3	90.2	81.1*	4.4	3.9
			6	12.5	91.1	87.3	5.5	4.5
			6	10.4	86.7	91.1*	10.7	4.5
			6	12.9	91.2	89.9*	5.0	4.1
			6	15.3	91.5	85.2	4.1*	3.7
			6	12.5	92.0	90.5*	5.0	4.3
11.5	25	6	10.4	90.7	85.3	6.1*	8.3*	
		6	12.9	91.3	86.0	4.8	7.2*	

^aDE – dehulling efficiency, DL – dehulling loss; n=2.

*Indicates significant difference (P<0.05) from the Reference (using the Holm-Sidak multiple comparison method).

Table 4.27 cont'd.

Storage Pre-Treatment	Storage MC (%, wb)	Storage Temperature (°C)	Storage Time (months)	Pre-Milling MC (%, wb)	DE (%)		DL (%)	
					Redberry	Impact	Redberry	Impact
Reference	as is	as is	6	12.5	92.9	85.9	5.1	4.2
B40	10	5	6	15.3	90.5	81.2*	4.0*	5.7*
			6	12.5	91.7	82.7	4.8	7.6*
			6	10.4	90.9	87.0	5.8	6.5*
			6	12.9	91.3	87.4	5.3	5.9*
			6	15.3	91.6	81.5*	4.3	4.5
			6	12.5	92.4	85.5	5.0	6.8*
	13	25	6	10.4	91.0	86.3	6.0*	8.4*
			6	12.9	91.8	87.0	4.8	7.4*
			6	15.3	91.8	82.1*	4.2	6.2*
			6	12.5	91.2	86.9	5.5	8.5*
			6	10.4	91.8	76.5*	6.4*	7.4*
			6	12.9	91.9	77.2*	5.1	6.1*
			6	15.3	91.3	80.6*	3.9*	5.5
			6	12.5	92.2	76.2*	4.8	6.3*
B80	10	5	6	10.4	91.5	90.3*	6.0*	6.6*
			6	12.9	92.8	91.8*	5.1	5.4
			6	15.3	92.2	87.8	4.1*	4.1
			6	12.5	92.7	91.2*	5.2	5.2
			6	10.4	91.5	91.0*	6.1*	6.2*
			6	12.9	92.4	90.3*	5.3	5.3
	13	25	6	15.3	92.3	83.7	4.1*	4.4
			6	12.5	92.7	88.9	5.2	5.9*
			6	10.4	92.0	91.3*	5.9	5.7*
			6	12.9	93.2	92.4*	5.0	4.6
			6	15.3	93.5	89.0	4.0*	3.5
			6	12.5	92.2	91.5*	5.0	4.9
			6	10.4	92.8	91.5*	5.3	5.7*
			6	12.9	92.7	90.6*	5.0	4.9
10	25	6	15.3	92.3	87.1	4.0*	4.1	
		6	12.5	93.0	91.0*	4.9	5.5	

4.3 Effects of storage pre-treatments and storage time on the cooking quality of red lentils

Cooking quality of pulses is a very important characteristic to be considered (Arntfield et al., 2000). In this study, the cooking quality of red lentils was assessed using textural parameters obtained from cooked lentils. Force-deformation curves of cooked red lentils were examined as described by Peleg (1997). Figure 4.21 shows a typical force-deformation diagram obtained for a cooked red lentil sample. Four regions are visible and show the stages of the compression test. The inflection point coincided when lentil sample started being extruded through the holes and was used as a guide in analyzing force-deformation data. Six parameters were obtained from each curve. Out of the six parameters, force ratio at inflection, deformation ratio at inflection and slope were used as indicators of textural and cooking quality. The rest of the parameters (force at inflection, deformation at inflection and plateau force) are already implicit in the force and deformation ratios and thus were not included as separate responses for factorial analysis.

4.3.1 Cooking quality results for 2007 crop analyzed in a general factorial

Complete results showing the percentage of the total contribution of every factor and interaction on the textural parameters for Redberry analyzed with a general factorial design are shown in Figures 4.22-4.24 and for Impact cultivar in Figures 4.25-4.27. It should be noted that the force ratio of Redberry samples (Figure 4.23) was not affected by three of the four main factors, but the major contributions were from two-

way interactions involving storage pre-treatment. This gives an indication of the importance of the post-harvest handling on the textural properties for Redberry lentils. Tables 4.28 and 4.29 are a list of significant factors (those that have > 5% of the total sum of squares) for the two lentil varieties.

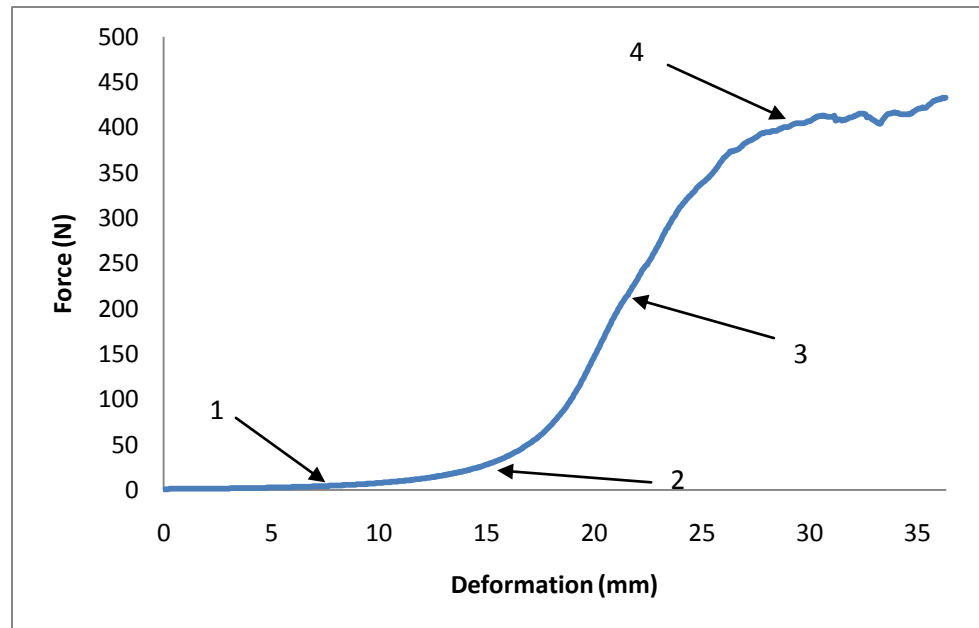


Figure 4.21 Typical force-deformation curve for cooked red lentil
1-initial compression 2- increase in slope 3- inflection point 4- plateau force

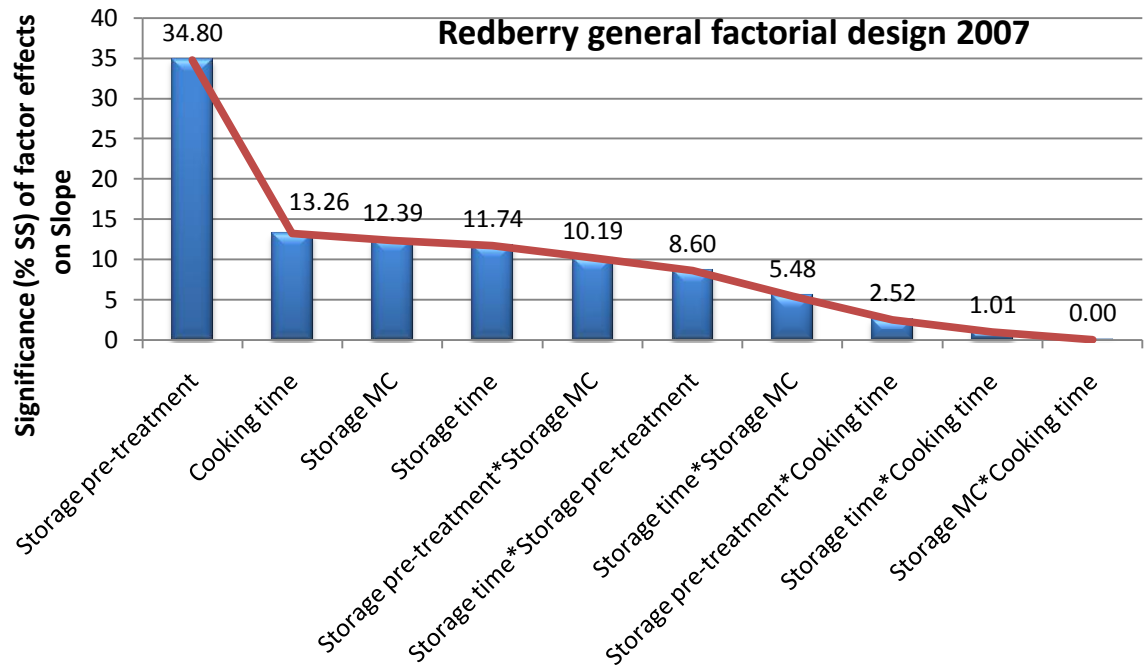


Figure 4.22 Significance of factor effects on the slope of the force-deformation curves for Redberry 2007 red lentils stored at 5°C

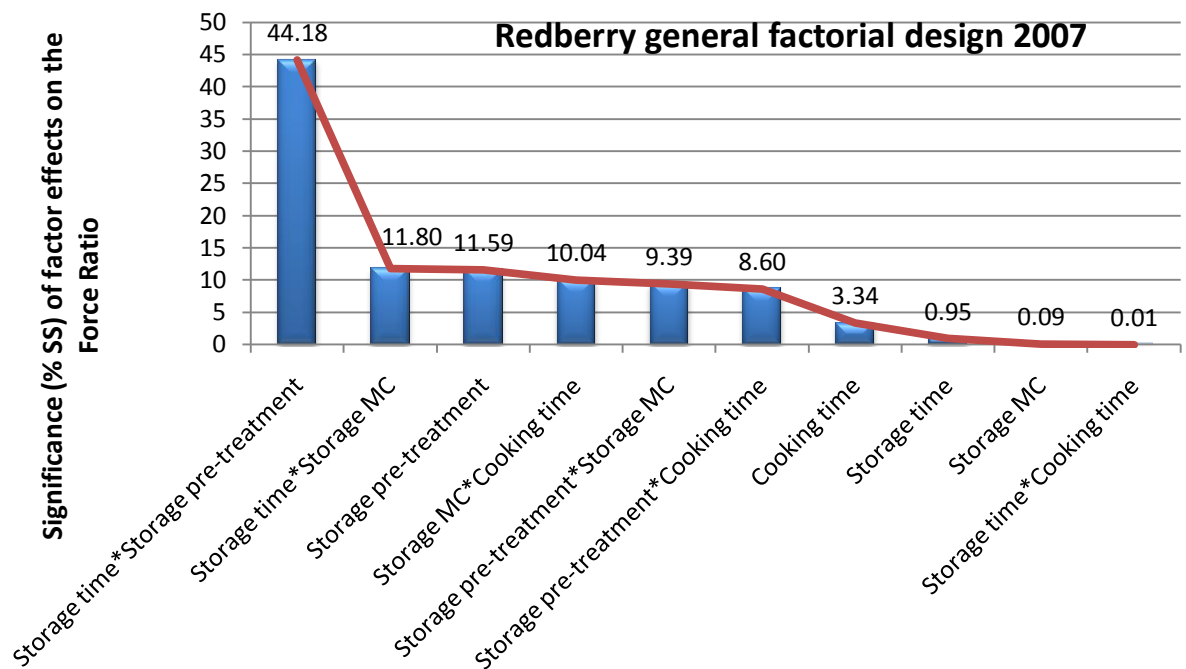


Figure 4.23 Significance of factor effects on the force ratio of the force-deformation curves for Redberry 2007 red lentils stored at 5°C

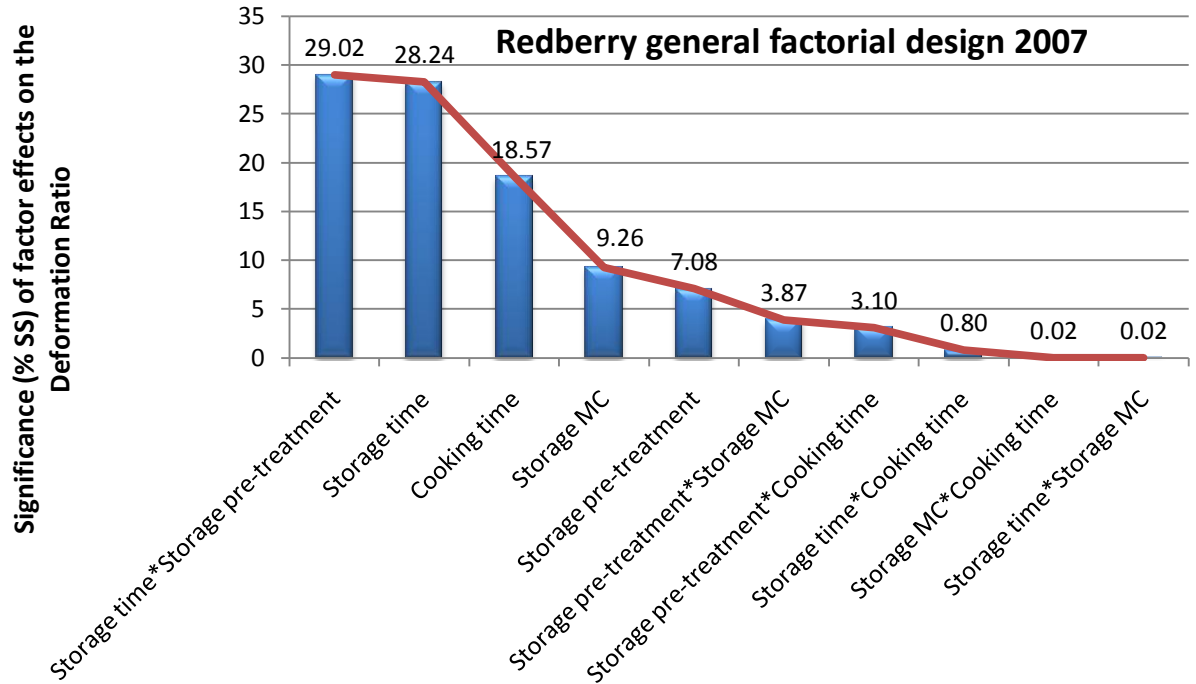


Figure 4.24 Significance of factor effects on the deformation ratio of the force-deformation curves for Redberry 2007 red lentils stored at 5°C

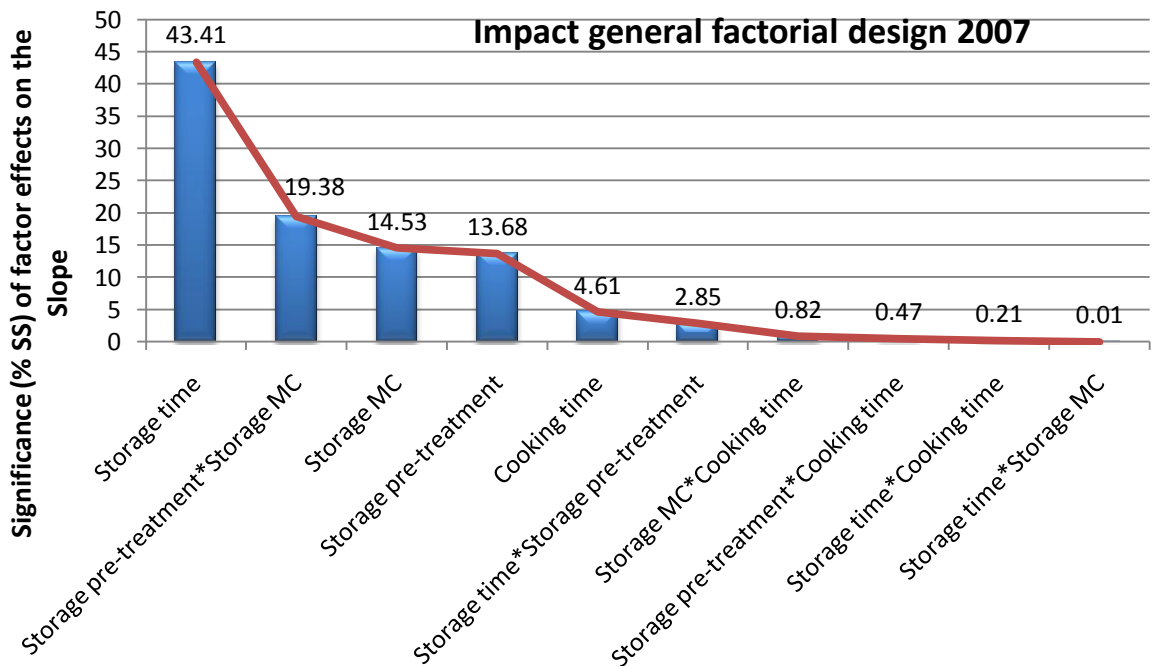


Figure 4.25 Significance of factor effects on the slope of the force-deformation curves for Impact 2007 red lentils stored at 5°C

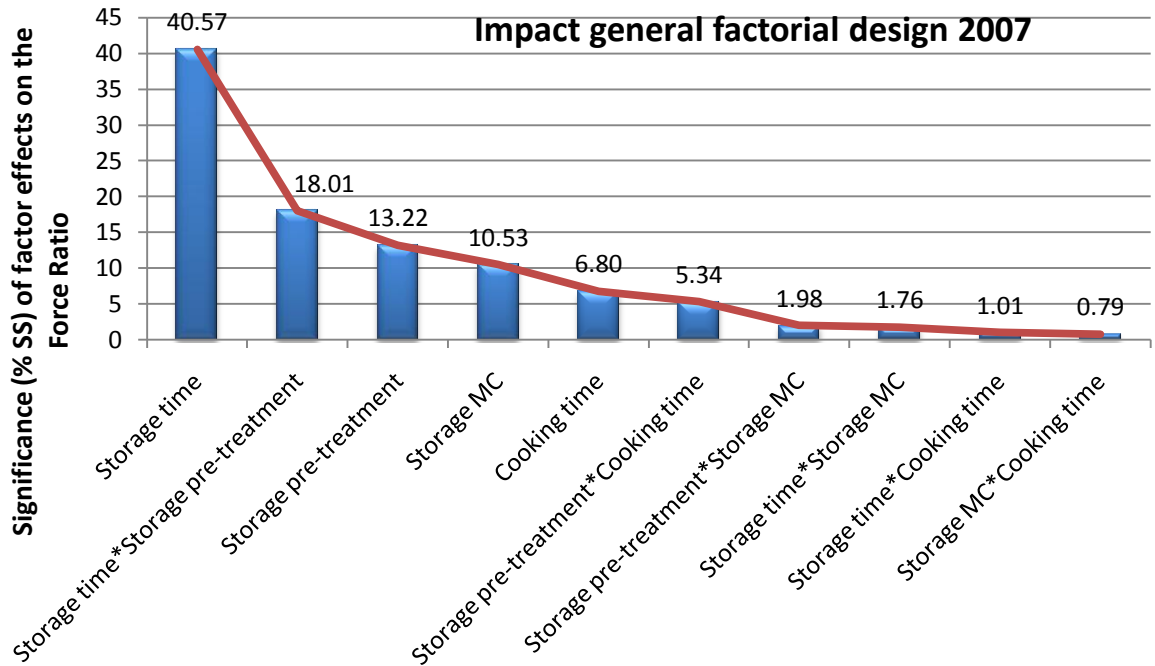


Figure 4.26 Significance of factor effects on the force ratio of the force-deformation curves for Impact 2007 red lentils stored at 5°C

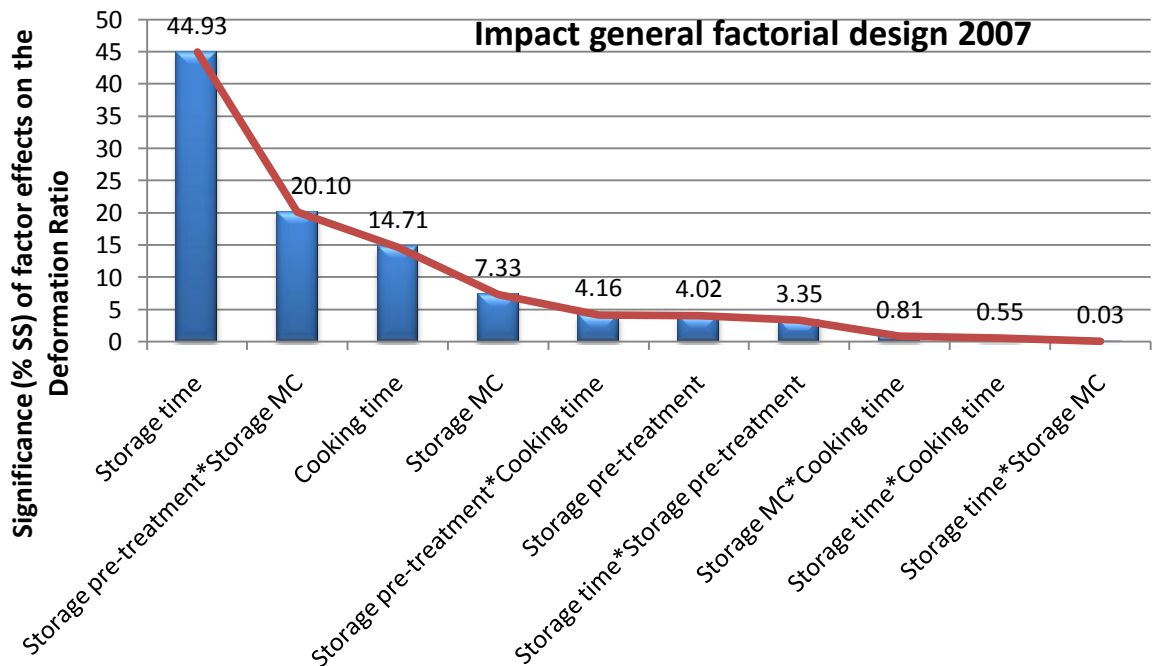


Figure 4.27 Significance of factor effects on the deformation ratio of the force-deformation curves for Redberry 2007 red lentils stored at 5°C

The textural parameters of Redberry and Impact cultivar red lentils were affected by all factors to some degree, but only some of the factors made the strongest contribution to the changes in these parameters. The slope of the force-deformation curves for Redberry red lentils was mostly affected by the storage pre-treatment, while force and deformation ratios appeared to be strongly dependent on the interaction between storage time and storage pre-treatment (Table 4.28). All parameters for Impact cultivar, on the other hand, were affected mainly by storage time (40-45% of total contribution), which is shown in Table 4.29. The slopes of the force-deformation curves for both Impact and Redberry lentils increased with increasing storage time, and the storage pre-treatments with higher slopes were B and C.

Cooking time and storage moisture content significantly affected the slope and deformation ratio of Redberry cultivar (Table 4.28). In general, higher slopes, force and deformation ratios were found in lentils cooked for 10 minutes but for Impact the differences were not big enough to achieve statistical significance (Table 4.29). All textural parameters of Impact were affected by storage moisture content, while for Redberry other factors had more significance even though for both cultivars, it is visible that higher slopes and force ratios were found in samples stored at 13%.

All two-way interactions that were significant for slope, force and deformation ratios for both cultivars involved storage pre-treatment with storage time, storage moisture content or cooking time. This is an indicative of the high dependency of the rest of the

factors on the storage pre-treatment applied. Generally, storage at 13% moisture increased the slope and therefore the hardness of the samples, and this made them more susceptible to the effects of the storage pre-treatments; this is particularly evident for pre-treatment C (visible in Appendix 48 for Redberry and 51 for Impact). Storage time also increased the hardness of the samples, and this made samples from storage pre-treatments B and C even harder than pre-treatments A and D.

Table 4.28 Significant factors affecting the texture parameters: slope, force ratio (FR) and deformation ratio (DR) for Redberry cultivar red lentils 2007 crop year

Parameter	Significant factors for Redberry 2007	% SS^a
Slope	Storage pre-treatment	34.8
	Cooking time	13.3
	Storage MC	12.4
	Storage time	11.7
	Storage pre-treatment*Storage MC	10.2
	Storage time*Storage pre-treatment	8.6
	Storage time*Storage MC	5.5
FR	Storage time*Storage pre-treatment	44.2
	Storage time*Storage MC	11.8
	Storage pre-treatment	11.6
	Storage MC*Cooking time	10.0
	Storage pre-treatment*Storage MC	9.4
	Storage pre-treatment*Cooking time	8.6
DR	Storage time*Storage pre-treatment	29.0
	Storage time	28.2
	Cooking time	18.6
	Storage MC	9.3
	Storage pre-treatment	7.1

^a percentage of the total sum of squares
MC-moisture content, FR- force ratio, DR- deformation ratio

Table 4.29 Significant factors affecting the texture parameters: slope, force ratio (FR) and deformation ratio (DR) for Impact cultivar red lentils 2007 crop year

Parameter	Significant factors for Impact 2007	% SS ^a
Slope	Storage time	43.4
	Storage pre-treatment*Storage MC	19.4
	Storage MC	14.5
	Storage pre-treatment	13.7
FR	Storage time	40.6
	Storage time*Storage pre-treatment	18.0
	Storage pre-treatment	13.2
	Storage MC	10.5
	Cooking time	6.8
	Storage pre-treatment*Cooking time	5.3
DR	Storage time	44.9
	Storage pre-treatment*Storage MC	20.1
	Cooking time	14.7
	Storage MC	7.3

^a percentage of the total sum of squares
MC-moisture content, FR- force ratio, DR- deformation ratio

Figures 4.27 and 4.28 show the prediction profiler results in all texture parameters for Redberry and Impact cultivars, respectively, as affected by the factors involved. For both cultivars, slope of the force-deformation curves of cooked red lentils increased with increasing storage time and increasing storage moisture content, while storage pre-treatments C and D as well as higher cooking times resulted in lower slope values.

Opposite trends were found with force ratio and deformation ratio results for Impact and Redberry red lentils, which indicates the effect on these factors is variety

dependent. Force ratio and deformation ratio of Redberry cultivar decreased with increasing storage time whereas for Impact it increased with increasing time. This indicates that Redberry variety red lentils may not be prone to hardening when stored for long periods. Erskine et al. (1985) found a significant correlation between the cooking time of lentils and the seed size, which might be causing these differences between Impact and Redberry cultivars.

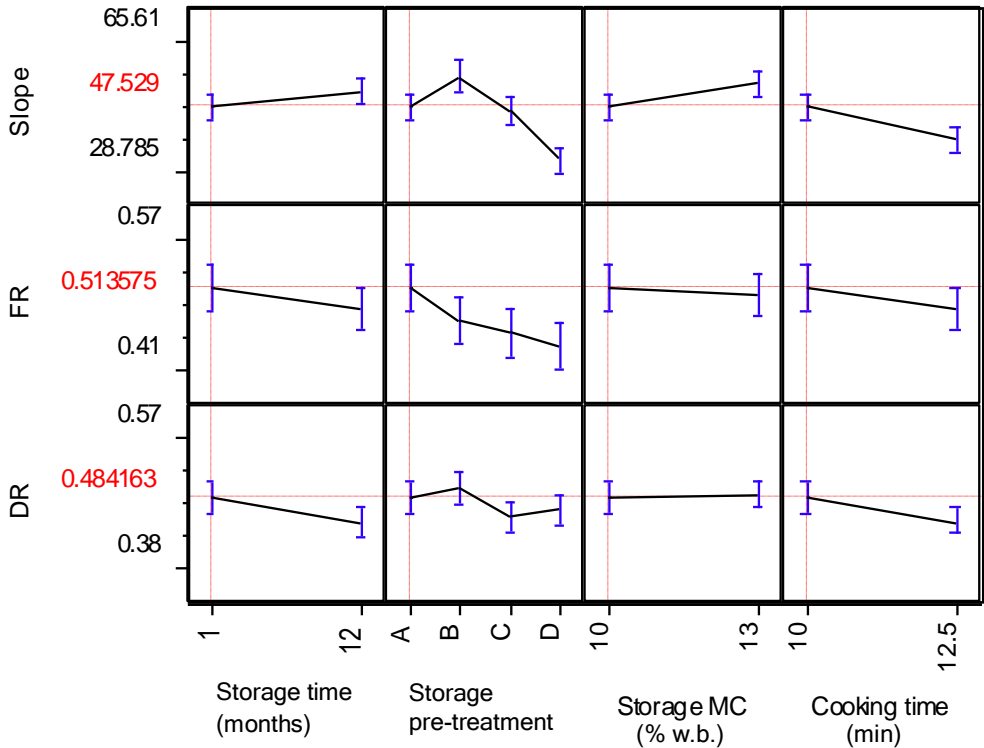


Figure 4.28 Prediction profiler for factors affecting texture parameters of the general factorial for Redberry 2007 red lentils

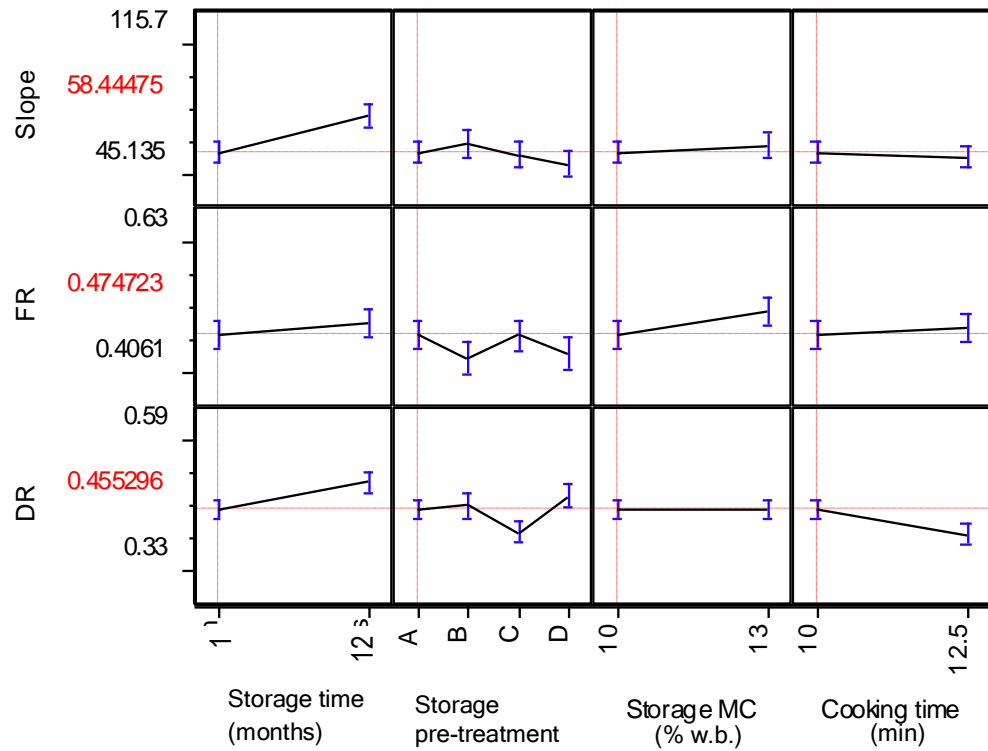


Figure 4.29 Prediction profiler for factors affecting texture parameters of the general factorial for Impact 2007 red lentils

4.3.2 Cooking quality results by storage pre-treatment for 2007 crop

4.3.2.1 Redberry cultivar

Table 4.30 shows the significant factors affecting the slopes of the force-deformation curves of Redberry red lentils 2007 crop year in all storage pre-treatments. Storage time was the main factor affecting the slope of Redberry cultivar that underwent storage pre-treatments A and B. It also affected storage pre-treatment C in a minor way and it was only present in D when interacting with storage moisture content.

For pre-treatments C and D, storage moisture content was the factor that mostly affected the slope and for A it was the second most important factor. Cooking time significantly affected the slope of lentils with all storage pre-treatments in a range between 7.9 and 21.2% of the total contribution, whereas storage temperature was significant only for storage pre-treatment B. Drying temperature also affected significantly the slope of the curves of lentils on storage pre-treatment B by 10% and was also significant when interacting with storage time.

From all significant two-way interactions, storage time by storage moisture contributed more significantly to pre-treatments C and D. These interactions can be observed in Appendices 57 and 58. Samples in pre-treatment C stored at 10% moisture had higher slopes after the second application of the drying/rewetting cycle, while samples at 13% showed similar values after the second application.

Table 4.30 Significant factors affecting the slope of the force-deformation curves for Redberry cultivar red lentils 2007 crop year

Storage Pre-treatment	Significant factors on Slope	% SS ^a
A	Storage time	23.9
	Storage MC	23.8
	Cooking time	21.2
	Storage time*Storage temperature	10.5
	Storage temperature*Storage MC	9.8
	Storage time*Storage MC	7.1
	B	Storage time
Cooking time		17.7
Drying temperature		10.4
Drying temperature*Storage time		10.0
Storage MC		7.0
Storage time*Cooking time		6.2
Storage temperature		5.2
C	Storage MC	51.8
	Storage time*Storage MC	26.5
	Storage time	12.2
	Cooking time	8.1
D	Storage MC	50.0
	Storage time*Storage MC	33.7
	Cooking time	7.9

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

Table 4.31 shows the factors affecting significantly the force ratio of Redberry cultivar red lentils from 2007 crop year. Storage time was the factor that mostly affected samples that underwent storage pre-treatments A, B and C and secondly affected D. All percentages of contribution were higher than 34%.

Storage moisture content was significant for the force ratio of storage pre-treatments A (19.4%) and C (5.5%), while it was only present in interactions for B and D. The same trend was found with cooking time, which significantly affected pre-treatment A but it was only present in interactions with storage time and storage moisture content for the rest of the storage pre-treatments.

Storage temperature did not affect the force ratio on any of the storage pre-treatments, with the exception of an interaction with storage time in pre-treatment A. In contrast, drying temperature affected the force ratio of pre-treatment B and was involved in a significant interaction with storage time.

Deformation ratio of the texture curves for Redberry red lentils (Table 4.32) was affected mostly by cooking time, with the exception of storage pre-treatment D. Storage moisture content affected all pre-treatments in some degree (from 6.3 to 32.3%) while storage time alone only affected pre-treatments C and D and it was present in A and B only when interacting with other factors.

Drying temperature did not affect the deformation ratio of Redberry samples that underwent storage pre-treatment B but was significant when interacting with storage

time. Similar results were found for storage temperature, which did not present any significance alone but it was present in two-way interactions in pre-treatments A and B.

Table 4.31 Significant factors affecting the force ratio of the force-deformation curves for Redberry cultivar red lentils 2007 crop year

Storage Pre-treatment	Significant factors on Force Ratio	% SS^a
A	Storage time	34.3
	Storage MC	19.4
	Storage time*Storage temperature	10.2
	Cooking time	10.1
	Storage time*Cooking time	8.6
	Storage time*Storage MC	6.1
B	Storage time	56.2
	Drying temperature*Storage time	13.5
	Storage time*Cooking time	8.3
	Drying temperature	6.8
	Storage temperature*Storage MC	5.3
C	Storage time	45.0
	Storage time*Storage MC	22.6
	Storage MC*Cooking time	20.2
	Storage time*Cooking time	6.4
	Storage MC	5.5
D	Storage MC*Cooking time	47.7
	Storage time	40.2
	Storage time*Cooking time	5.9

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

Table 4.32 Significant factors affecting the deformation ratio of the force-deformation curves for Redberry cultivar red lentils 2007 crop year

Storage Pre-treatment	Significant factors on Deformation Ratio	% SS^a
A	Storage MC	32.3
	Cooking time	29.8
	Storage temperature*Storage MC	12.8
	Storage time*Storage MC	7.9
	Storage time*Storage temperature	5.5
B	Cooking time	22.6
	Storage MC	20.8
	Storage temperature*Storage MC	12.7
	Drying temperature*Storage time	11.6
	Storage time*Storage temperature	11.0
	Storage time*Storage MC	7.2
C	Cooking time	47.6
	Storage time*Cooking time	25.9
	Storage time	13.9
	Storage MC	7.6
D	Storage time	68.9
	Storage time*Storage MC	13.2
	Cooking time	7.4
	Storage MC	6.3

^a – percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

4.3.2.2 Impact cultivar

As can be seen in Table 4.33, storage time had a very important effect on the slope of the force-deformation curves for Impact 2007 red lentils, having between 19% and 72% of the total contribution.

Cooking time was the second most present factor affecting the slope of Impact cultivar for most storage pre-treatments, but affected frozen/thawed samples (D) in a more significant way, which might be an indication of the lack of impact of other factors affecting this pre-treatment and not necessarily a strong effect from cooking time.

Storage temperature affected significantly the slope of Impact samples on pre-treatment B, a trend not seen with Redberry cultivar, while drying temperature did not have a significant effect by itself.

Tables 4.34 and 4.35 show, respectively, the terms having significant effects (> than 5% of total sum of squares) on the force ratio and deformation ratio for Impact cultivar red lentils. Storage time or an interaction between storage time and another factor were responsible for the majority of the changes in force ratios (Appendices 78-84), while deformation ratios were affected by more factors, depending on the storage pre-treatment.

Storage moisture content affected significantly the force ratios of pre-treatments A, B and C, while it affects the deformation ratios of B, and C. Two-way interactions

between storage moisture content and cooking time affected the force ratios of pre-treatments C and D and deformation ratios of A and D.

Storage temperature again influenced the deformation ratio of pre-treatment B, while it significantly interacted with storage time for the force ratios of A and B. Drying temperature only contributed to changes in force ratio through an interaction with storage time for Impact 2007. The deformation ratio for the Impact cultivar 2007 was not affected by drying temperature

Table 4.33 Significant factors affecting the slope of the force-deformation curves for Impact cultivar red lentils 2007 crop year

Storage Pre-treatment	Significant factors on Slope	% SS^a
A	Storage time	72.4
	Storage time*Storage temperature	6.2
	Cooking time	5.3
B	Storage time	34.9
	Storage MC	16.9
	Storage temperature	16.0
	Drying temperature*Storage time	9.2
	Cooking time	7.7
C	Storage MC	69.2
	Storage time	19.3
D	Storage time	58.1
	Cooking time	28.9
	Storage MC*Cooking time	7.9

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

Table 4.34 Significant factors affecting the force ratio of the force-deformation curves for Impact cultivar red lentils 2007 crop year

Storage Pre-treatment	Significant factors on Force Ratio	% SS^a
A	Storage time	62.8
	Storage MC	14.2
	Storage time*Storage temperature	8.2
B	Drying temperature*Storage time	60.5
	Storage MC	10.7
	Storage time*Storage temperature	6.0
C	Storage time	39.1
	Cooking time	24.2
	Storage MC	20.5
	Storage MC*Cooking time	8.7
	Storage time*Storage MC	5.4
D	Storage time*Cooking time	52.5
	Storage time	33.6
	Storage MC*Cooking time	7.9

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

Table 4.35 Significant factors affecting the deformation ratio of the force-deformation curves for Impact cultivar red lentils 2007 crop year

Storage Pre-treatment	Significant factors on Deformation Ratio	% SS^a
A	Storage time	61.1
	Cooking time	24.1
	Storage MC*Cooking time	5.4
B	Cooking time	29.3
	Storage temperature	20.8
	Storage time	15.2
	Storage MC	11.8
	Storage time*Storage temperature	7.2
C	Storage MC	50.2
	Storage time	45.7
D	Storage MC*Cooking time	55.6
	Cooking time	26.4
	Storage time	13.3

^a percentage of the total sum of squares

A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

4.3.3 Cooking quality results analyzed with a general factorial for 2008 red lentils

Red lentils from the 2008 crop year were subjected to a maximum of 6 months storage and therefore storage time was not taken into account as a factor affecting the textural parameters of both cultivars of red lentils.

As shown in Figures 4.30, 4.31 and 4.32 and Table 4.36, texture parameters of Redberry cultivar red lentils were mainly affected by the storage pre-treatment applied or an interaction with cooking time or storage moisture content, with the exception of deformation ratio, which is mainly influenced by the cooking time.

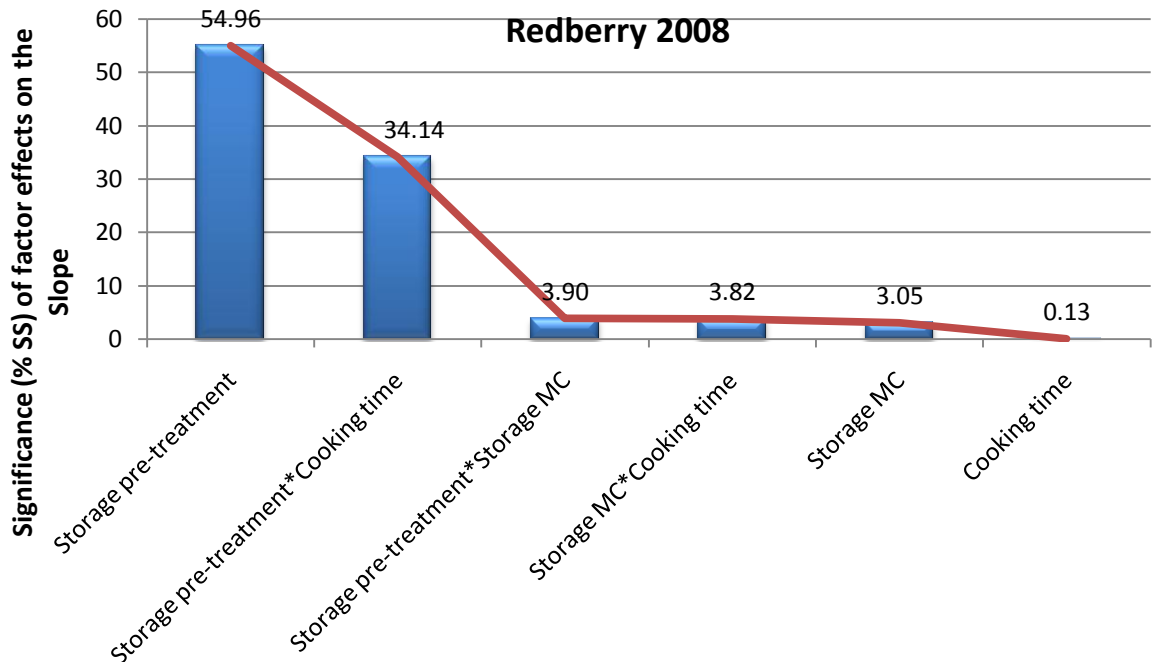


Figure 4.30 Significance of factor effects on the slope of the force-deformation curves for Redberry 2008 red lentils stored at 5°C

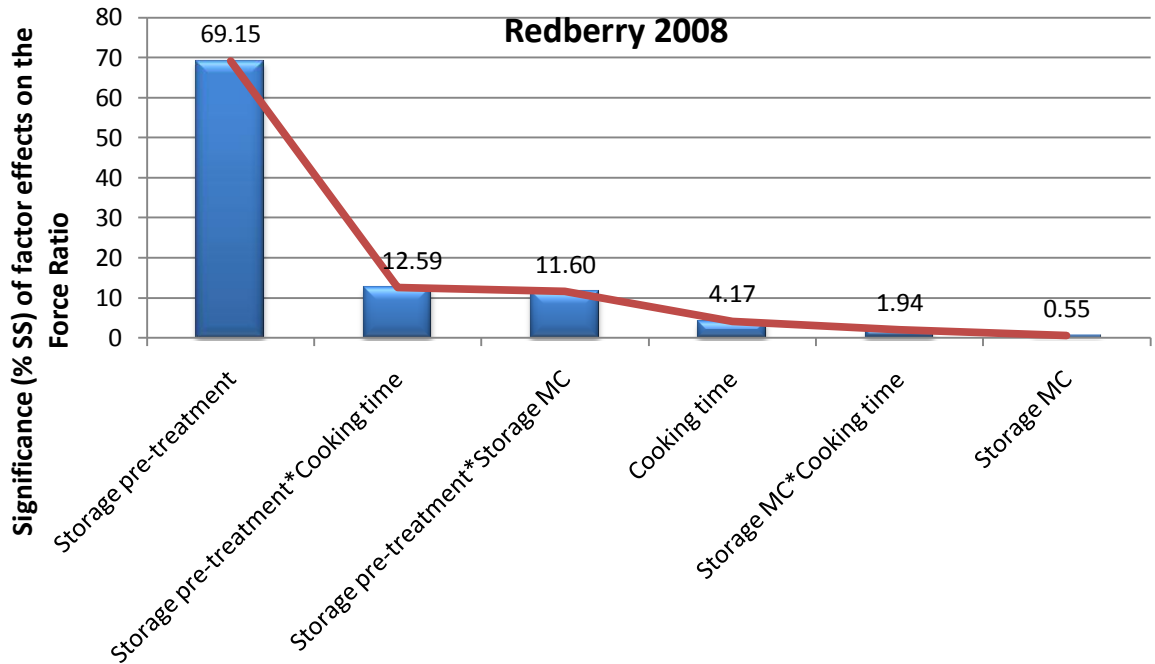


Figure 4.31 Significance of factor effects on the force ratio of the force-deformation curves for Redberry 2008 red lentils stored at 5°C

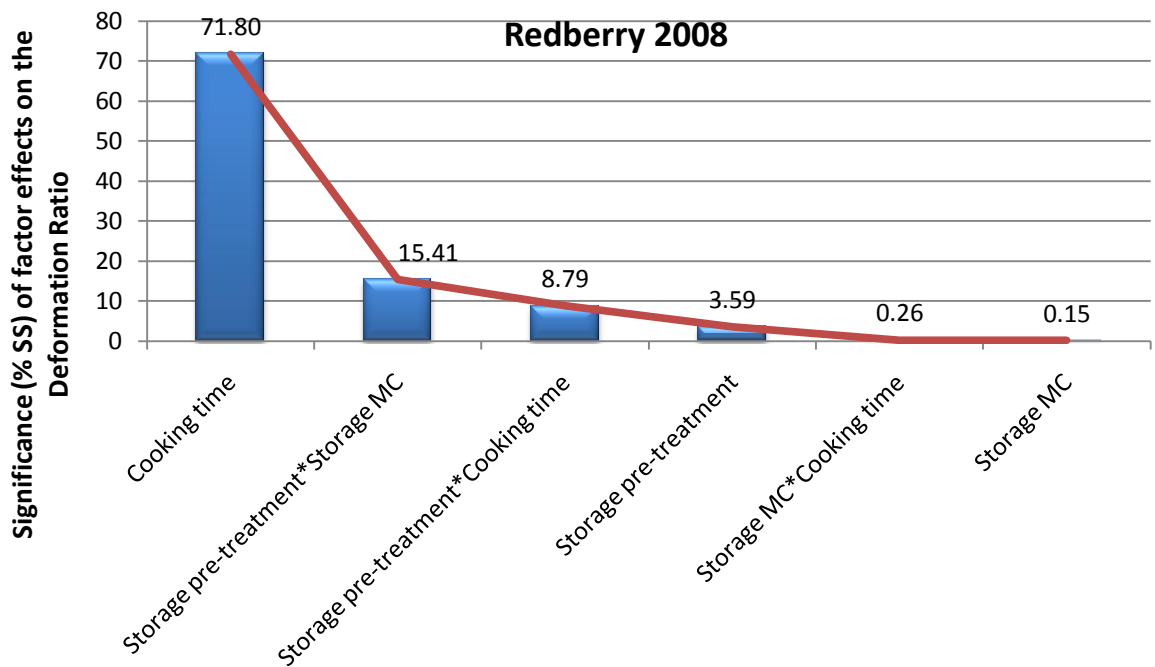


Figure 4.32 Significance of factor effects on the deformation ratio of the force-deformation curves for Redberry 2008 red lentils stored at 5°C

Impact cultivar has more factors and two-way interactions affecting the texture parameters than Redberry, but storage pre-treatment and an interaction with cooking time seem to be responsible for the changes in slope and force ratios, while deformation ratios are affected mostly by storage moisture content. This can be seen in Figures 4.33, 4.34 and 4.35 as well as Table 4.37.

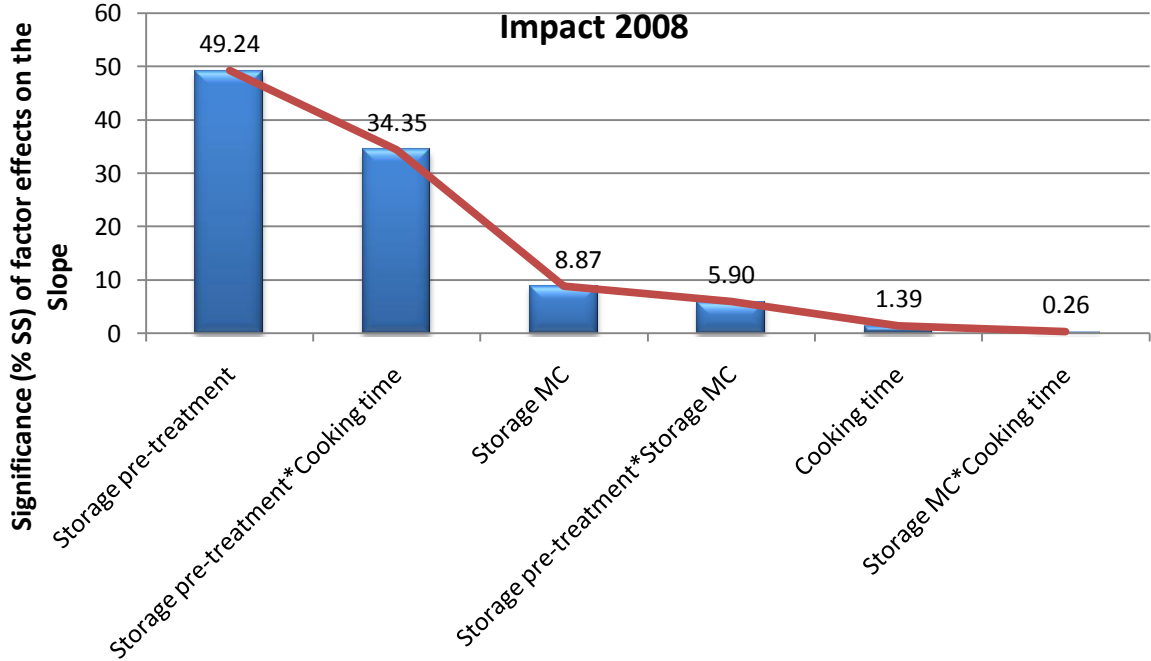


Figure 4.33 Significance of factor effects on the slope of the force-deformation curves for Impact 2008 red lentils stored at 5°C

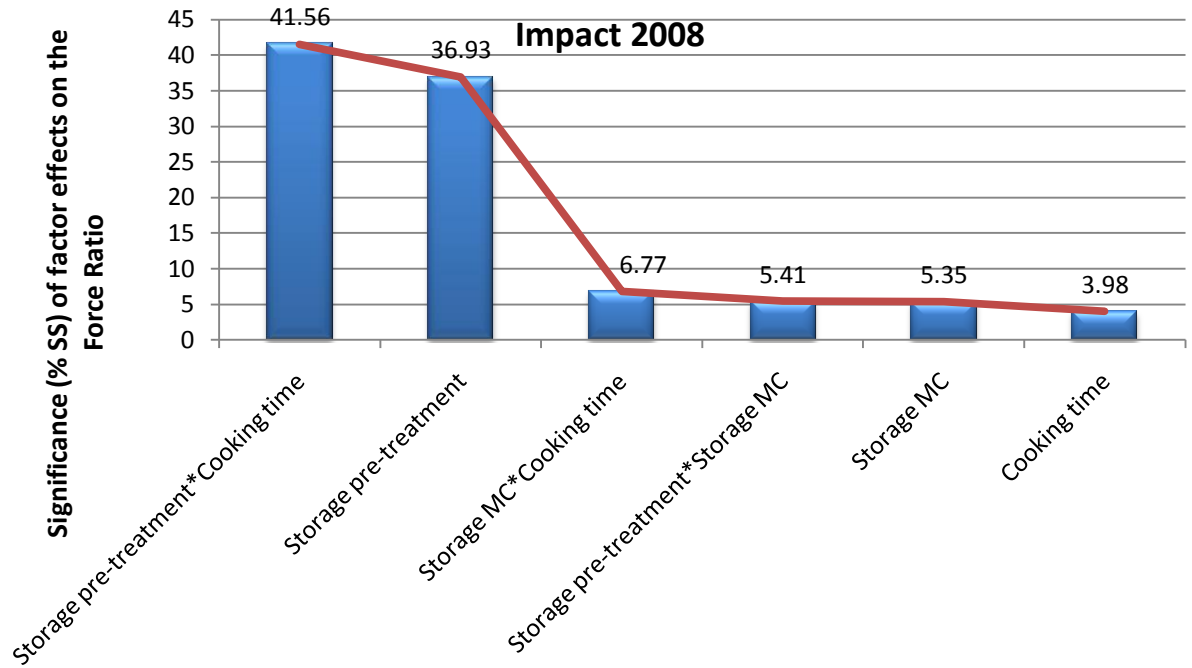


Figure 4.34 Significance of factor effects on the force ratio of the force-deformation curves for Impact 2008 red lentils stored at 5°C

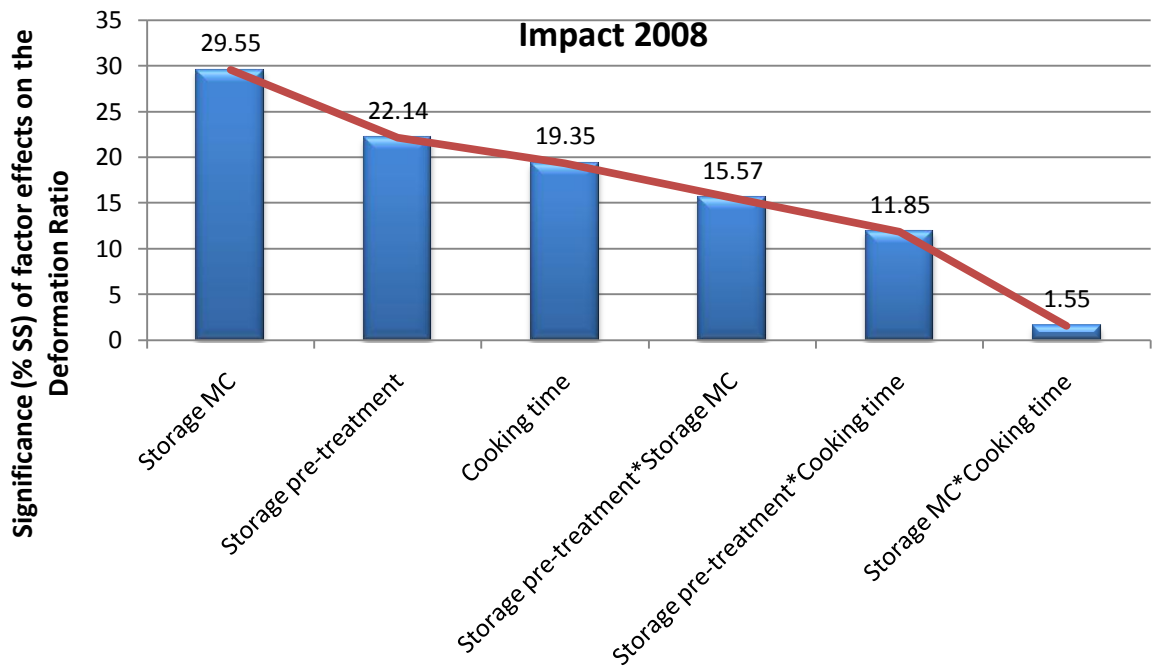


Figure 4.35 Significance of factor effects on the deformation ratio of the force-deformation curves for Impact 2008 red lentils stored at 5°C

Table 4.36 Significant factors affecting the texture parameters: slope, force ratio (FR) and deformation ratio (DR) for Redberry cultivar red lentils 2008 crop year

Parameter	Significant factors for Redberry 2008	% SS ^a
Slope	Storage pre-treatment	55.0
	Storage pre-treatment*Cooking time	34.1
FR	Storage pre-treatment	69.2
	Storage pre-treatment*Cooking time	12.6
	Storage pre-treatment*Storage MC	11.6
DR	Cooking time	71.8
	Storage pre-treatment*Storage MC	15.4
	Storage pre-treatment*Cooking time	8.8

^a percentage of the total sum of squares

Table 4.37 Significant factors affecting the texture parameters: slope, force ratio (FR) and deformation ratio (DR) for Impact cultivar red lentils 2008 crop year

Parameter	Significant factors for Impact 2008	% SS ^a
Slope	Storage pre-treatment	49.2
	Storage pre-treatment*Cooking time	34.3
	Storage MC	8.9
	Storage pre-treatment*Storage MC	5.9
FR	Storage pre-treatment*Cooking time	41.6
	Storage pre-treatment	36.9
	Storage MC*Cooking time	6.8
	Storage pre-treatment*Storage MC	5.4
	Storage MC	5.4
DR	Storage MC	29.5
	Storage pre-treatment	22.1
	Cooking time	19.4
	Storage pre-treatment*Storage MC	15.6
	Storage pre-treatment*Cooking time	11.9

^a percentage of the total sum of squares

MC-moisture content, FR- force ratio, DR- deformation ratio

For the Redberry cultivar, storage pre-treatments B80, C and D exhibited much lower slopes and force ratios than pre-treatments A and B40 (Figure 4.36), perhaps because of the higher amount of broken and damaged seeds (reflected in dehulling results). Impact lentils had less of a variation between storage pre-treatments (Figure 4.37).

An increase in storage moisture content for Redberry resulted in higher slopes, force and deformation ratios while an increase in cooking time decreased all parameters. Impact cultivar showed opposite trends.

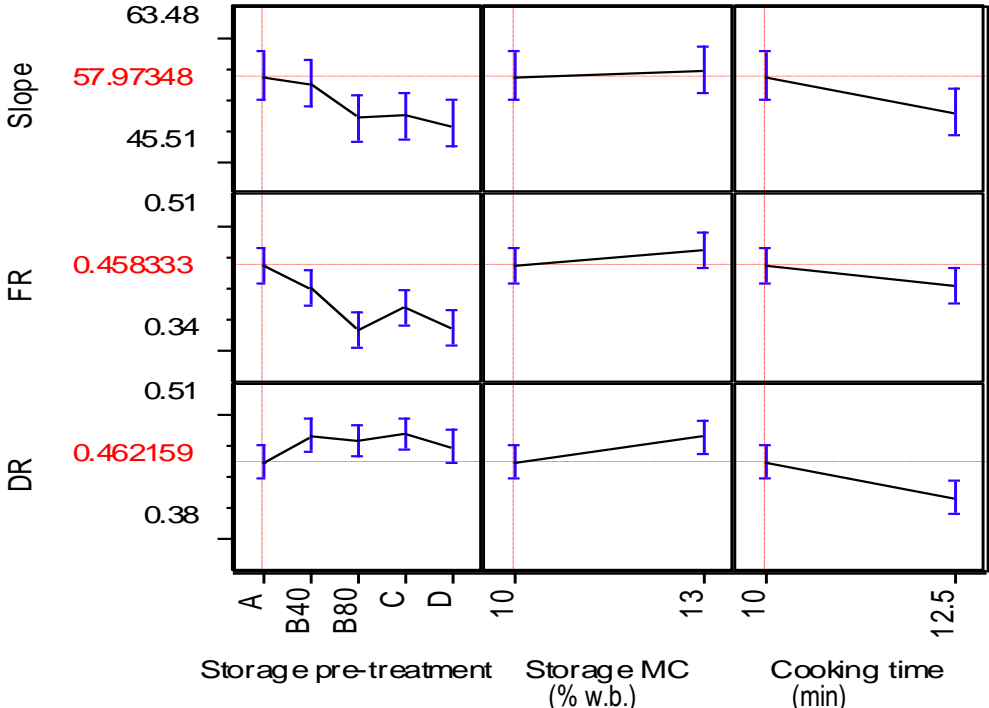


Figure 4.36 Prediction profiler for factors affecting texture parameters of the general factorial for Redberry 2008 red lentils

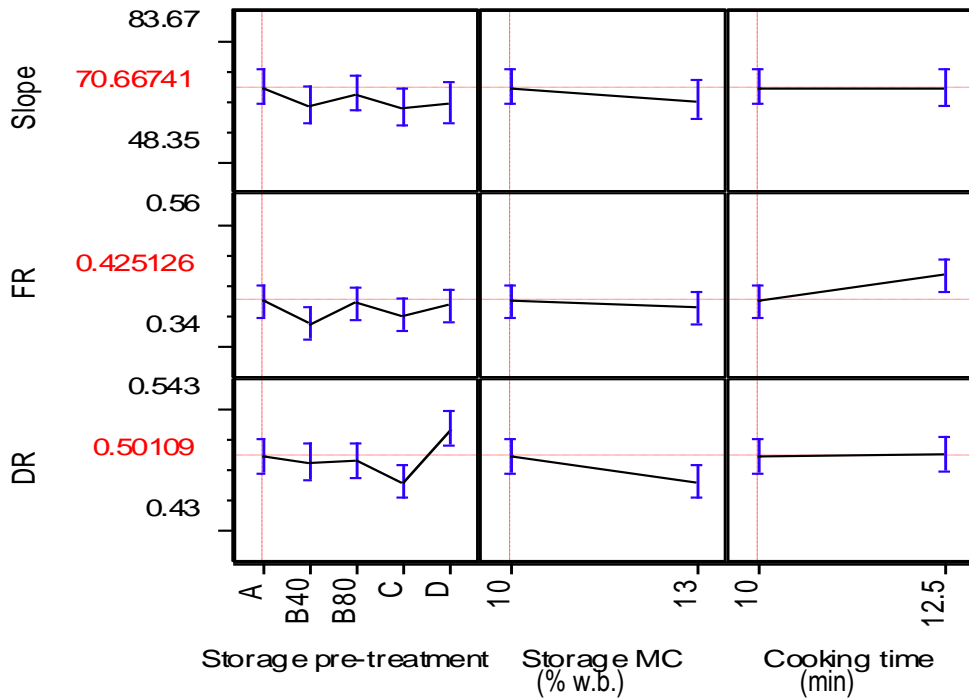


Figure 4.37 Prediction profiler for factors affecting texture parameters of the general factorial for Impact 2008 red lentils

4.3.4 Cooking quality results by storage pre-treatment for 2008 crop

4.3.4.1 Redberry cultivar

For Redberry samples from the 2008 crop, storage time and its equivalent (number of cycles in treatment C) had the most significant effect (Table 4.38) on the changes in the slopes of the force-deformation curves of cooked lentils for all storage pre-treatments (all percentages of contribution are close to 50%). Cooking time had a lower, although still statistically significant, effect in the slope of samples from all pre-treatments. Storage moisture content affected minimally the slopes of pre-treatments A and C, while it did not affect B.

Two-way interactions representing the co-dependence of factors affected significantly all storage pre-treatments, principally involving cooking time or storage time. For pre-treatment B (Appendix 104), all slopes tended to increase after 6 months, but samples dried at 40°C were much less affected (change of only 3 units) than samples dried at 80°C (change of 17 units).

Samples following pre-treatment C and stored at 10% moisture were also less affected by cooking time than samples stored at 13%. This can be observed in Appendix 105.

Table 4.38 Significant factors affecting the slope of the force-deformation curves for Redberry cultivar red lentils 2008 crop year

Storage Pre-treatment	Significant factors on Slope	% SS ^a
A	Storage time	42.9
	Cooking time	32.3
	Storage MC*Cooking time	7.6
	Storage time*Cooking time	6.0
	Storage MC	5.6
B	Storage time	50.2
	Drying temperature*Storage time	24.1
	Cooking time	10.5
C	Number of cycles	46.8
	Storage MC*Cooking time	22.3
	Cooking time	17.2
	Storage MC	8.2

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

For storage pre-treatment A, storage time was the main factor contributing to the changes in force ratio, while moisture content and an interaction between storage time and moisture content also contributed (Table 4.39).

The force ratio for Pre-treatment B was only affected by storage time (majorly) and drying temperature (minimally), while for pre-treatment C, force ratio was affected principally by storage moisture content, the number of cycles applied, and an interaction between these factors. As visible in Appendix 118, samples in pre-treatment C that underwent only one application of the drying/rewetting treatment were less affected by the storage moisture content, whereas after two applications of the C treatment, the force ratio of Redberry samples in 2008 decreased dramatically at 13% storage moisture.

Cooking time only affected significantly the force ratio of pre-treatment C, and had no effect in the other storage pre-treatments. Pre-treatment C showed the highest percentage of broken seeds and therefore seeds might be more susceptible to water uptake and softening with increasing cooking time.

Table 4.39 Significant factors affecting the force ratio of the force-deformation curves for Redberry cultivar red lentils 2008 crop year

Storage Pre-treatment	Significant factors on Force Ratio	% SS^a
A	Storage time	62.3
	Storage MC	14.9
	Storage time*Storage MC	14.9
B	Storage time	83.6
	Drying temperature	5.4
C	Storage MC	34.6
	Number of cycles*Storage MC	31.4
	Number of cycles	17.5
	Cooking time	16.3

^a percentage of the total sum of squares

A-moisture tempering, B-drying from high moisture, C-drying/rewetting cycles, D-freezing/thawing cycles

Storage time was primarily the factor affecting the deformation ratio of storage pre-treatment A, and it was significant (in a minor way) for pre-treatments B and C (Table 4.40).

Cooking time was the principal contributor to the changes for pre-treatments B and C and the second main contributor for pre-treatment A. This is an indication that the high differences in texture represented by deformation ratios are affected by the cooking time of the sample. On the other hand, storage moisture content only affected minimally the deformation ratios of pre-treatments A and B.

Table 4.40 Significant factors affecting the deformation ratio of the force-deformation curves for Redberry cultivar red lentils 2008 crop year

Storage Pre-treatment	Significant factors on Deformation Ratio	% SS^a
A	Storage time	45.3
	Cooking time	26.9
	Storage MC	10.3
	Storage time*Cooking time	5.1
B	Cooking time	55.9
	Storage time	12.0
	Storage temperature	9.7
	Storage MC	7.3
C	Cooking time	70.7
	Number of cycles	18.7
	Number of cycles*Cooking time	9.1

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture, C-drying/rewetting cycles, D-freezing/thawing cycles

4.3.4.2 Impact cultivar

Tables 4.41-4.44 show the factors that affect significantly the slope, force ratios and deformation ratios of Impact cultivar red lentils 2008 crop, respectively. As with Redberry, storage time was the major contributor to the changes in slope for storage pre-treatments A and B, while cooking time was the most important factor affecting pre-treatment C (Table 4.41).

Storage moisture content did not contribute to the changes in slopes, with the exception of a two-way interaction with storage time in pre-treatment B. The effects of cooking time were also dependent on the storage pre-treatment applied; it was the

major contributor to the changes in slope for pre-treatment C but it was barely significant for A.

Force ratios of pre-treatments A and B were mostly affected by storage time (higher than 50% contribution of the total change), while for pre-treatment C, the number of cycles applied was more significant when interacting with the cooking time and only minimally significant by itself (Table 4.42). This interaction can be further observed in Appendix 123, which shows samples that underwent only one application of the drying/rewetting cycle were more affected by cooking time than samples that followed two applications.

Storage moisture content affects the force ratio of pre-treatment A and it is only present in two-way interactions for pre-treatment B. Appendices 120 and 121

Storage pre-treatment C is affected primarily by the cooking time and presents no effect of storage moisture content.

Table 4.41 Significant factors affecting the slope of the force-deformation curves for Impact cultivar red lentils 2008 crop year

Storage Pre-treatment	Significant factors on Slope	% SS^a
A	Storage time	72.4
	Storage time*Storage temperature	6.2
	Cooking time	5.3
B	Storage time	52.9
	Drying temperature*Cooking time	16.3
	Drying temperature*Storage time	12.1
	Storage time*Storage MC	6.4
C	Cooking time	55.1
	Number of cycles	19.6
	Number of cycles*Cooking time	16.5
	Storage MC*Cooking time	7.6

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

Table 4.42 Significant factors affecting the force ratio of the force-deformation curves for Impact cultivar red lentils 2008 crop year

Storage Pre-treatment	Significant factors on Force Ratio	% SS^a
A	Storage time	62.8
	Storage MC	14.2
	Storage time*Storage temperature	8.2
B	Storage time	56.0
	Drying temperature*Cooking time	12.3
	Storage time*Storage MC	7.7
	Drying temperature	5.7
	Storage temperature*Storage MC	5.2
C	Cooking time	43.2
	Number of cycles*Cooking time	26.1
	Storage MC*Cooking time	13.2
	Number of cycles	9.2

^a percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

Storage time (or number of cycles for C) and cooking time are the factors that generated the majority of the changes in deformation ratios for Impact 2008 red lentils (Table 4.43). Storage moisture content was only significant for pre-treatment C, while drying temperature, by itself, did not contribute to the changes in deformation ratios on lentils after pre-treatment B, though it was involved in an interaction with cooking time. Again, samples dried at 40°C were less affected than samples dried at 80°C (Appendix 133).

Table 4.43 Significant factors affecting the deformation ratio of the force-deformation curves for Impact cultivar red lentils 2008 crop year

Storage Pre-treatment	Significant factors on Deformation Ratio	% SS ^a
A	Storage time	61.1
	Cooking time	24.1
	Storage MC*Cooking time	5.4
B	Cooking time	37.0
	Storage time	23.4
	Storage time*Cooking time	10.7
	Drying temperature*Storage time	7.6
	Storage MC*Cooking time	5.2
C	Cooking time	56.5
	Number of cycles	17.4
	Storage MC	17.4

^a – percentage of the total sum of squares
A-moisture tempering, B-drying from high moisture,
C-drying/rewetting cycles, D-freezing/thawing cycles

4.3.5 General discussion of cooking quality

Unlike the dehulling efficiency results, storage time was the factor that mostly affected the textural parameters of the force-deformation curves of cooked red lentils since most of the slopes, deformation and force ratios increased with increasing time. Iliadis (2001) reported a 6% increase in time needed to cook lentils after 1 year of storage. Vimala & Pushpamma (1985) showed similar results for green, Bengal, red and black gram. Burr et al. (1968) estimated the detrimental effect of long storage, coupled with high temperatures and moisture contents, to be the main cause of reduced cookability of dry beans. Although Sefa-Dedeh et al. (1979) did not find microstructural changes in

cowpeas after 12 months storage, they did find increased hardness of the seeds leading to increased cooking times.

Storage moisture content also contributed significantly to the changes in textural parameters for both cultivars in both crop years, especially for storage pre-treatments C and D, which is in accordance to the results of Burr et al. (1968). Samples stored at high moisture contents (13% w.b.) had the highest hardness, represented by high slopes and force ratios, for most samples in both cultivars. This shows the detrimental effect of storage at high moisture levels even when the general guidelines for storage of red lentils state that it is safe to store them up until 13% (Saskatchewan Agriculture and Food, 2007).

The firmness of lentils has been reported to decrease with increasing cooking time (Varoquaux et al., 1995), as well as cooking temperature (Sefa-Dedeh et al., 1979). In this study, increasing cooking time decreased the slopes, force and deformation ratios of red lentils in most cases, and therefore showed a significant contribution to the changes in the textural parameters. Cooking time was also involved in significant interactions with storage moisture content, storage time and drying temperature.

Storage pre-treatment A resulted in the softer samples in the majority of the cases for both cultivars, since their slopes and force ratios were much lower than other storage pre-treatments. Even though the slope values of pre-treatment A increased after 1 year, values were still lower than those of other pre-treatments.

Samples that underwent drying and rewetting cycles (storage pre-treatments B and C) had the highest slope and force ratios among the different treatments when stored at 13% moisture (Appendices 48 and 51). This indicates the changes in the seeds after the application of pre-treatments B and C result in harder samples even though these pre-treatments had generally more split and broken fractions. It is also important to note that slopes of B samples dried at 40°C were much higher than those of samples dried at 80°C at 12 months of storage (Appendix 70).

Storage pre-treatment D, along with A, had lower slopes, as well as force and deformation ratios. These results are in agreement with those of dehulling efficiency, which was unaffected by freezing and thawing cycles.

4.3.6 Comparison of cooking quality parameters with Reference samples

Tables 4.44-4.55 show all the texture parameters of both cultivars, Redberry and Impact, in both crop years as compared to values for a Reference (untreated samples). For Redberry 2007 during initial storage (0, 1 or 2 months), storage pre-treatments C and D presented slope values that were significantly different from the Reference, while B pre-treatment dried at 40°C was different from the Reference only when cooked for 12.5 minutes. After 6 months storage, B40 and B80 stored at 5°C had similar slope values as to the Reference, while for pre-treatment A, only for samples stored at 25°C were the slopes similar to the Reference. After 12 months the majority of lentils cooked for 12.5 minutes did not differ significantly from the Reference, while when cooked for 10 minutes, the differences were significant (Table 4.44).

Force ratios of Redberry 2007 did not show differences when compared to the Reference, with the exception of samples in pre-treatment B80 stored for 12 months (Table 4.45). Deformation ratios of samples (Table 4.46) stored for 6 months at 5°C were not significantly different from the Reference, but at 25°C differences were visible. After 12 months, lower deformation ratios were found for samples in storage pre-treatment D, and higher deformation ratios for pre-treatment B40 stored at 10% moisture content, A stored at 13%, and B80 stored at 13%.

Slopes of Impact 2007 samples at initial storage and pre-treatment A were not different from the Reference, while B40, B80, C and D cooked for 10 minutes did present a statistically significant difference (Table 4.4.7). After 6 months, it was pre-treatment A stored at ambient temperature that had significantly higher slope than the Reference samples, indicating an increase in hardness of the cooked sample. With 12 months storage, higher slopes were found in pre-treatment C stored at 13% and B80 stored at 25°C and 13%.

Similar to Redberry, force ratios of Impact 2007 samples under the different storage pre-treatment were not different when compared to the Reference (Table 4.48). On the other hand, deformation ratios of samples at initial storage and cooked for 12.5 minutes were significantly different than the Reference (Table 4.49). After 6 and 12 months storage most samples presented similar deformation ratios to the Reference, with the exception of pre-treatments A, B40 and B80 stored at 25°C and 13%.

Slopes of Redberry samples from the 2008 crop year are shown in Table 4.50. Most samples showed similar values as to those of the Reference with a few exceptions. The highest slope was 74.5 N/mm for the B80 pre-treatment stored at 13% moisture for 12 months and cooked for 12.5 minutes. Force ratios of samples stored under pre-treatment A at 25°C and cooked for 10 minutes were significantly higher than the Reference (Table 4.51). Deformation ratios of Redberry 2008 at initial storage were very similar to Reference, with the exception of those in pre-treatment C after 2 drying/wetting cycles and cooked for 10 minutes, as well as pre-treatment D at 2 months and 13% (Table 4.52).

Slopes of Impact 2008 samples did not differ significantly from Reference values (Table 4.53), with very few exceptions. Force ratios of Impact samples 2008 crop are shown in Table 4.54; the force ratios of B80 samples stored for 1 month at 25°C were significantly lower than the Reference, but most of the other samples presented similar values compared to it. Deformation ratios (Table 4.55) were different than the Reference values in most cases at the beginning of storage (0, 1 and 2 months) whereas after 6 months only two random samples were different than the Reference.

As mentioned in the materials and methods section (Chapter 2), force and deformation ratios have been used to depict if a sample was undercooked, overcooked or optimally cooked (Ross et al., 2009). Force ratios higher than 0.5 proved to have an undercooked texture, while deformation ratios lower than 0.35 were labeled as overcooked.

No sample showed overcooked texture after 12.5 minutes of cooking. Redberry cultivar 2007 lentils exhibited undercooked texture after 6 and 12 month storage in pre-treatments A and B80, respectively. Unlike Redberry, the majority of Impact 2007 samples displayed undercooked texture regardless of the storage time or pre-treatment. Bhatti et al. (1984) and Wang et al. (2010) also reported differences in cooking quality of different cultivars of lentils and field peas; location was also involved in changes which might be another factor contributing to the differences between Impact and Redberry cultivars, grown in Elbow, SK and Limerick, SK respectively. Differences in cooking quality of field peas were also attributed to the time of seeding and harvesting (Gubbels et al., 1985). Overall, 2008 lentils were optimally cooked and showed only 5 samples with undercooked texture along all storage treatments and times. It is worth mentioning that 2007 and 2008 red lentils were purchased from different producers, which may be a factor in the differences that were found.

Differences between cultivars can also be explained by their difference in seed size, which Erskine et al. (1985) found to be correlated with cooking quality. Williams et al. (1983) also reported a correlation between weight, volume and cooking time of chickpeas.

Table 4.44 Slopes (N/mm) of Redberry red lentils 2007 crop year after different storage pre-treatments^a and storage times

Temperature (°C)	Storage Pre-treatment	MC (% wb)	Cooking Time (min)	Storage time (months)				
				0	1	2	6	12
5	Reference	as is	10	48.9	-	-	49.3	61.8
			12.5	37.0	-	-	44.8	49.1
	A	10	10	-	-	-	60.6*	51.7*
			12.5	-	-	-	54.4*	44.9
	A	11.5	10	-	-	-	64.6*	49.8*
			12.5	-	-	-	52.1	48.4
	A	13	10	-	-	-	63.1*	52.5*
			12.5	-	-	-	65.8*	45.4*
	B40	10	10	-	59.1	-	58.3	56.0
			12.5	-	44.7	-	50.4	50.9
	B40	13	10	-	64.4*	-	62.5*	57.5
			12.5	-	45.0	-	53.3	53.1*
	B 80	10	10	-	51.5	-	57.5	49.6*
			12.5	-	-	-	53.6	31.0*
	B 80	13	10	-	45.7	-	57.8	52.8*
			12.5	-	-	-	52.5	49.8
	C	10	10	-	45.3	58.6	-	55.6
			12.5	-	38.1	54.2*	-	49.6
	C	13	10	-	62.4*	63.8*	-	60.4
			12.5	-	62.8*	57.2*	-	58.0*
	D	10	10	-	32.1*	65.5*	-	51.3*
			12.5	-	-	54.5*	-	47.8
	D	13	10	-	39.0	42.1	-	48.3*
			12.5	-	-	41.8	-	47.2
25	A	10	10	43.7	-	-	57.2	50.9*
			12.5	42.5	-	-	46.4	47.2
	A	11.5	10	50.7	-	-	41.3	48.9*
			12.5	43.9	-	-	40.9	40.6
	A	13	10	55.2	-	-	74.3*	71.6*
			12.5	42.5	-	-	51.3	61.5
	B 40	10	10	-	60.1	-	54.9	52.4*
			12.5	-	46.1*	-	59.2*	51.8
	B 40	13	10	-	58.1	-	63.3*	62.6
			12.5	-	46.0*	-	64.7*	61.0
	B 80	10	10	-	36.6	-	59.7*	49.0*
			12.5	-	-	-	61.7*	50.9
	B 80	13	10	-	47.8	-	66.8*	77.2*
			12.5	-	-	-	63.1*	54.3

^a A- Moisture tempering, B-40 dried at 40°C, B80- dried at 80°C, C- drying/wetting cycles, D- freezing/thawing cycles

*Indicates significant difference (P<0.05) from the Reference at each cooking time using the Holm-Sidak multiple comparison method.

Table 4.45 Force ratios of Redberry red lentils 2007 crop year after different storage pre-treatments^a and storage times

Temperature (°C)	Storage Pre-treatment	MC (%) wb	Cooking Time (min)	Storage time (months)				
				0	1	2	6	12
5	Reference	as is	10	0.492	-	-	0.461	0.476
			12.5	0.506	-	-	0.474	0.459
	A	10	10	-	-	-	0.496	0.477
			12.5	-	-	-	0.514	0.471
	A	11.5	10	-	-	-	0.553	0.401
			12.5	-	-	-	0.529	0.462
	A	13	10	-	-	-	0.515	0.467
			12.5	-	-	-	0.511	0.433
	B40	10	10	-	0.493	-	0.458	0.502
			12.5	-	0.434	-	0.427	0.473
	B40	13	10	-	0.476	-	0.482	0.465
			12.5	-	0.415*	-	0.449	0.483
	B 80	10	10	-	0.512	-	0.483	0.486
			12.5	-	-	-	0.453	0.651*
	B 80	13	10	-	0.477	-	0.475	0.479
			12.5	-	-	-	0.447	0.558*
	C	10	10	-	0.436	0.511	-	0.493
			12.5	-	0.440	0.480	-	0.449
	C	13	10	-	0.469	0.497	-	0.449
			12.5	-	0.496	0.507	-	0.466
	D	10	10	-	0.441	0.428	-	0.478
			12.5	-	-	0.492	-	0.492
	D	13	10	-	0.461	0.491	-	0.480
			12.5	-	-	0.393*	-	0.484
25	A	10	10	0.527	-	-	0.535	0.443
			12.5	0.474	-	-	0.458	0.500
	A	11.5	10	0.482	-	-	0.446	0.470
			12.5	0.427*	-	-	0.433	0.423
	A	13	10	0.484	-	-	0.571*	0.478
			12.5	0.520	-	-	0.442	0.460
	B 40	10	10	-	0.494	-	0.449	0.509
			12.5	-	0.442	-	0.500	0.499
	B 40	13	10	-	0.484	-	0.477	0.503
			12.5	-	0.433	-	0.491	0.537*
	B 80	10	10	-	0.464	-	0.465	0.542
			12.5	-	-	-	0.476	0.538*
	B 80	13	10	-	0.489	-	0.476	0.641*
			12.5	-	-	-	0.473	0.595*

^aA- Moisture tempering, B-40 dried at 40°C, B80- dried at 80°C, C- drying/wetting cycles, D- freezing/thawing cycles

*Indicates significant difference (P<0.05) from the Reference at each cooking time using the Holm-Sidak multiple comparison method.

Table 4.46 Deformation ratios of Redberry red lentils 2007 crop year after different storage pre-treatments^a and storage times

Temperature (°C)	Storage Pre-treatment	MC (%) wb	Cooking Time (min)	Storage time (months)				
				0	1	2	6	12
5	Reference	as is	10	0.442	-	-	0.436	0.467
			12.5	0.473	-	-	0.385	0.469
	A	10	10	-	-	-	0.471	0.441
			12.5	-	-	-	0.401	0.426
	A	11.5	10	-	-	-	0.443	0.433
			12.5	-	-	-	0.424	0.418*
	A	13	10	-	-	-	0.466	0.446
			12.5	-	-	-	0.444*	0.437
	B40	10	10	-	0.506	-	0.474	0.434
			12.5	-	0.433	-	0.423	0.415*
	B40	13	10	-	0.542*	-	0.481	0.465
			12.5	-	0.493	-	0.419	0.425
	B 80	10	10	-	0.484	-	0.433	0.433
			12.5	-	-	-	0.405	0.431
	B 80	13	10	-	0.469	-	0.443	0.450
			12.5	-	-	-	0.424	0.406*
	C	10	10	-	0.451	0.465	-	0.478
			12.5	-	0.450	0.403*	-	0.423
	C	13	10	-	0.454	0.496	-	0.498
			12.5	-	0.449	0.407*	-	0.467
	D	10	10	-	0.464	0.513*	-	0.415*
			12.5	-	-	0.479	-	0.409*
	D	13	10	-	0.484	0.467	-	0.421*
			12.5	-	-	0.434	-	0.421*
25	A	10	10	0.484	-	-	0.469	0.470
			12.5	0.450	-	-	0.393	0.394*
	A	11.5	10	0.466	-	-	0.453	0.450
			12.5	0.398*	-	-	0.371	0.433
	A	13	10	0.503	-	-	0.545*	0.566*
			12.5	0.439	-	-	0.473*	0.557*
	B 40	10	10	-	0.500	-	0.447	0.423*
			12.5	-	0.384*	-	0.440*	0.396*
	B 40	13	10	-	0.513*	-	0.497*	0.503
			12.5	-	0.476	-	0.442*	0.477
	B 80	10	10	-	0.469	-	0.451	0.439
			12.5	-	-	-	0.403	0.424
	B 80	13	10	-	0.453	-	0.515*	0.607*
			12.5	-	-	-	0.427	0.571*

^aA- Moisture tempering, B-40 dried at 40°C, B80- dried at 80°C, C- drying/wetting cycles, D- freezing/thawing cycles

*Indicates significant difference (P<0.05) from the Reference at each cooking time using the Holm-Sidak multiple comparison method.

Table 4.47 Slopes (N/mm) of Impact red lentils 2007 crop year after different storage pre-treatments^a and storage times

Temperature (°C)	Storage Pre-treatment	MC (%) wb	Cooking Time (min)	Storage time (months)				
				0	1	2	6	12
5	Reference	as is	10	69.6a	-	-	81.8a	81.5a
			12.5	68.61a	-	-	72.9a	75.0a
	A	10	10	-	-	-	83.1	82.2
			12.5	-	-	-	75.6	66.9
	A	11.5	10	-	-	-	89.1	79.9
			12.5	-	-	-	82.9	70.8
	A	13	10	-	-	-	91.6	79.0
			12.5	-	-	-	90.3*	70.8
	B40	10	10	-	49.7*	-	82.0	87.8
			12.5	-	63.1	-	77.8	80.9
	B40	13	10	-	90.0*	-	88.2	92.1
			12.5	-	71.7	-	75.6	83.1
	B 80	10	10	-	56.6	-	65.1	71.0
			12.5	-	-	-	77.6	65.2*
	B 80	13	10	-	61.1	-	94.2	87.1
			12.5	-	-	-	89.6*	75.5
	C	10	10	-	51.9*	59.7	-	75.1
			12.5	-	57.5	66.2	-	65.6
	C	13	10	-	97.4*	86.0*	-	108.1*
			12.5	-	69.2	87.0*	-	100.9*
	D	10	10	-	55.8*	84.9*	-	86.3
			12.5	-	-	60.6	-	79.3
	D	13	10	-	52.9*	69.9	-	91.3
			12.5	-	-	70.1	-	83.9
25	A	10	10	60.0	-	-	96.8	74.1
			12.5	54.1	-	-	84.2	64.6*
	A	11.5	10	68.3	-	-	114.2*	79.6
			12.5	56.0	-	-	92.3*	66.4
	A	13	10	57.3	-	-	115.3*	88.3
			12.5	56.8	-	-	121.3*	81.1
	B 40	10	10	-	75.0	-	85.1	96.1
			12.5	-	72.5	-	77.5	91.7*
	B 40	13	10	-	92.7*	-	88.6	101.6
			12.5	-	69.9	-	85.2	106.1*
	B 80	10	10	-	60.9	-	95.5	95.1
			12.5	-	-	-	80.2	79.0
	B 80	13	10	-	66.5	-	114.3*	134.9*
			12.5	-	-	-	95.2*	95.6*

^a A- Moisture tempering, B-40 dried at 40°C, B80- dried at 80°C, C- drying/wetting cycles, D- freezing/thawing cycles

*Indicates significant difference (P<0.05) from the Reference at each cooking time using the Holm-Sidak multiple comparison method.

Table 4.48 Force ratios of Impact red lentils 2007 crop year after different storage pre-treatments^a and storage times

Temperature (°C)	Storage Pre-treatment	MC (%) wb	Cooking Time (min)	Storage time (months)				
				0	1	2	6	12
5	Reference	as is	10	0.551	-	-	0.560	0.557
			12.5	0.537	-	-	0.587	0.556
	A	10	10	-	-	-	0.495	0.508
			12.5	-	-	-	0.507	0.479*
	A	11.5	10	-	-	-	0.526	0.522
			12.5	-	-	-	0.585	0.507
	A	13	10	-	-	-	0.546	0.504
			12.5	-	-	-	0.540	0.505
	B40	10	10	-	0.414*	-	0.500	0.540
			12.5	-	0.472	-	0.515	0.551
	B40	13	10	-	0.497	-	0.506	0.582
			12.5	-	0.526	-	0.509	0.558
	B 80	10	10	-	0.557	-	0.498	0.424*
			12.5	-	-	-	0.539	0.440*
	B 80	13	10	-	0.490	-	0.558	0.523
			12.5	-	-	-	0.607	0.479*
	C	10	10	-	0.465	0.482	-	0.524
			12.5	-	0.520	0.528	-	0.563
	C	13	10	-	0.526	0.533	-	0.547
			12.5	-	0.509	0.562	-	0.565
	D	10	10	-	0.447*	0.585	-	0.551
			12.5	-	-	0.519	-	0.602
	D	13	10	-	0.471	0.547	-	0.563
			12.5	-	-	0.563	-	0.605
25	A	10	10	0.484	-	-	0.540	0.498
			12.5	0.479	-	-	0.562	0.504
	A	11.5	10	0.501	-	-	0.589	0.489
			12.5	0.481	-	-	0.568	0.504
	A	13	10	0.504	-	-	0.558	0.511
			12.5	0.523	-	-	0.605	0.525
	B 40	10	10	-	0.478	-	0.480	0.535
			12.5	-	0.497	-	0.496	0.556
	B 40	13	10	-	0.534	-	0.511	0.515
			12.5	-	0.505	-	0.489*	0.564
	B 80	10	10	-	0.503	-	0.547	0.547
			12.5	-	-	-	0.513	0.490*
	B 80	13	10	-	0.511	-	0.531	0.571
			12.5	-	-	-	0.549	0.446*

^a A- Moisture tempering, B-40 dried at 40°C, B80- dried at 80°C, C- drying/wetting cycles, D- freezing/thawing cycles

*Indicates significant difference (P<0.05) from the Reference at each cooking time using the Holm-Sidak multiple comparison method.

Table 4.49 Deformation ratios of Impact red lentils 2007 year after different storage pre-treatments^a and storage times

Temperature (°C)	Storage Pre-treatment	MC (%) wb	Cooking Time (min)	Storage time (months)				
				0	1	2	6	12
5	Reference	as is	10	0.497	-	-	0.486	0.496
			12.5	0.513	-	-	0.443	0.477
	A	10	10	-	-	-	0.517	0.514
			12.5	-	-	-	0.485	0.465
	A	11.5	10	-	-	-	0.510	0.507
			12.5	-	-	-	0.438	0.486
	A	13	10	-	-	-	0.505	0.510
			12.5	-	-	-	0.488	0.485
	B40	10	10	-	0.446	-	0.491	0.490
			12.5	-	0.422*	-	0.460	0.464
	B40	13	10	-	0.482	-	0.515	0.485
			12.5	-	0.393*	-	0.461	0.466
	B 80	10	10	-	0.488	-	0.430*	0.485
			12.5	-	-	-	0.434	0.413*
	B 80	13	10	-	0.549	-	0.493	0.495
			12.5	-	-	-	0.453	0.463
	C	10	10	-	0.407	0.443	-	0.469
			12.5	-	0.396*	0.448	-	0.484
	C	13	10	-	0.478	0.494	-	0.563*
			12.5	-	0.477	0.484	-	0.535
D	10	10	-	0.491	0.524	-	0.523	
		12.5	-	-	0.429*	-	0.458	
D	13	10	-	0.463	0.442	-	0.503	
		12.5	-	-	0.487	-	0.493	
25	A	10	10	0.464	-	-	0.529	0.525
			12.5	0.394*	-	-	0.502	0.469
	A	11.5	10	0.468	-	-	0.534	0.519
			12.5	0.380*	-	-	0.483	0.479
	A	13	10	0.444	-	-	0.561*	0.496
			12.5	0.436*	-	-	0.522*	0.499
	B 40	10	10	-	0.498	-	0.511	0.484
			12.5	-	0.444	-	0.483	0.515
	B 40	13	10	-	0.531	-	0.528	0.544*
			12.5	-	0.425*	-	0.481	0.544*
	B 80	10	10	-	0.467	-	0.547*	0.525
			12.5	-	-	-	0.467	0.444
	B 80	13	10	-	0.471	-	0.535	0.624*
			12.5	-	-	-	0.521*	0.563*

^aA- Moisture tempering, B-40 dried at 40°C, B80- dried at 80°C, C- drying/wetting cycles, D- freezing/thawing cycles

*Indicates significant difference (P<0.05) from the Reference at each cooking time using the Holm-Sidak multiple comparison method.

Table 4.50 Slopes (N/mm) of Redberry red lentils 2008 crop year after different storage pre-treatments^a and storage times

Temperature (°C)	Storage Pre-treatment	MC (%) wb	Cooking Time (min)	Storage time (months)			
				0	1	2	6
5	Reference	as is	10	50.6	-	-	63.5
			12.5	52.5	-	-	61.6
	A	10	10	-	-	-	65.2
			12.5	-	-	-	59.8
	A	11.5	10	-	-	-	64.3
			12.5	-	-	-	56.6
	A	13	10	-	-	-	66.4
			12.5	-	-	-	59.5
	B40	10	10	-	56.2	-	59.3
			12.5	-	56.0	-	57.2
	B40	13	10	-	56.6	-	66.7
			12.5	-	56.0	-	60.1
	B 80	10	10	-	51.9	-	70.4
			12.5	-	46.4	-	54.9
	B 80	13	10	-	53.2	-	67.7
			12.5	-	49.2	-	62.0
	C	10	10	-	51.4	66.1*	-
			12.5	-	57.4	59.1	-
	C	13	10	-	51.5	51.9	-
			12.5	-	55.6	64.3*	-
	D	10	10	-	50.8	55.8	-
			12.5	-	52.8	53.3	-
	D	13	10	-	52.0	57.6	-
			12.5	-	55.2	56.7	-
25	A	10	10	60.3*	-	-	67.8
			12.5	50.7	-	-	59.8
	A	11.5	10	57.4	-	-	63.3
			12.5	56.4	-	-	56.2
	A	13	10	56.8	-	-	68.8
			12.5	58.9	-	-	61.6
	B 40	10	10	-	54.3	-	61.1
			12.5	-	63.6*	-	55.4
	B 40	13	10	-	71.5*	-	67.5
			12.5	-	50.1	-	61.7
	B 80	10	10	-	51.1	-	68.7
			12.5	-	48.8	-	59.0
	B 80	13	10	-	46.6	-	71.9
			12.5	-	43.6*	-	74.5*

^aA- Moisture tempering, B-40 dried at 40°C, B80- dried at 80°C, C- drying/wetting cycles, D- freezing/thawing cycles

*Indicates significant difference (P<0.05) from the Reference at each cooking time using the Holm-Sidak multiple comparison method.

Table 4.51 Force ratios of Redberry red lentils 2008 crop year after different storage pre-treatments^a and storage times

Temperature (°C)	Storage Pre-treatment	MC (%) wb	Cooking Time (min)	Storage time (months)			
				0	1	2	6
5	Reference	as is	10	0.390	-	-	0.465
			12.5	0.422	-	-	0.477
	A	10	10	-	-	-	0.483
			12.5	-	-	-	0.505
	A	11.5	10	-	-	-	0.485
			12.5	-	-	-	0.476
	A	13	10	-	-	-	0.477
			12.5	-	-	-	0.492
	B40	10	10	-	0.433	-	0.453
			12.5	-	0.425	-	0.443
	B40	13	10	-	0.380	-	0.469
			12.5	-	0.410	-	0.478
	B 80	10	10	-	0.368	-	0.479
			12.5	-	0.351*	-	0.452
	B 80	13	10	-	0.370	-	0.467
			12.5	-	0.370	-	0.461
	C	10	10	-	0.396	0.510*	-
			12.5	-	0.439	0.557*	-
	C	13	10	-	0.392	0.369	-
			12.5	-	0.437	0.428	-
	D	10	10	-	0.368	0.421	-
			12.5	-	0.418	0.437	-
	D	13	10	-	0.402	0.433	-
			12.5	-	0.437	0.477	-
25	A	10	10	0.467*	-	-	0.477
			12.5	0.423	-	-	0.505
	A	11.5	10	0.456*	-	-	0.483
			12.5	0.472	-	-	0.477
	A	13	10	0.470*	-	-	0.517*
			12.5	0.479	-	-	0.490
	B 40	10	10	-	0.382	-	0.476
			12.5	-	0.440	-	0.483
	B 40	13	10	-	0.434	-	0.480
			12.5	-	0.352*	-	0.448
	B 80	10	10	-	0.380	-	0.460
			12.5	-	0.394	-	0.459
	B 80	13	10	-	0.341	-	0.469
			12.5	-	0.339*	-	0.484

^a A- Moisture tempering, B-40 dried at 40°C, B80- dried at 80°C, C- drying/wetting cycles, D- freezing/thawing cycles

* Indicates significant difference (P<0.05) from the Reference at each cooking time using the Holm-Sidak multiple comparison method.

Table 4.52 Deformation ratios of Redberry red lentils 2008 crop year after different storage pre-treatments^a and storage times

Temperature (°C)	Storage Pre-treatment	MC (%) wb	Cooking Time (min)	Storage time (months)			
				0	1	2	6
5	Reference	as is	10	0.480	-	-	0.498
			12.5	0.438	-	-	0.480
	A	10	10	-	-	-	0.552*
			12.5	-	-	-	0.452
	A	11.5	10	-	-	-	0.502
			12.5	-	-	-	0.459
	A	13	10	-	-	-	0.518
			12.5	-	-	-	0.477
	B40	10	10	-	0.500	-	0.493
			12.5	-	0.410	-	0.429*
	B40	13	10	-	0.490	-	0.510
			12.5	-	0.447	-	0.482
	B 80	10	10	-	0.482	-	0.487
			12.5	-	0.439	-	0.439*
	B 80	13	10	-	0.451*	-	0.514
			12.5	-	0.413	-	0.425*
	C	10	10	-	0.480	0.581*	-
			12.5	-	0.443	0.424	-
	C	13	10	-	0.488	0.542*	-
			12.5	-	0.415	0.467	-
	D	10	10	-	0.476	0.464	-
			12.5	-	0.454	0.433	-
	D	13	10	-	0.463	0.441*	-
			12.5	-	0.440	0.394*	-
25	A	10	10	0.460	-	-	0.506
			12.5	0.422	-	-	0.452
	A	11.5	10	0.433*	-	-	0.540*
			12.5	0.440	-	-	0.501
	A	13	10	0.486	-	-	0.565*
			12.5	0.457	-	-	0.503
	B 40	10	10	-	0.470	-	0.504
			12.5	-	0.439	-	0.451
	B 40	13	10	-	0.529*	-	0.534
			12.5	-	0.471	-	0.468
	B 80	10	10	-	0.476	-	0.506
			12.5	-	0.460	-	0.453
	B 80	13	10	-	0.473	-	0.568*
			12.5	-	0.452	-	0.504

^a A- Moisture tempering, B-40 dried at 40°C, B80- dried at 80°C, C- drying/wetting cycles, D- freezing/thawing cycles

*Indicates significant difference (P<0.05) from the Reference at each cooking time using the Holm-Sidak multiple comparison method.

Table 4.53 Slopes (N/mm) of Impact red lentils 2008 crop year after different storage pre-treatments^a and storage times

Temperature (°C)	Storage Pre-treatment	MC (%) wb	Cooking Time (min)	Storage time (months)			
				0	1	2	6
5	Reference	as is	10	70.2	-	-	76.9
			12.5	64.9	-	-	72.0
	A	10	10	-	-	-	75.4
			12.5	-	-	-	82.1
	A	11.5	10	-	-	-	87.8
			12.5	-	-	-	75.1
	A	13	10	-	-	-	87.1
			12.5	-	-	-	63.9
	B40	10	10	-	63.8	-	54.5
			12.5	-	71.1	-	66.9
	B40	13	10	-	66.0	-	83.9
			12.5	-	66.2	-	83.9
	B 80	10	10	-	69.7	-	79.1
			12.5	-	54.6	-	77.6
	B 80	13	10	-	62.7	-	78.0
			12.5	-	49.7*	-	71.5
	C	10	10	-	62.3	66.8	-
			12.5	-	77.7*	67.7	-
	C	13	10	-	70.0	63.9	-
			12.5	-	71.1	68.4	-
	D	10	10	-	69.6	69.7	-
			12.5	-	54.4	68.6	-
	D	13	10	-	53.4*	76.9	-
			12.5	-	53.8	69.5	-
25	A	10	10	70.1	-	-	77.2
			12.5	71.1	-	-	73.9
	A	11.5	10	69.9	-	-	79.0
			12.5	69.5	-	-	74.3
	A	13	10	67.5	-	-	74.7
			12.5	64.7	-	-	73.0
	B 40	10	10	-	68.2	-	80.9*
			12.5	-	71.7	-	77.6
	B 40	13	10	-	59.0	-	72.3
			12.5	-	70.1	-	70.0
	B 80	10	10	-	71.6	-	82.9
			12.5	-	52.4*	-	70.8
	B 80	13	10	-	60.5	-	84.7
			12.5	-	51.5*	-	78.1

^aA- Moisture tempering, B-40 dried at 40°C, B80- dried at 80°C, C- drying/wetting cycles, D- freezing/thawing cycles

*Indicates significant difference (P<0.05) from the Reference at each cooking time using the Holm-Sidak multiple comparison method.

Table 4.54 Force ratios of Impact red lentils 2008 crop year after different storage pre-treatments^a and storage times

Temperature (°C)	Storage Pre-treatment	MC (%) wb	Cooking Time (min)	Storage time (months)			
				0	1	2	6
5	Reference	as is	10	0.429	-	-	0.451
			12.5	0.440	-	-	0.464
	A	10	10	-	-	-	0.469
			12.5	-	-	-	0.512
	A	11.5	10	-	-	-	0.485
			12.5	-	-	-	0.483
	A	13	10	-	-	-	0.471
			12.5	-	-	-	0.442
	B40	10	10	-	0.389	-	0.359*
			12.5	-	0.435	-	0.453
	B40	13	10	-	0.406	-	0.482
			12.5	-	0.436	-	0.482
	B 80	10	10	-	0.436	-	0.447
			12.5	-	0.368*	-	0.458
	B 80	13	10	-	0.389	-	0.462
			12.5	-	0.349*	-	0.467
	C	10	10	-	0.390	0.432	-
			12.5	-	0.499	0.448	-
	C	13	10	-	0.438	0.415	-
			12.5	-	0.463	0.416	-
	D	10	10	-	0.419	0.513*	-
			12.5	-	0.422	0.479	-
	D	13	10	-	0.413	0.429	-
			12.5	-	0.375	0.465	-
25	A	10	10	0.414	-	-	0.512
			12.5	0.483	-	-	0.490
	A	11.5	10	0.390	-	-	0.474
			12.5	0.439	-	-	0.479
	A	13	10	0.422	-	-	0.454
			12.5	0.417	-	-	0.472
	B 40	10	10	-	0.414	-	0.477
			12.5	-	0.469	-	0.487
	B 40	13	10	-	0.356*	-	0.478
			12.5	-	0.423	-	0.473
	B 80	10	10	-	0.413	-	0.465
			12.5	-	0.346*	-	0.462
	B 80	13	10	-	0.360*	-	0.462
			12.5	-	0.335*	-	0.452

^a A- Moisture tempering, B-40 dried at 40°C, B80- dried at 80°C, C- drying/wetting cycles, D- freezing/thawing cycles

*Indicates significant difference (P<0.05) from the Reference at each cooking time using the Holm-Sidak multiple comparison method.

Table 4.55 Deformation ratios of Impact red lentils 2008 crop year after different storage pre-treatments^a and storage times

Temperature (°C)	Storage Pre-treatment	MC (%) wb	Cooking Time (min)	Storage time (months)			
				0	1	2	6
5	Reference	as is	10	0.487	-	-	0.492
			12.5	0.530	-	-	0.491
	A	10	10	-	-	-	0.489
			12.5	-	-	-	0.444*
	A	11.5	10	-	-	-	0.508
			12.5	-	-	-	0.461
	A	13	10	-	-	-	0.509
			12.5	-	-	-	0.450
	B40	10	10	-	0.495	-	0.478
			12.5	-	0.457*	-	0.463
	B40	13	10	-	0.487	-	0.491
			12.5	-	0.457*	-	0.491
	B 80	10	10	-	0.499	-	0.494
			12.5	-	0.465*	-	0.493
	B 80	13	10	-	0.466	-	0.507
			12.5	-	0.455*	-	0.481
	C	10	10	-	0.468	0.488	-
			12.5	-	0.463*	0.461*	-
	C	13	10	-	0.463	0.478	-
			12.5	-	0.432*	0.454*	-
	D	10	10	-	0.528*	0.488	-
			12.5	-	0.484*	0.472*	-
	D	13	10	-	0.465	0.481	-
			12.5	-	0.432*	0.465*	-
25	A	10	10	0.507	-	-	0.479
			12.5	0.496*	-	-	0.481
	A	11.5	10	0.486	-	-	0.528
			12.5	0.471*	-	-	0.508
	A	13	10	0.472	-	-	0.537*
			12.5	0.490*	-	-	0.477
	B 40	10	10	-	0.488	-	0.493
			12.5	-	0.463*	-	0.485
	B 40	13	10	-	0.488	-	0.477
			12.5	-	0.464*	-	0.487
	B 80	10	10	-	0.515	-	0.521
			12.5	-	0.426*	-	0.477
B 80	13	10	-	0.491	-	0.519	
		12.5	-	0.455*	-	0.515	

^a A- Moisture tempering, B-40 dried at 40°C, B80- dried at 80°C, C- drying/wetting cycles, D- freezing/thawing cycles

*Indicates significant difference (P<0.05) from the Reference at each cooking time using the Holm-Sidak multiple comparison method.

5. CONCLUSIONS

The effects of storage time and conditions on the dehulling efficiency and cooking quality of two varieties of red lentils harvested in two consecutive crop years were evaluated. Dehulling efficiency was principally affected by pre-milling moisture content. The different levels of this factor resulted in samples with completely different dehulling properties, samples with low pre-milling moisture (10.4%) had the highest broken and powder fractions whereas high moisture levels (15.3%) resulted in the lowest dehulling efficiency regardless of storage conditions.

Storage time did not affect the dehulling efficiency of samples as much as other factors like the storage pre-treatment applied. Pre-treatments involving moisture gradients had the most detrimental effects on the dehulling properties of red lentils because of the percentage of damaged, broken seeds as well as the powder produced, all of which are considered as losses. Storage pre-treatments involving only moisture tempering and freezing and thawing cycles before storage resulted in similar properties to samples stored without any treatment.

Drying from high moisture contents at high temperatures did not produce lower dehulling quality as much as drying at near-ambient temperature. On the other hand, samples stored at room temperature did not differ in their dehulling properties with samples refrigerated at 5°C.

Textural properties of red lentils changed after storage. The cooked lentil became harder to extrude, which is reflected in both the slopes and force ratios of the force-deformation curves.

Higher moisture contents affected the textural properties of cooked lentils and produced harder samples. Increasing the cooking time from 10 to 12.5 minutes decreased the hardness of samples but, at these cooking times, no samples presented overcooked texture and most samples, especially 2008 crop, showed optimally cooked texture.

Storage pre-treatments applied, especially those involving moisture changes (either with one or several drying cycles), also affected the cooked red lentil behaviour. These pre-treatments had the highest slopes, force and deformation ratios when compared to untreated samples as well as storage pre-treatments involving only moisture tempering and freezing/thawing cycles before storage.

After optimization of dehulling operation conditions, it was found that the criteria coincided with the previously reported results (Wang, 2005). Optimum regions decreased after 6 months of storage but signs of stabilization were found after 12 months, which indicates the length of storage of untreated samples was not an issue.

The Impact cultivar generally exhibited lower dehulling efficiency, higher dehulling loss and harder texture when compared to Redberry. The final recommendation arising from this study is to select the cultivar based on the preferred outcome, which would

be Redberry if a high dehulling efficiency is required. Selecting the optimum pre-milling moisture content is also recommended in order to achieve the maximum yield and minimum losses in the dehulling operation. This requirement varied with the storage time and should be tested prior to milling.

The final remark of this study is to recommend producers and processors to control as much as possible the moisture changes in the samples, since fluctuations in moisture content result in severe damage to the cotyledons when milled and harder texture after cooking. It should be noted that the majority of the storage conditions, freezing, thawing, storage temperature or long storage times do not affect the quality of neither variety of lentils as much as the moisture content, which should be highly taken into consideration when storing them.

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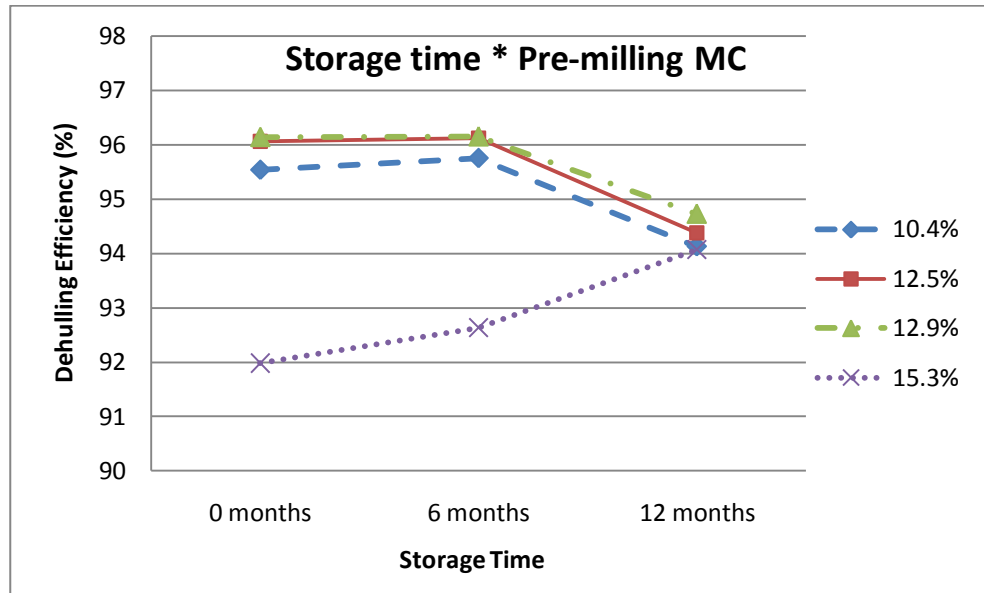
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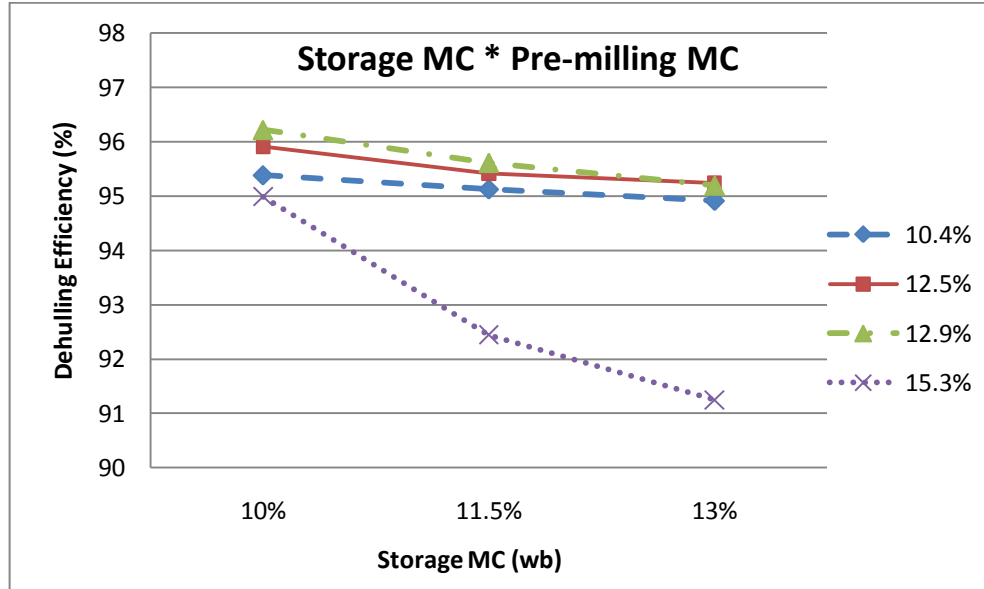
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7. APPENDICES

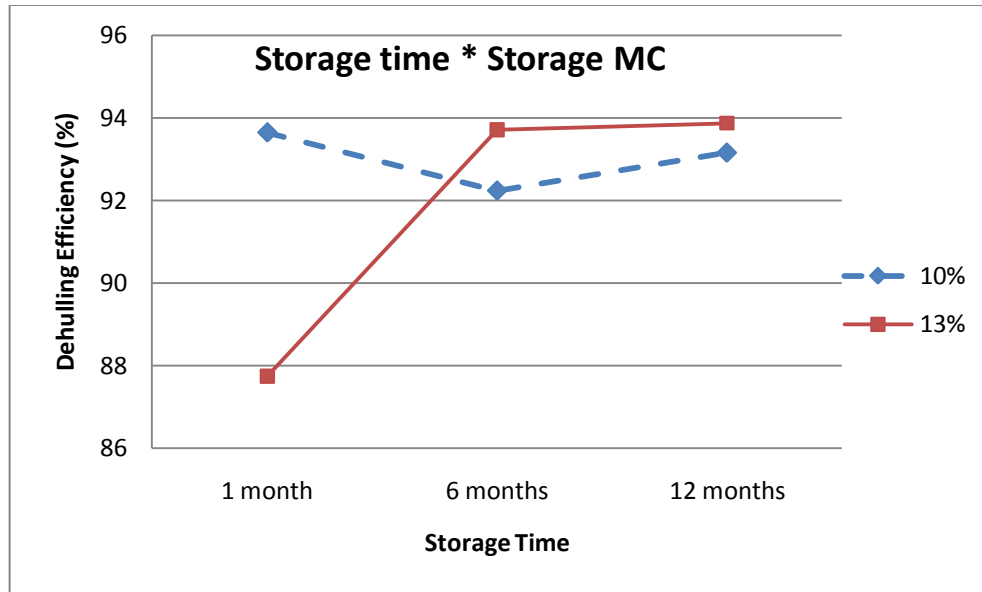
Interactions in Dehulling Efficiency for 2007 samples



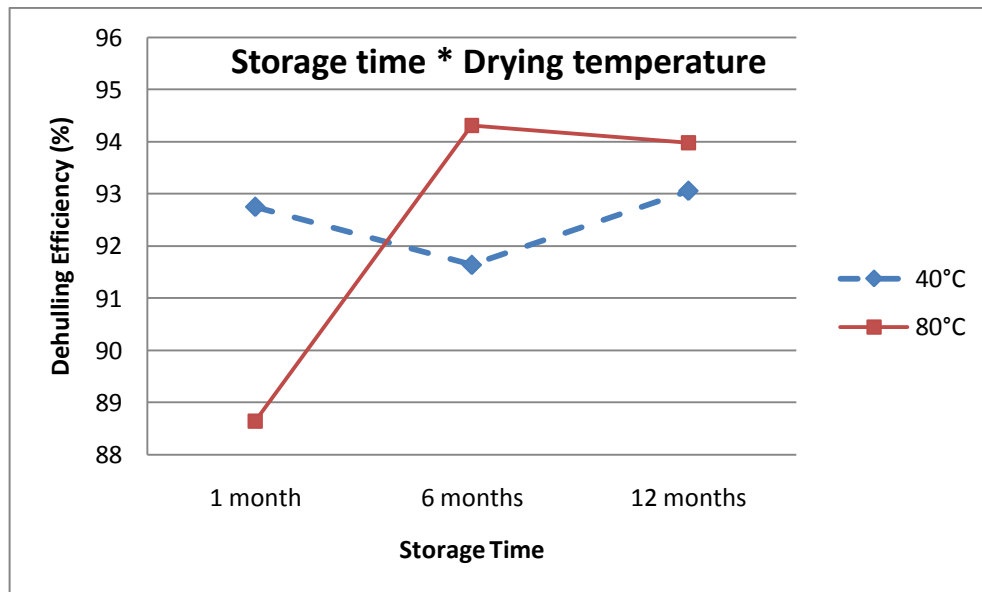
Appendix 1. Least square means plot showing the dehulling efficiency as affected by storage time and pre-milling moisture content for Redberry 2007 in storage pre-treatment A.



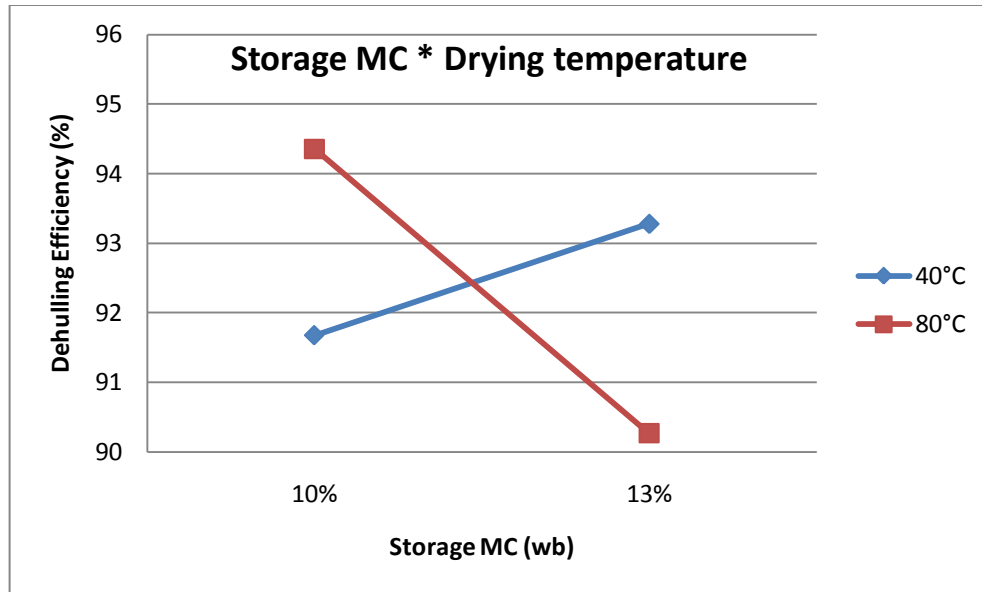
Appendix 2. Least square means plot showing the dehulling efficiency as affected by storage moisture content and pre-milling moisture content for Redberry 2007 in storage pre-treatment A.



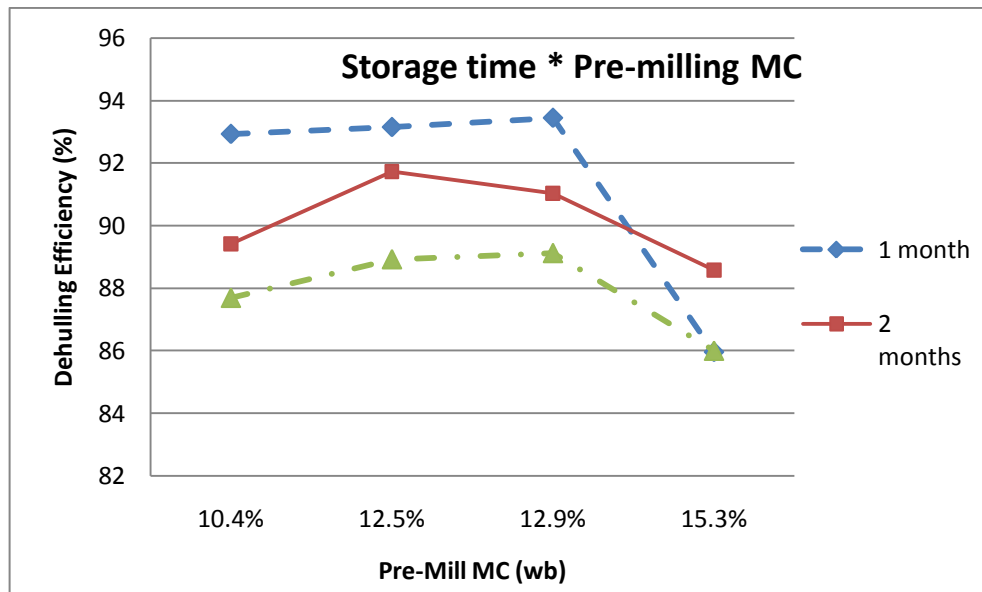
Appendix 3. Least square means plot showing the dehulling efficiency as affected by storage time and storage moisture content for Redberry 2007 in storage pre-treatment B.



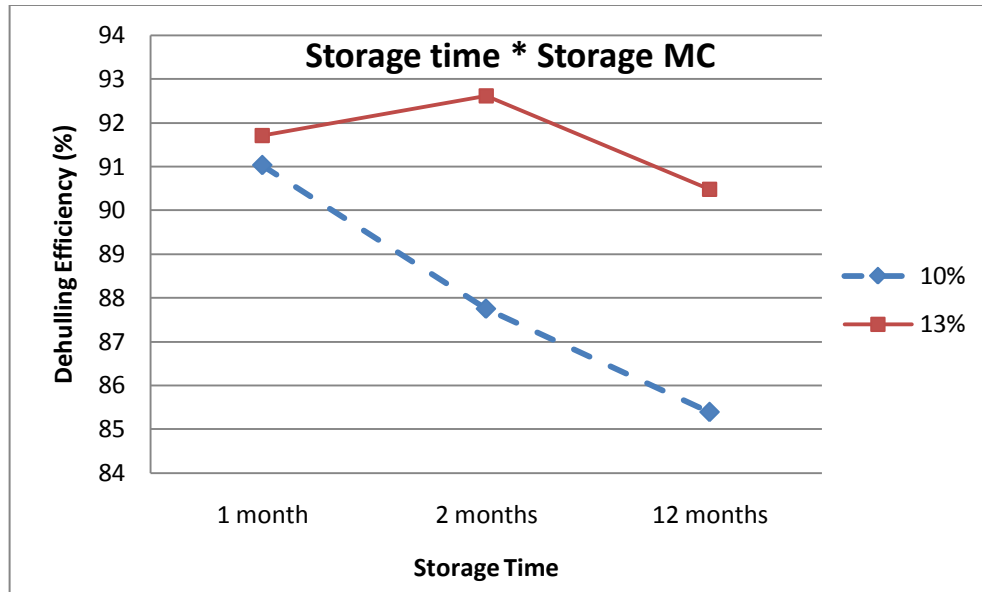
Appendix 4. Least square means plot showing the dehulling efficiency as affected by storage time and drying temperature for Redberry 2007 in storage pre-treatment B.



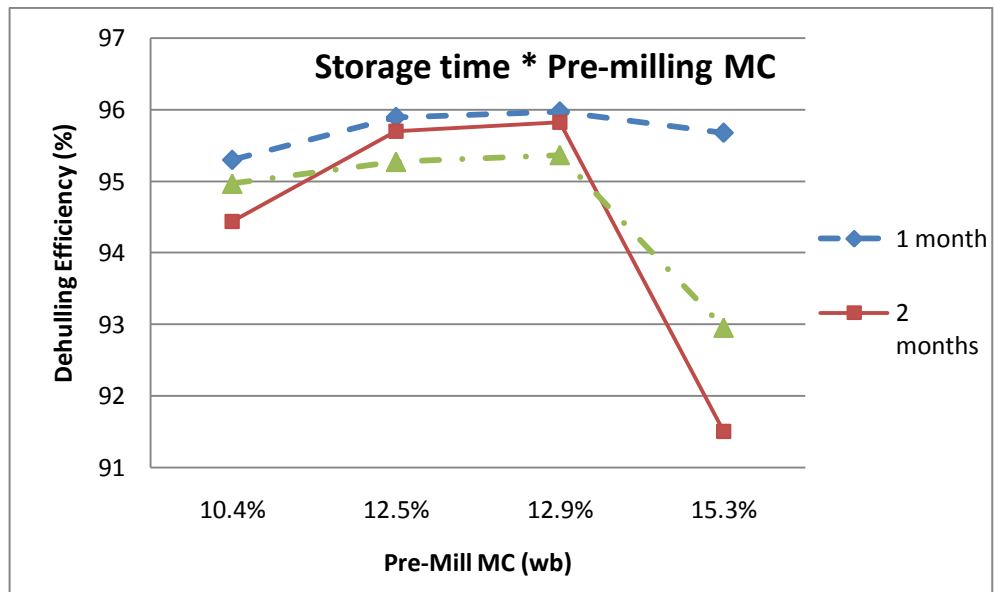
Appendix 5. Least square means plot showing the dehulling efficiency as affected by drying temperature and storage moisture content for Redberry 2007 in storage pre-treatment B.



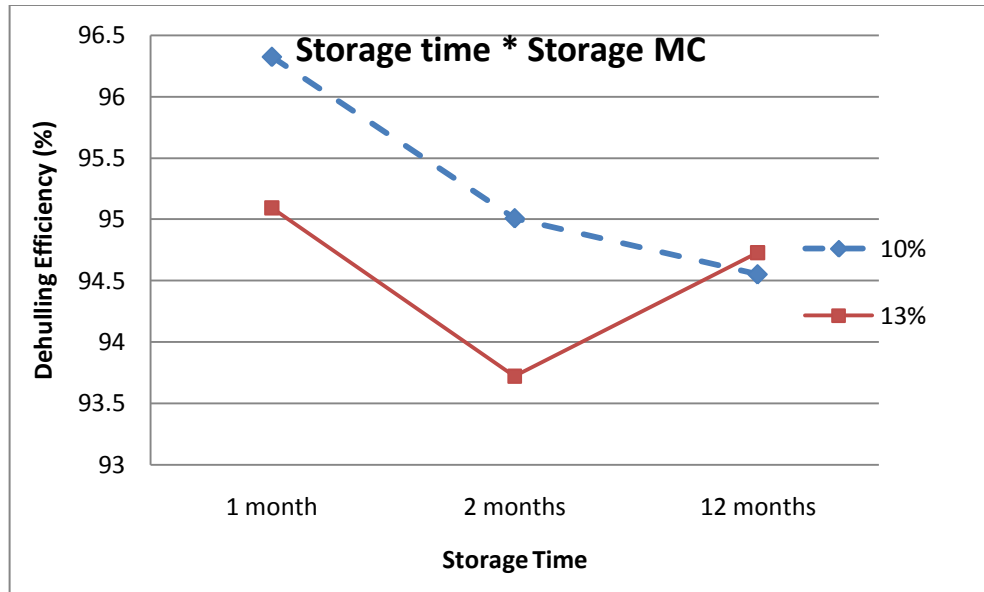
Appendix 6. Least square means plot showing the dehulling efficiency as affected by storage time and pre-milling moisture content for Redberry 2007 in storage pre-treatment C.



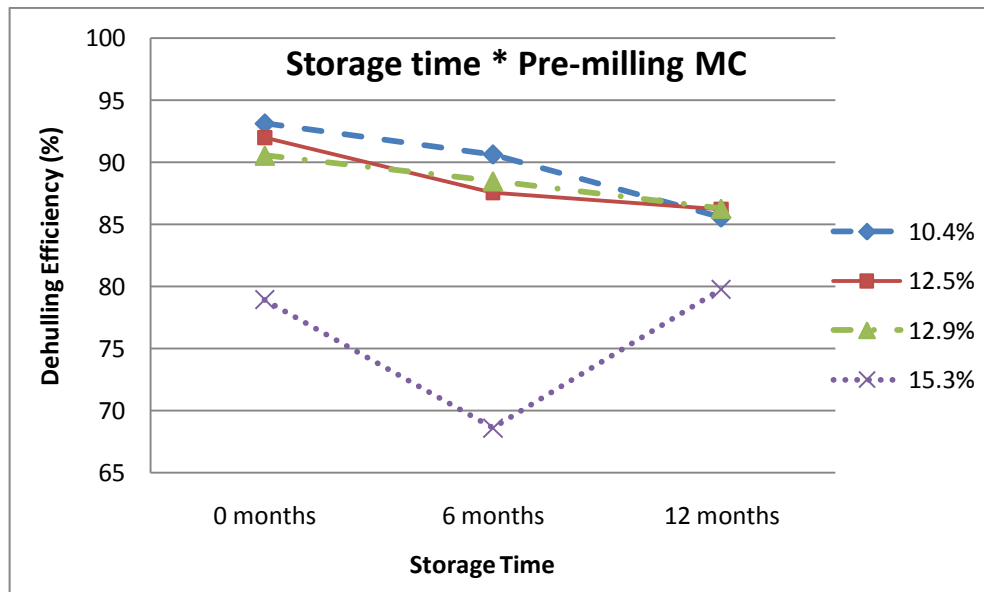
Appendix 7. Least square means plot showing the dehulling efficiency as affected by storage time and storage moisture content for Redberry 2007 in storage pre-treatment C.



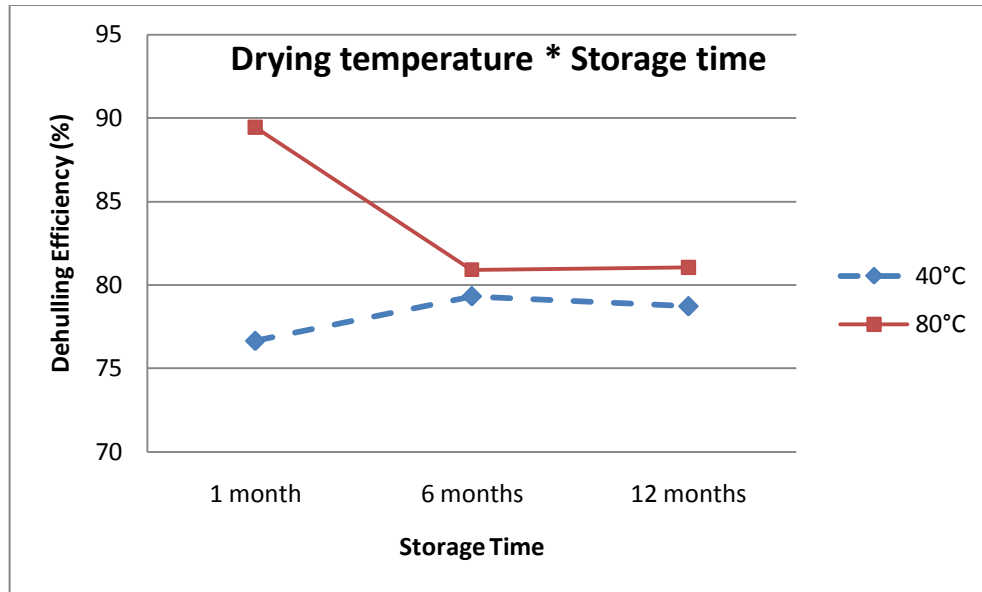
Appendix 8. Least square means plot showing the dehulling efficiency as affected by storage time and pre-milling moisture content for Redberry 2007 in storage pre-treatment D.



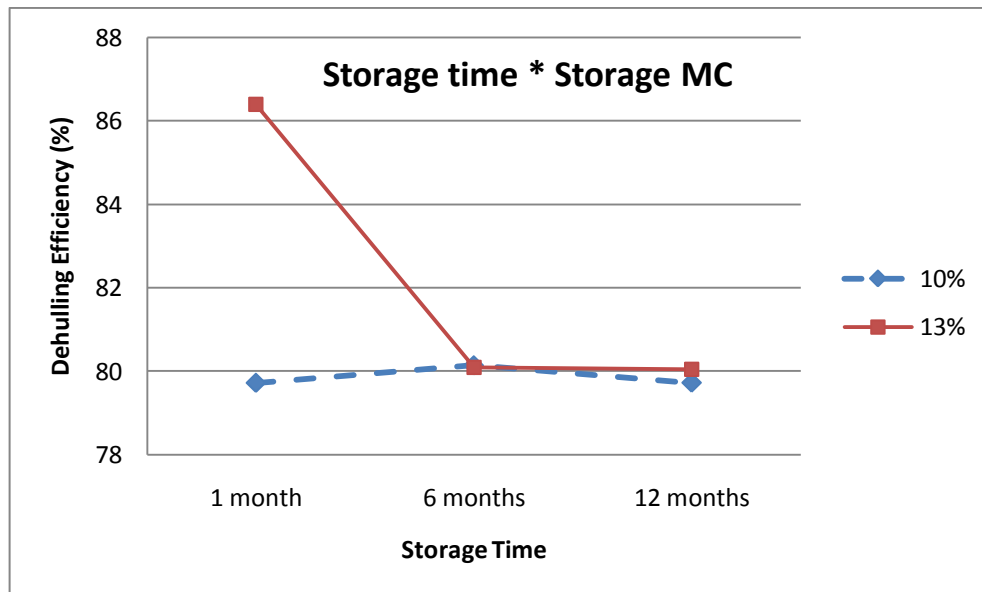
Appendix 9. Least square means plot showing the dehulling efficiency as affected by storage time and storage moisture content for Redberry 2007 in storage pre-treatment D.



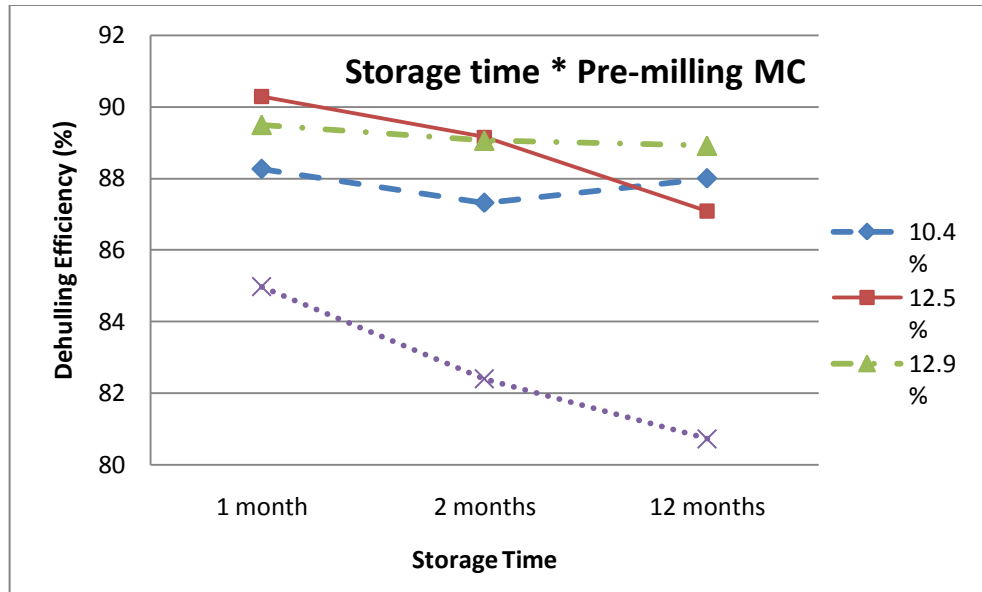
Appendix 10. Least square means plot showing the dehulling efficiency as affected by storage time and pre-milling moisture content for Impact 2007 in storage pre-treatment A.



Appendix 11. Least square means plot showing the dehulling efficiency as affected by storage time and drying temperature for Impact 2007 in storage pre-treatment B.

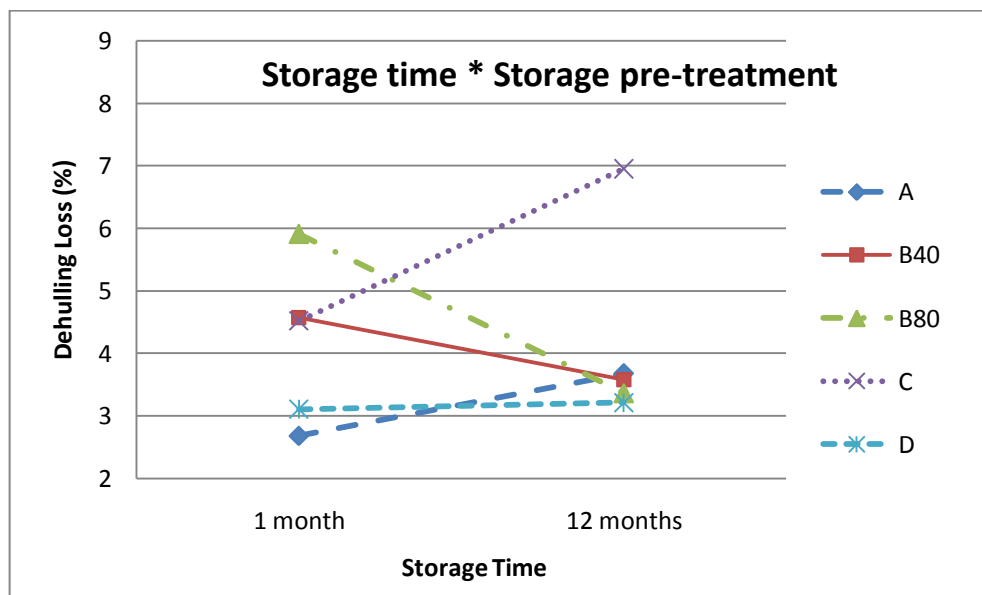


Appendix 12. Least square means plot showing the dehulling efficiency as affected by storage time and storage moisture content for Impact 2007 in storage pre-treatment B.

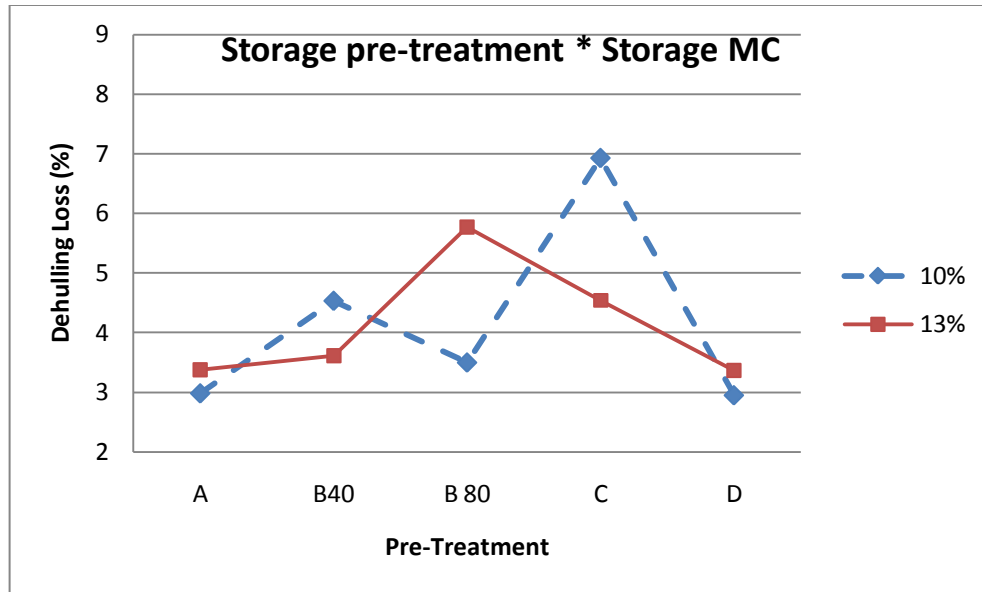


Appendix 13. Least square means plot showing the dehulling efficiency as affected by storage time and pre-milling moisture content for Impact 2007 in storage pre-treatment D.

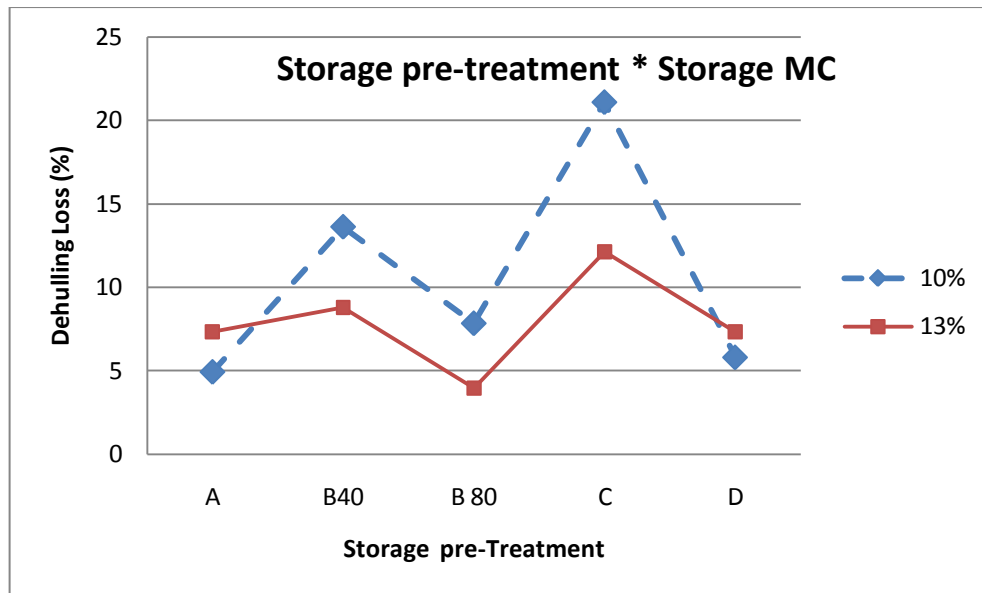
Interactions in Dehulling loss for 2007 samples



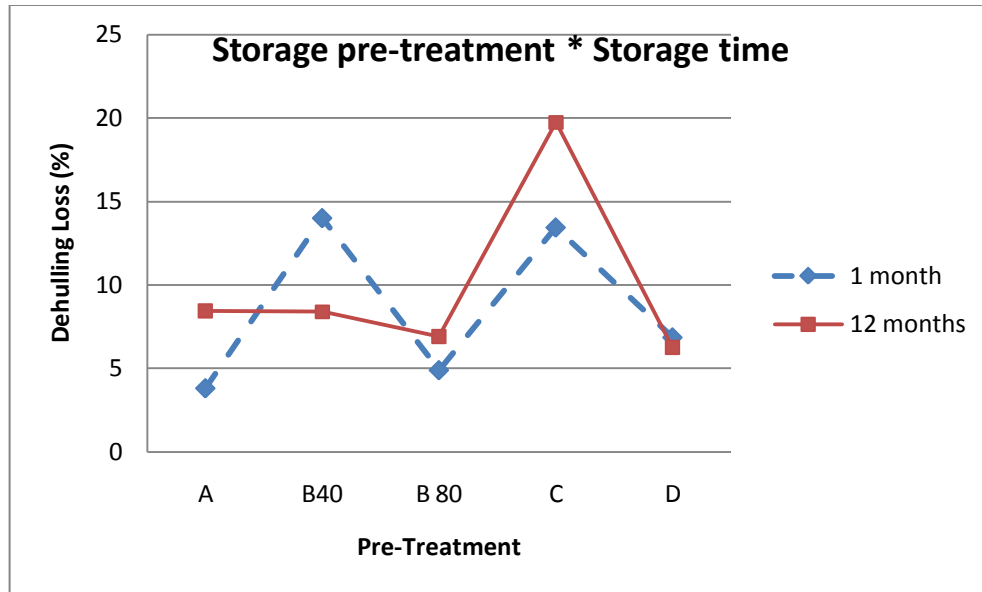
Appendix 14. Least square means plot showing the dehulling loss as affected by storage time and storage pre-treatment for Redberry 2007 analyzed with the general factorial design.



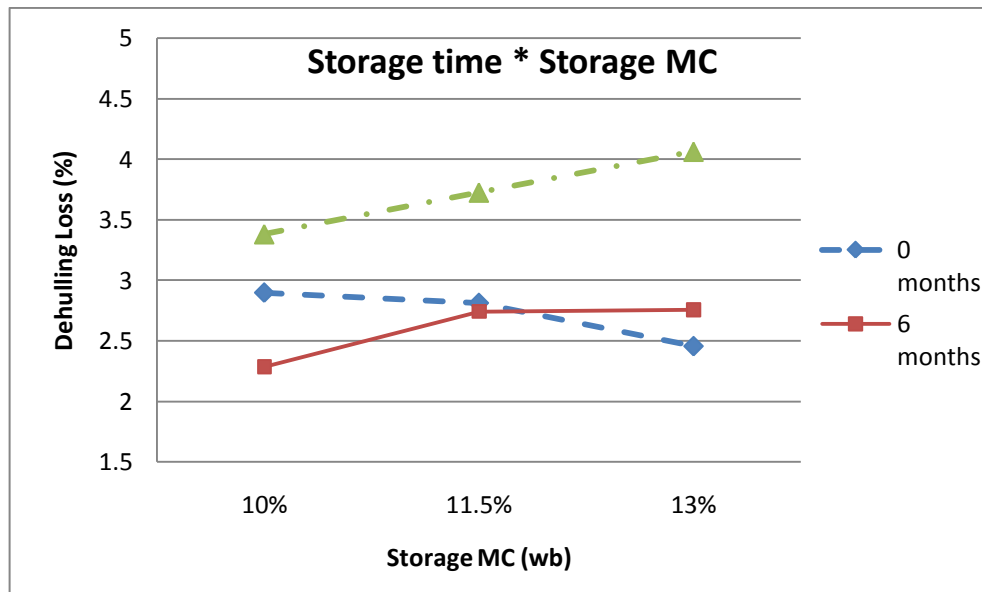
Appendix 15. Least square means plot showing the dehulling loss as affected by storage moisture content and storage pre-treatment for Redberry 2007 analyzed with the general factorial design.



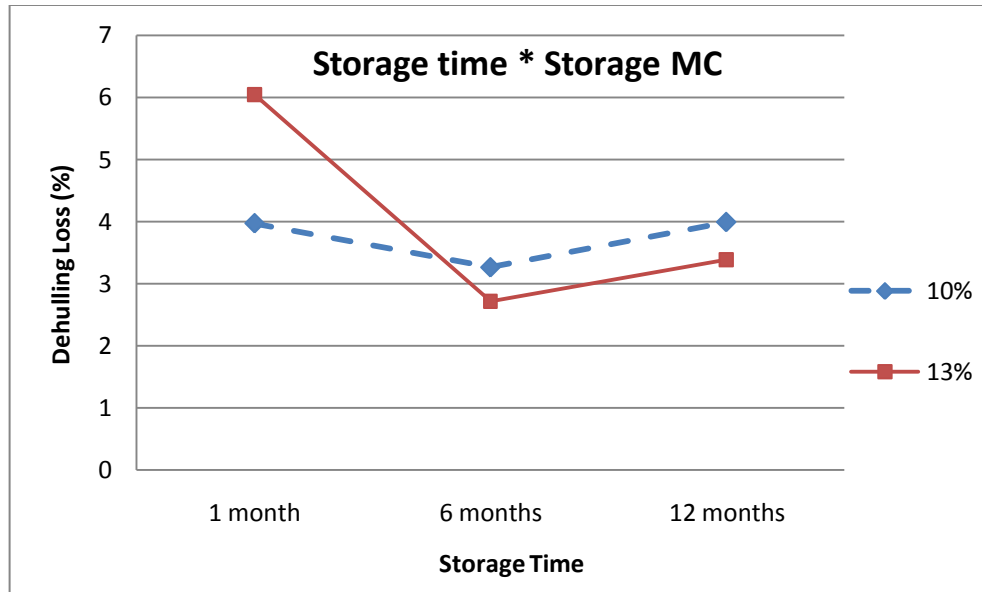
Appendix 16. Least square means plot showing the dehulling loss as affected by storage moisture content and storage pre-treatment for Impact 2007 analyzed with the general factorial design.



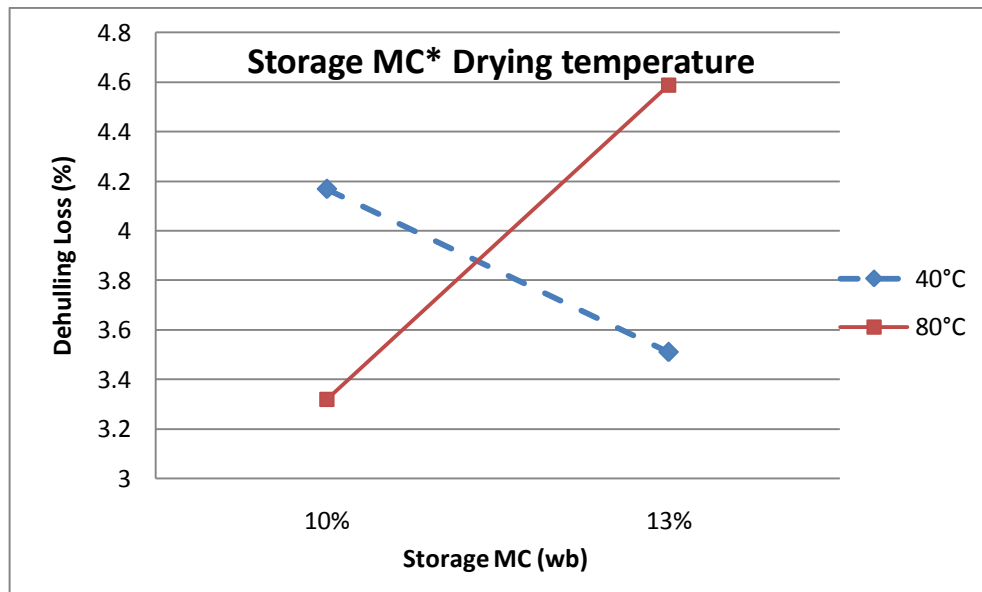
Appendix 17. Least square means plot showing the dehulling loss as affected by storage time and storage pre-treatment for Impact 2007 analyzed with the general factorial design.



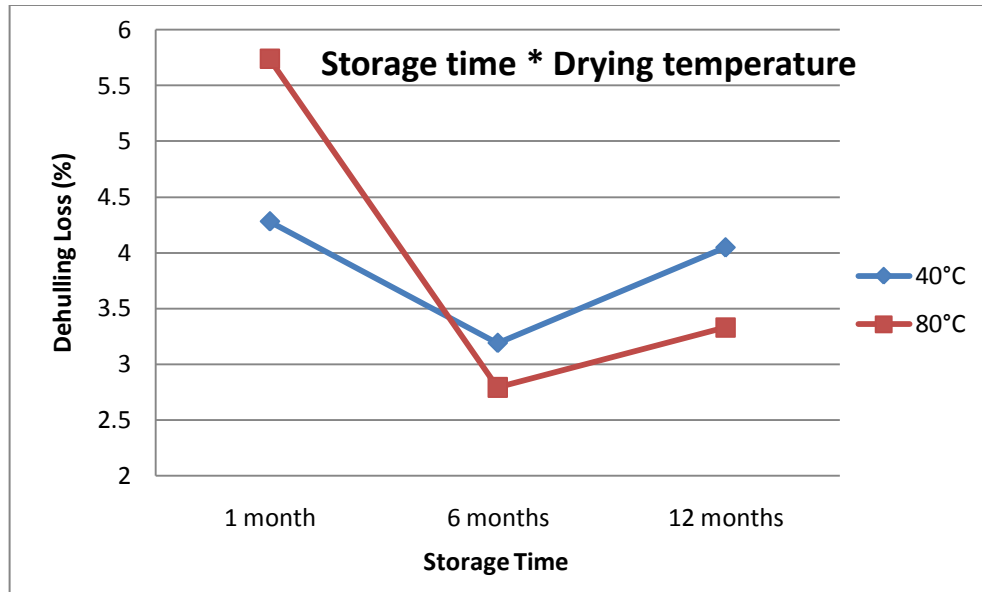
Appendix 18. Least square means plot showing the dehulling loss as affected by storage time and storage moisture content for Redberry 2007 in storage pre-treatment A.



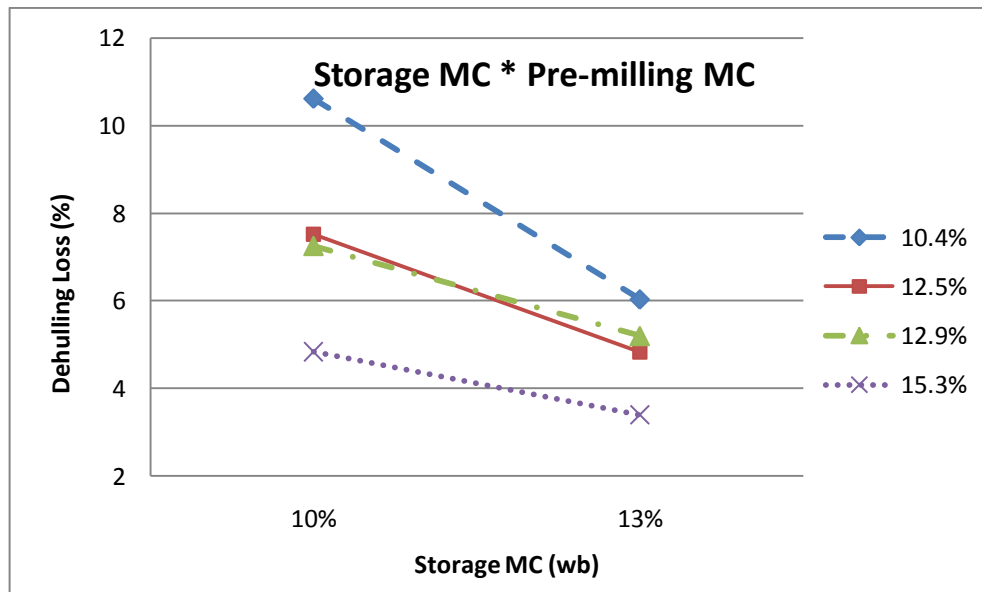
Appendix 19. Least square means plot showing the dehulling loss as affected by storage time and storage moisture content for Redberry 2007 in storage pre-treatment B.



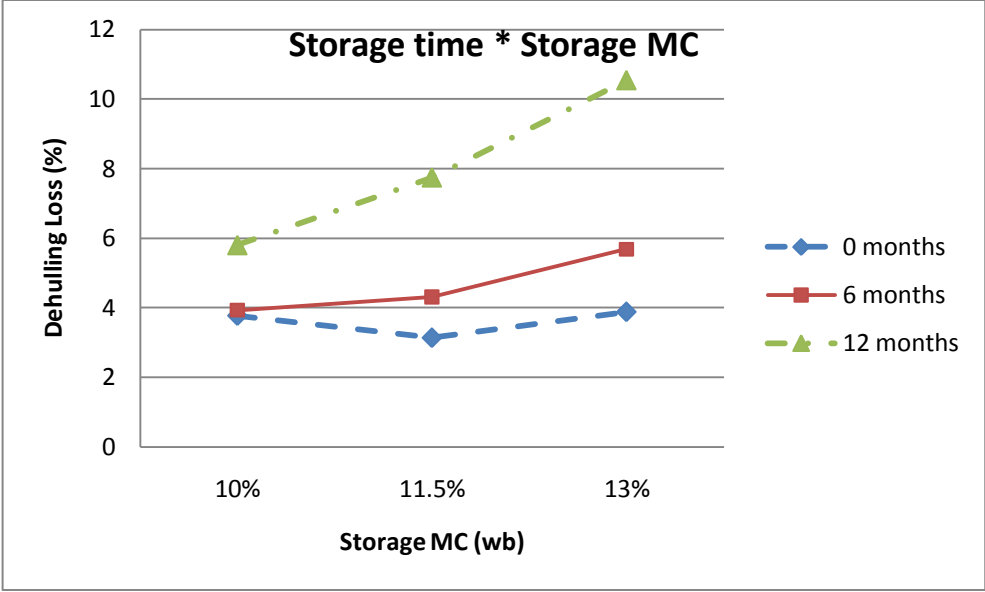
Appendix 20. Least square means plot showing the dehulling loss as affected by drying temperature and storage moisture content for Redberry 2007 in storage pre-treatment B.



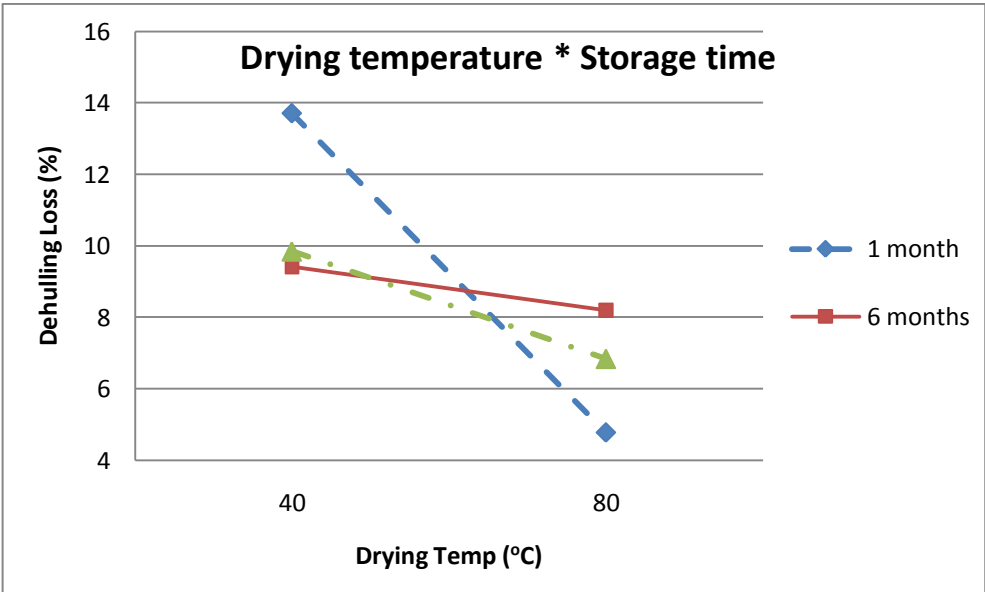
Appendix 21. Least square means plot showing the dehulling loss as affected by drying temperature and storage time for Redberry 2007 in storage pre-treatment B.



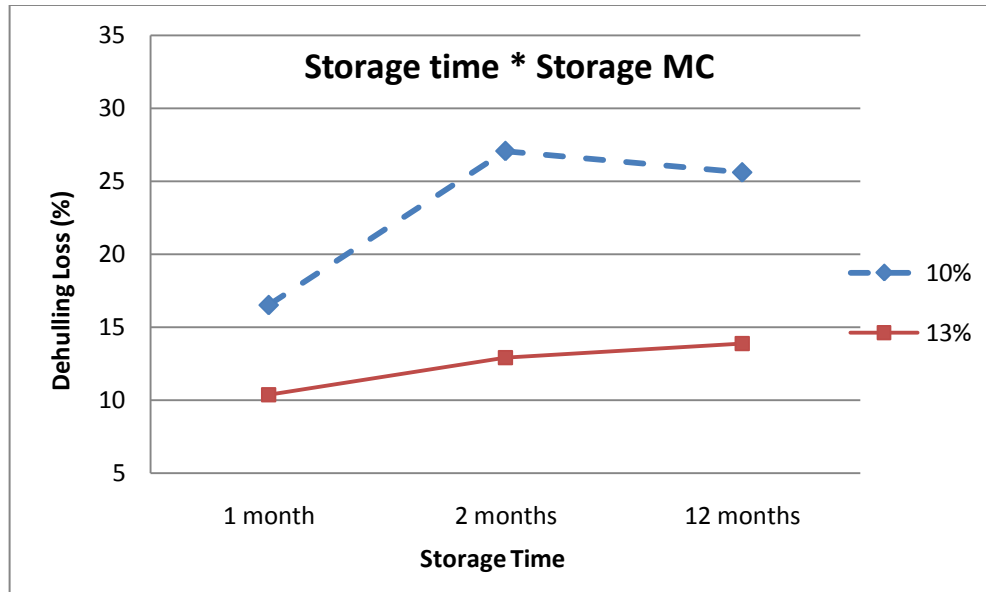
Appendix 22. Least square means plot showing the dehulling loss as affected by drying temperature and storage time for Redberry 2007 in storage pre-treatment C.



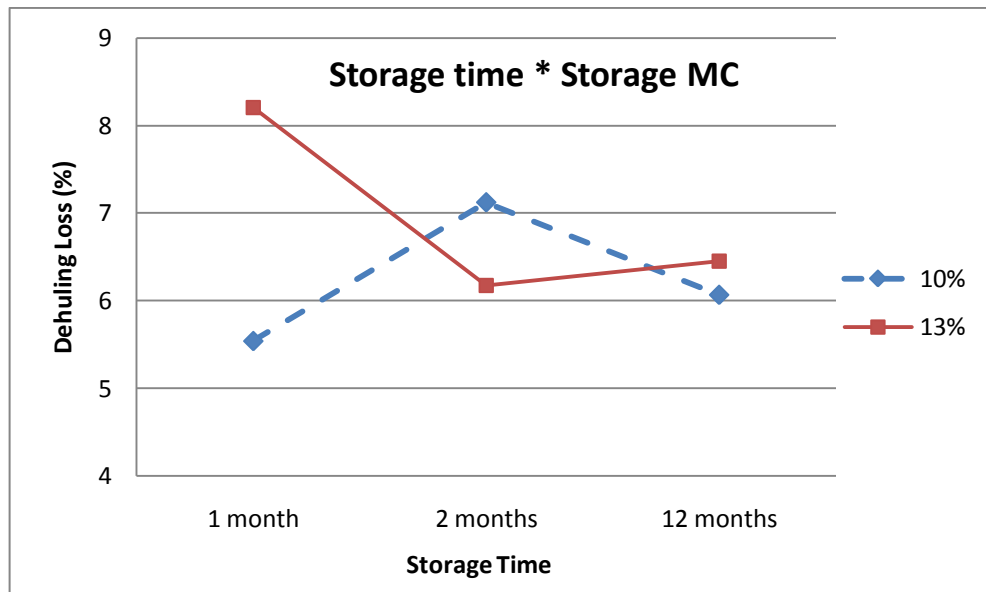
Appendix 23. Least square means plot showing the dehulling loss as affected by storage moisture content and storage time for Impact 2007 in storage pre-treatment A.



Appendix 24. Least square means plot showing the dehulling loss as affected by drying temperature and storage time for Impact 2007 in storage pre-treatment B.

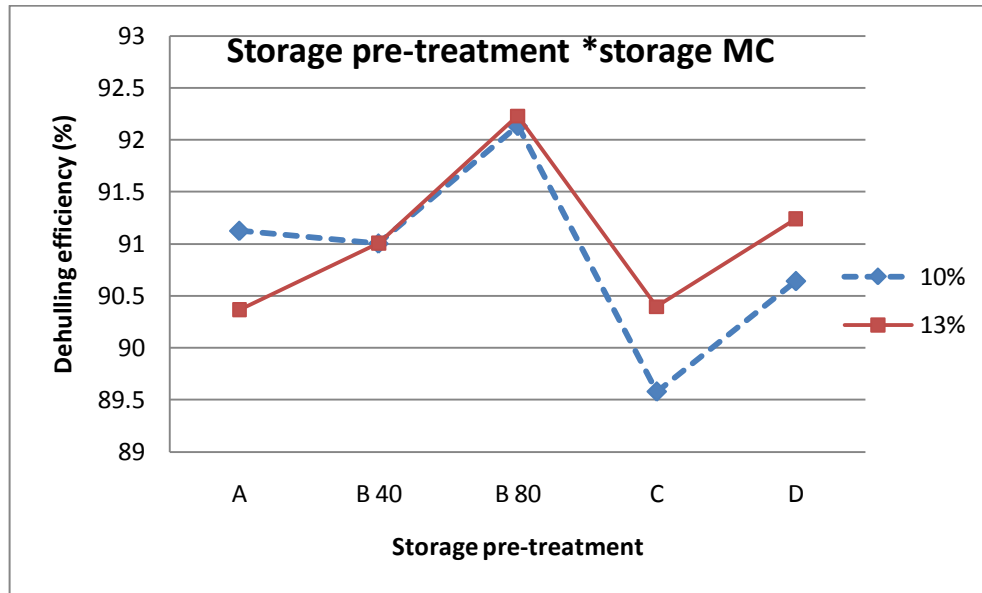


Appendix 25. Least square means plot showing the dehulling loss as affected by storage moisture content and storage time for Impact 2007 in storage pre-treatment C.

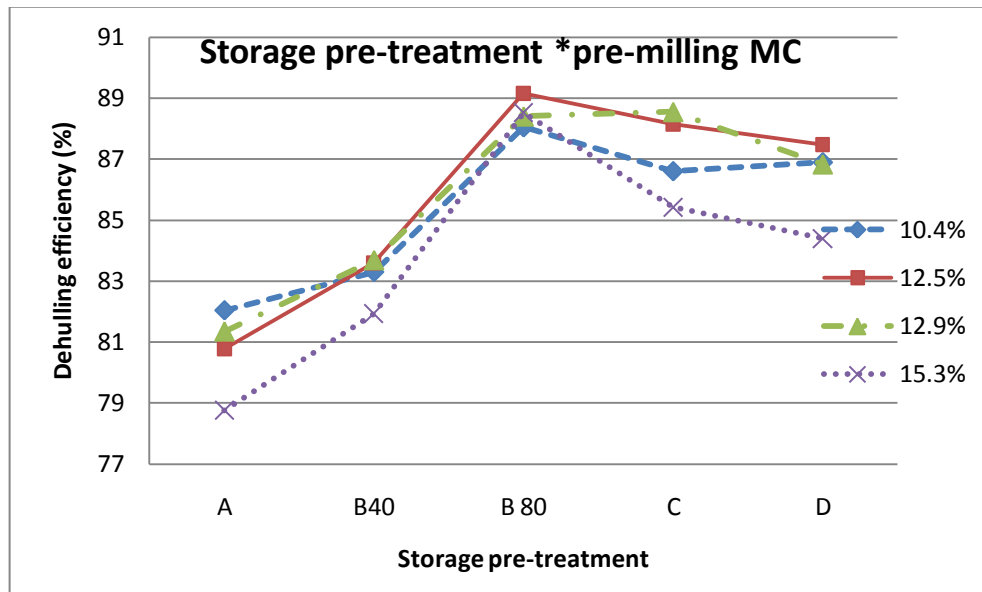


Appendix 26. Least square means plot showing the dehulling loss as affected by storage moisture content and storage time for Impact 2007 in storage pre-treatment D.

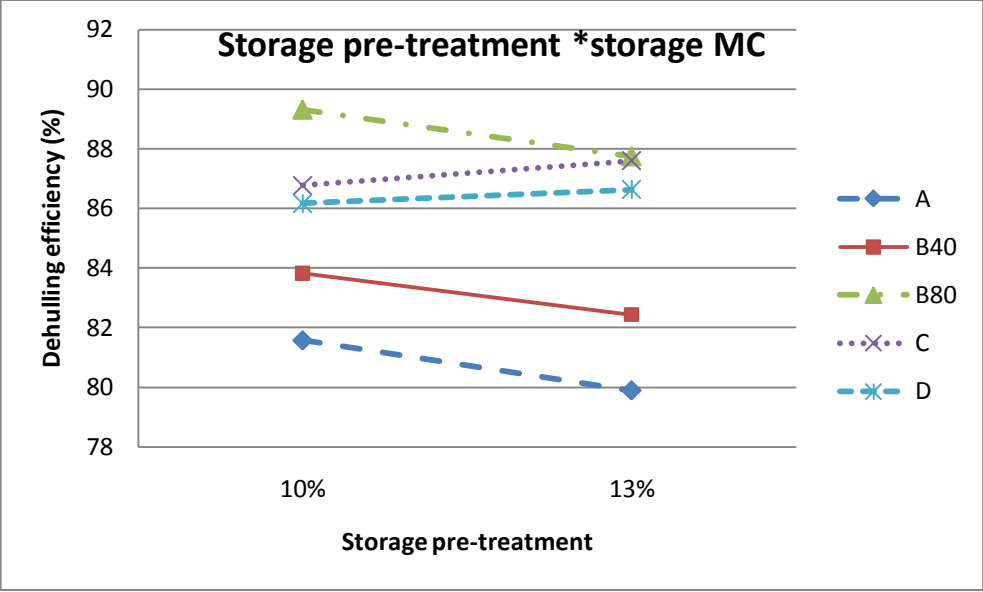
Interactions in dehulling efficiency for 2008 crop



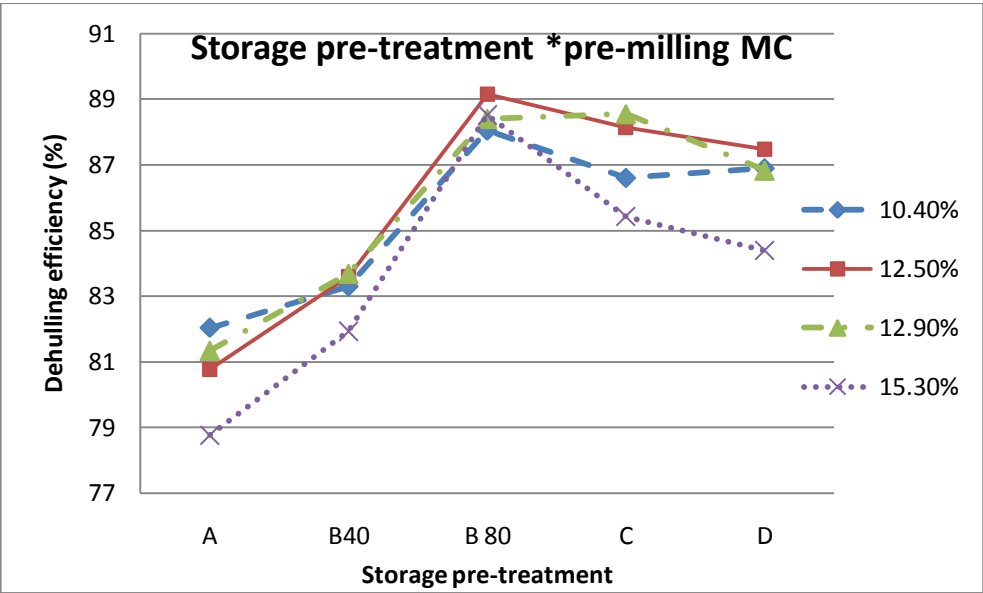
Appendix 27. Least square means plot showing the dehulling efficiency as affected by storage moisture content and storage pre-treatment for Redberry 2008 analyzed with the general factorial design.



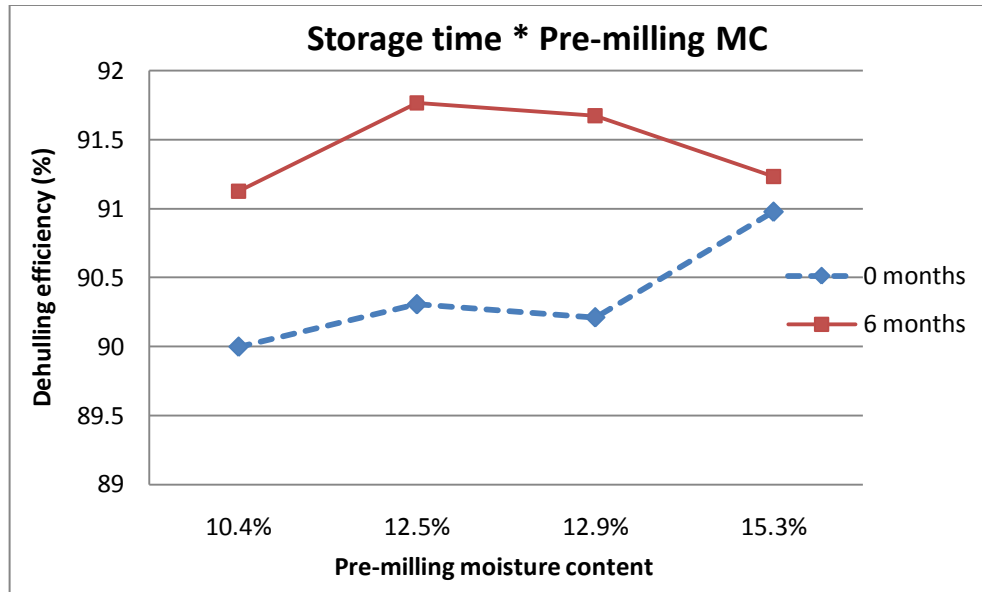
Appendix 28. Least square means plot showing the dehulling efficiency as affected by pre-milling moisture content and storage pre-treatment for Redberry 2008 analyzed with the general factorial design.



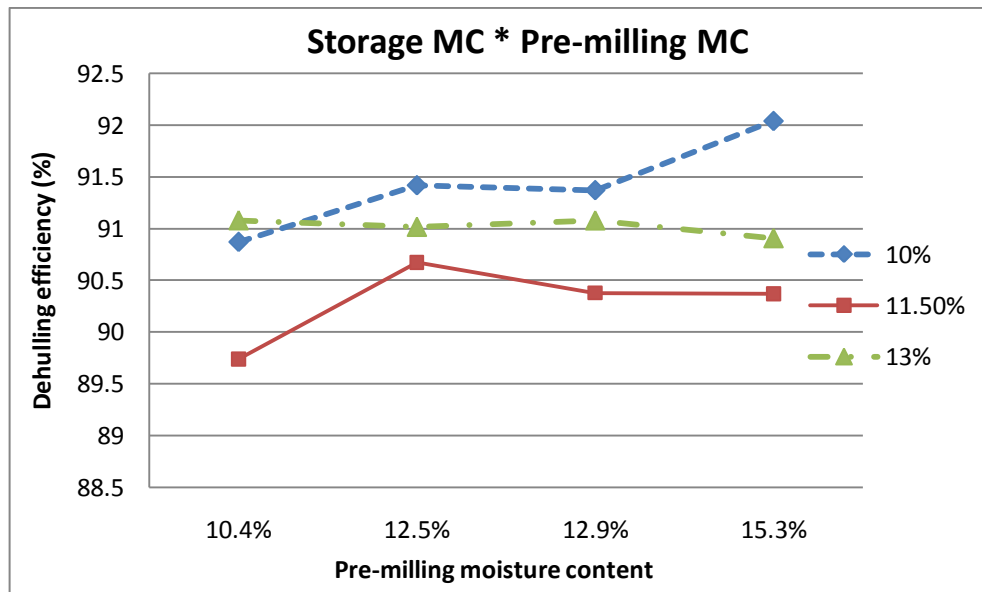
Appendix 29. Least square means plot showing the dehulling efficiency as affected by storage moisture content and storage pre-treatment for Impact 2008 analyzed with the general factorial design.



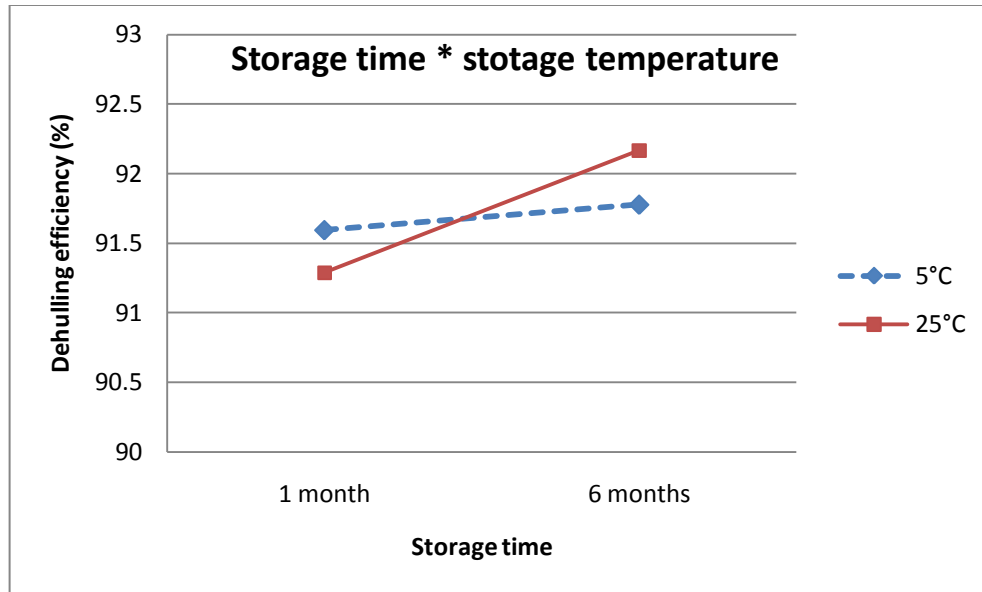
Appendix 30. Least square means plot showing the dehulling efficiency as affected by pre-milling moisture content and storage pre-treatment for Impact 2008 analyzed with the general factorial design.



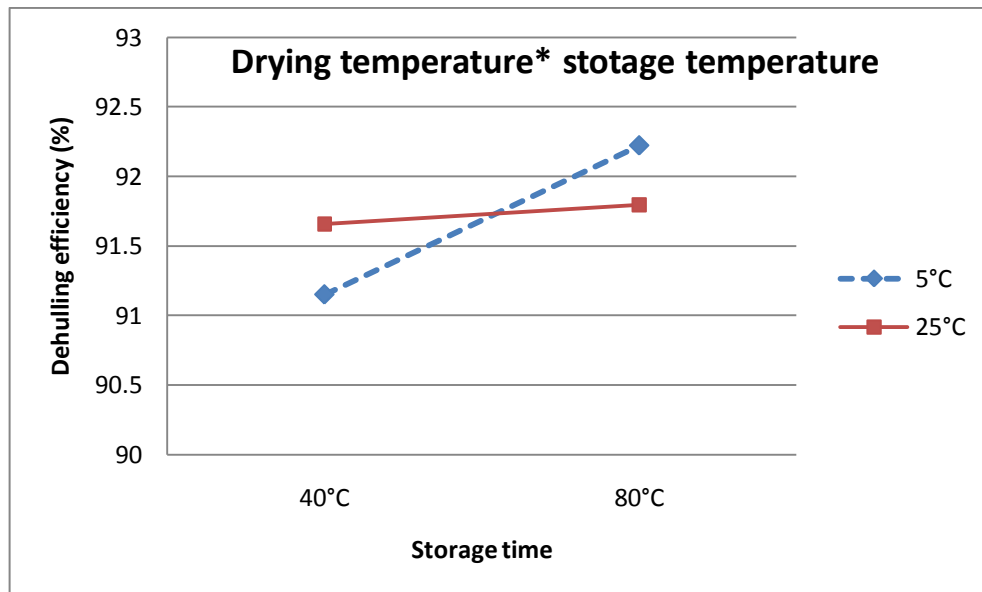
Appendix 31. Least square means plot showing the dehulling efficiency as affected by pre-milling moisture content and storage time for Redberry 2008 in storage pre-treatment A.



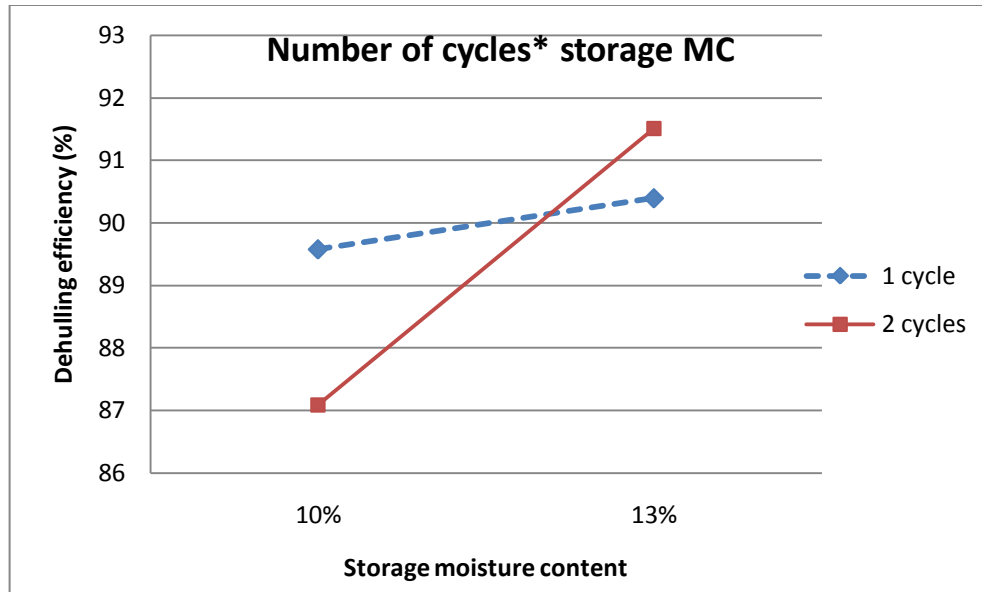
Appendix 32. Least square means plot showing the dehulling efficiency as affected by pre-milling moisture content and storage moisture content for Redberry 2008 in storage pre-treatment A.



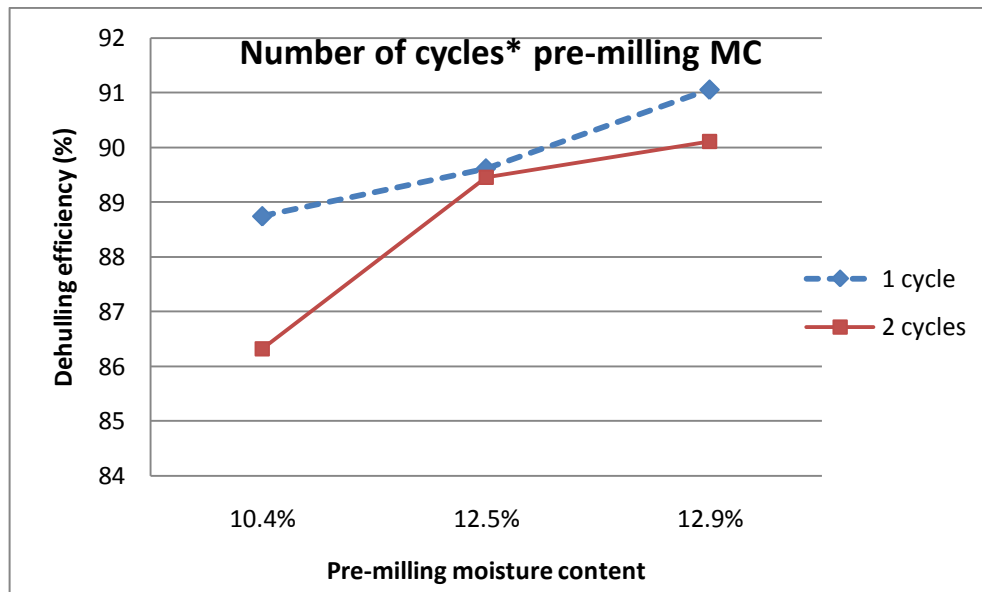
Appendix 33. Least square means plot showing the dehulling efficiency as affected by storage time and storage temperature content for Redberry 2008 in storage pre-treatment B.



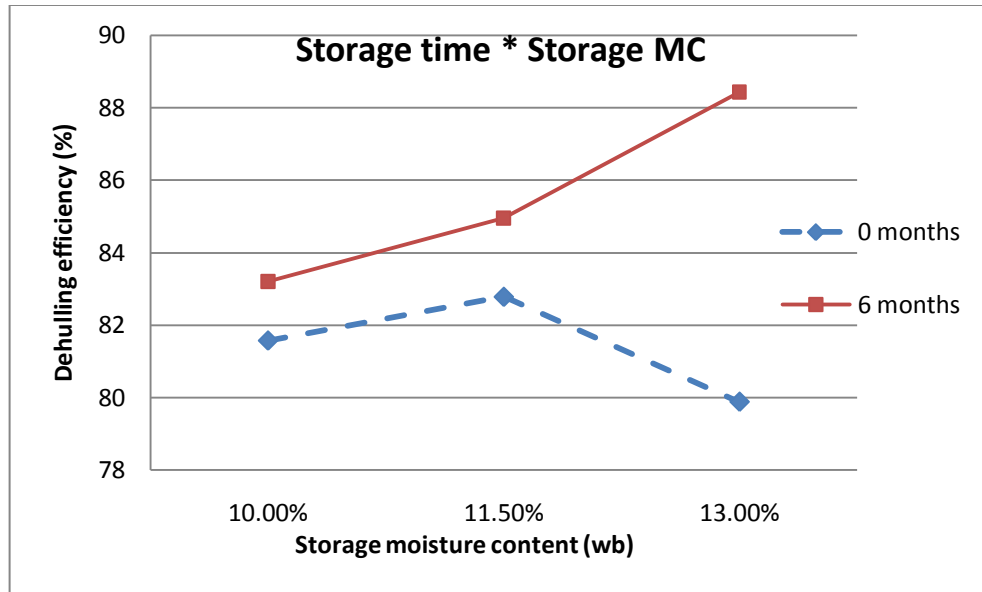
Appendix 34. Least square means plot showing the dehulling efficiency as affected by storage temperature and drying temperature for Redberry 2008 in storage pre-treatment B.



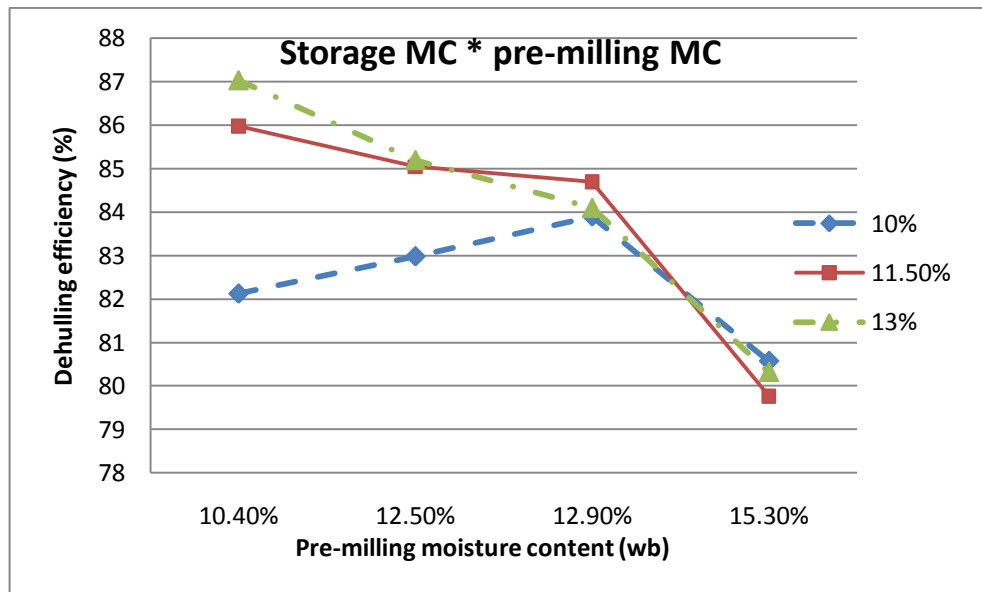
Appendix 35. Least square means plot showing the dehulling efficiency as affected by storage moisture content and number of cycles for Redberry 2008 in storage pre-treatment C.



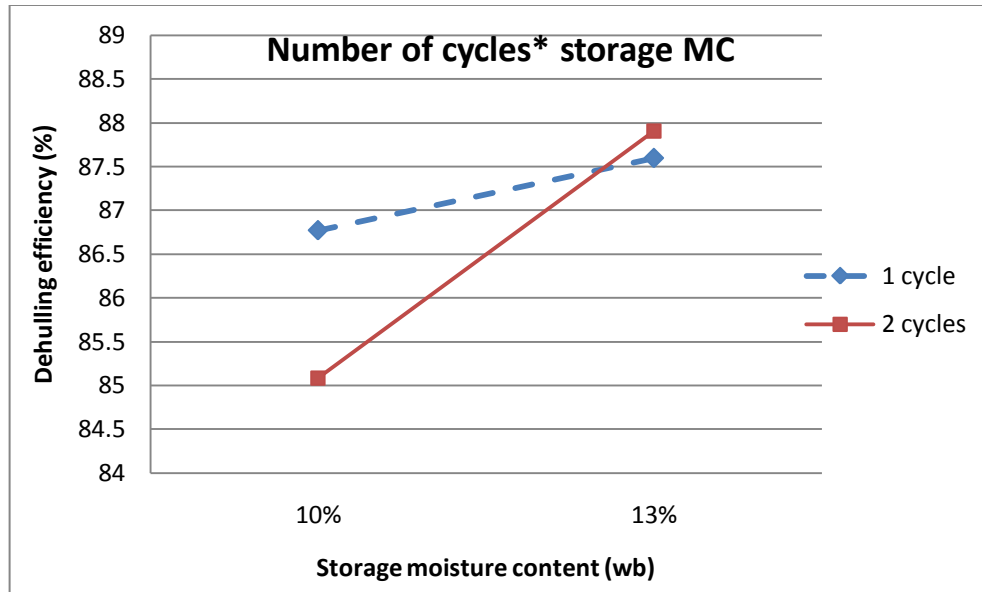
Appendix 36. Least square means plot showing the dehulling efficiency as affected by pre-milling moisture content and number of cycles for Redberry 2008 in storage pre-treatment C.



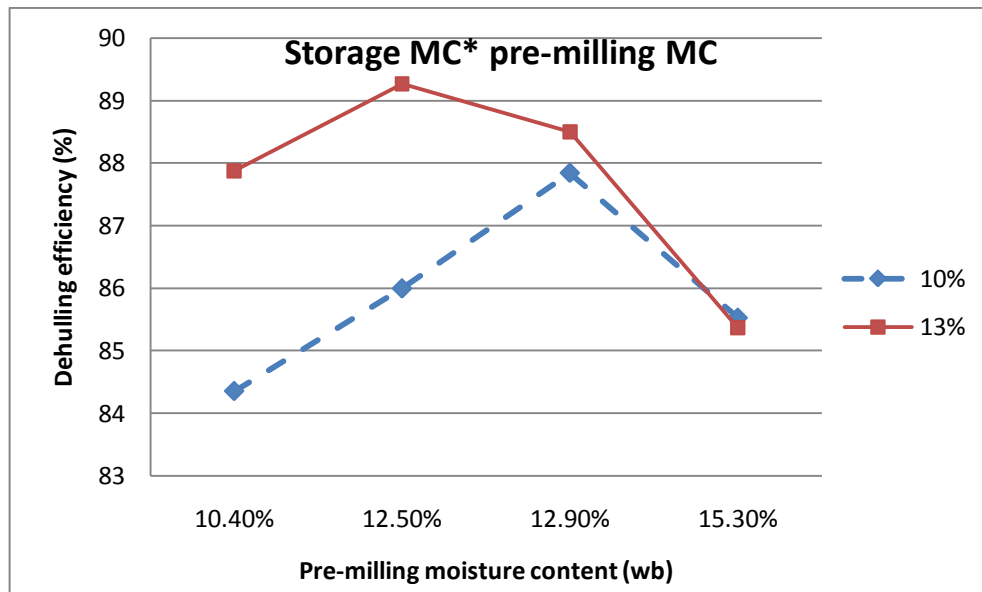
Appendix 37. Least square means plot showing the dehulling efficiency as affected by storage moisture content and storage time for Impact 2008 in storage pre-treatment A.



Appendix 38. Least square means plot showing the dehulling efficiency as affected by storage moisture content and pre-milling moisture content for Impact 2008 in storage pre-treatment A.

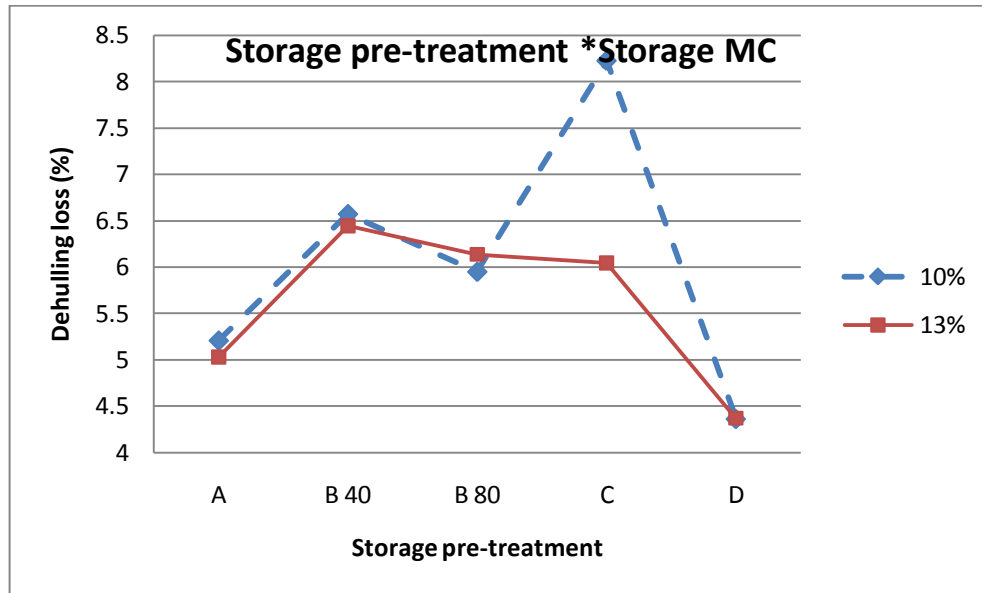


Appendix 39. Least square means plot showing the dehulling efficiency as affected by storage moisture content and number of cycles for Impact 2008 in storage pre-treatment C.

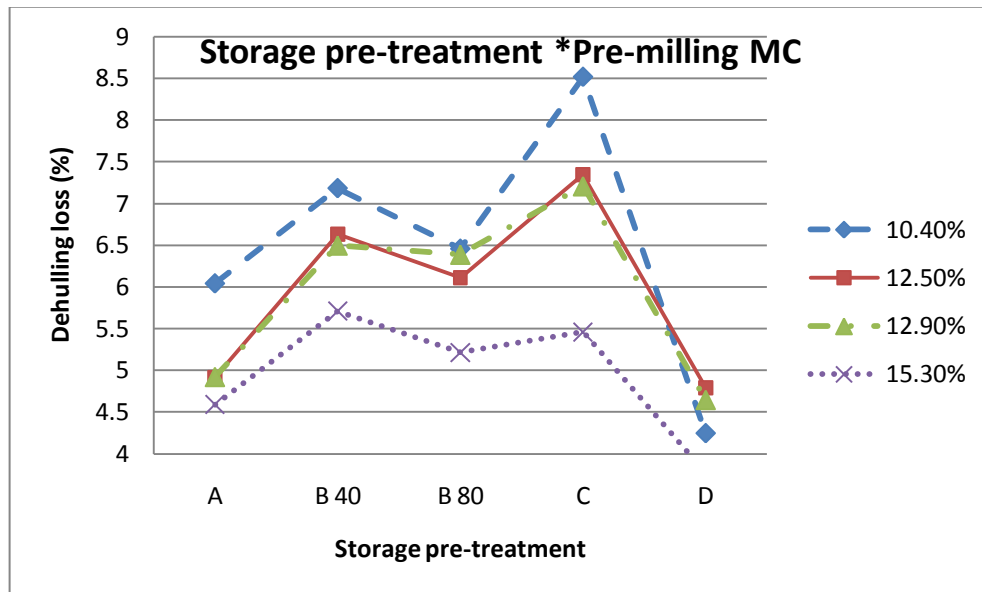


Appendix 40. Least square means plot showing the dehulling efficiency as affected by storage moisture content and pre-milling moisture content for Impact 2008 in storage pre-treatment C.

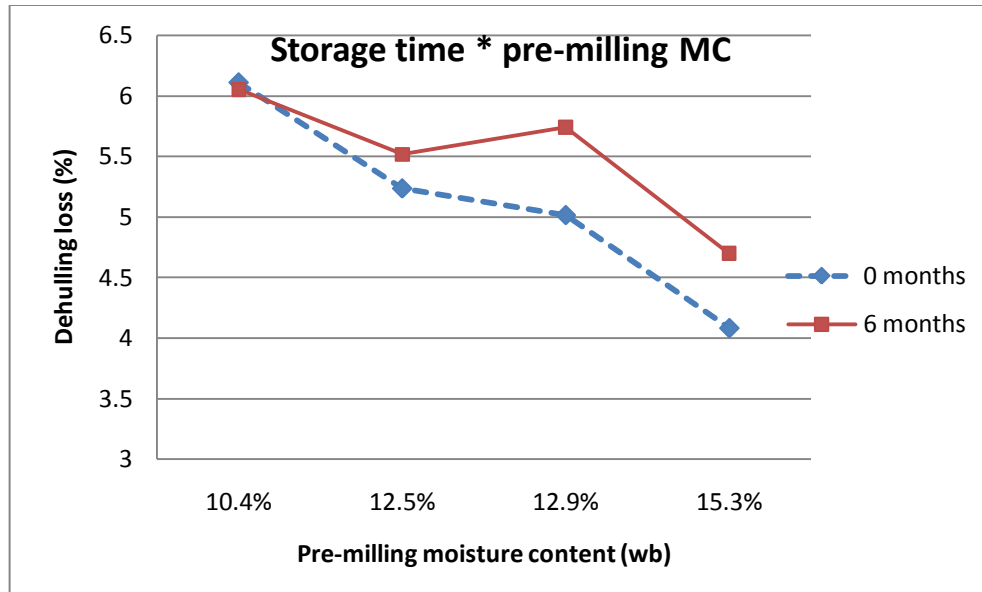
Interactions in dehulling loss for 2008 crop



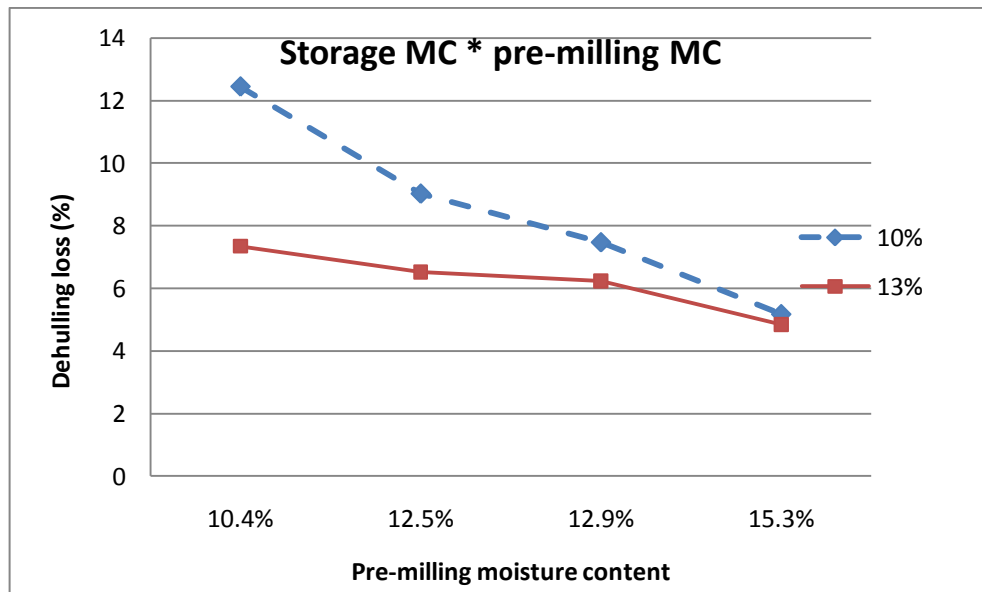
Appendix 41. Least square means plot showing the dehulling loss as affected by storage moisture content and storage pre-treatment for Impact 2008 analyzed with the general factorial design.



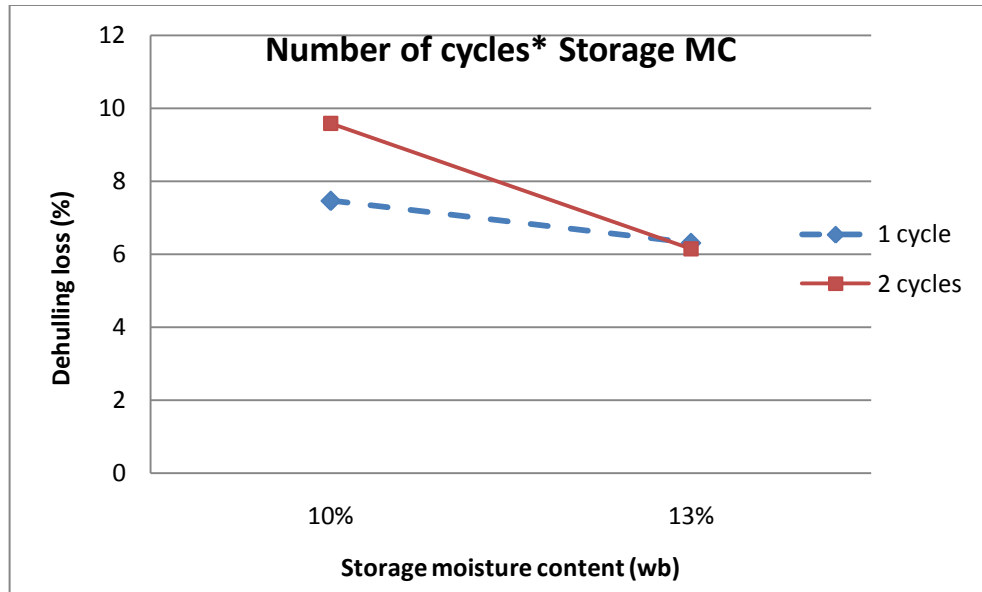
Appendix 42. Least square means plot showing the dehulling loss as affected by pre-milling moisture content and storage pre-treatment for Impact 2008 analyzed with the general factorial design.



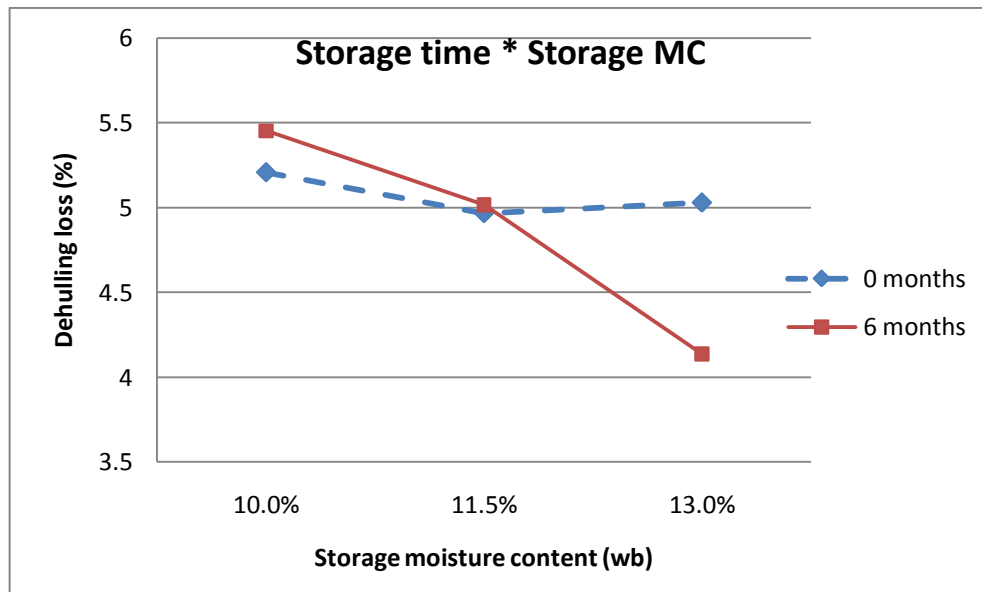
Appendix 43. Least square means plot showing the dehulling loss as affected by storage time and pre-milling moisture content for Redberry 2008 in storage pre-treatment A.



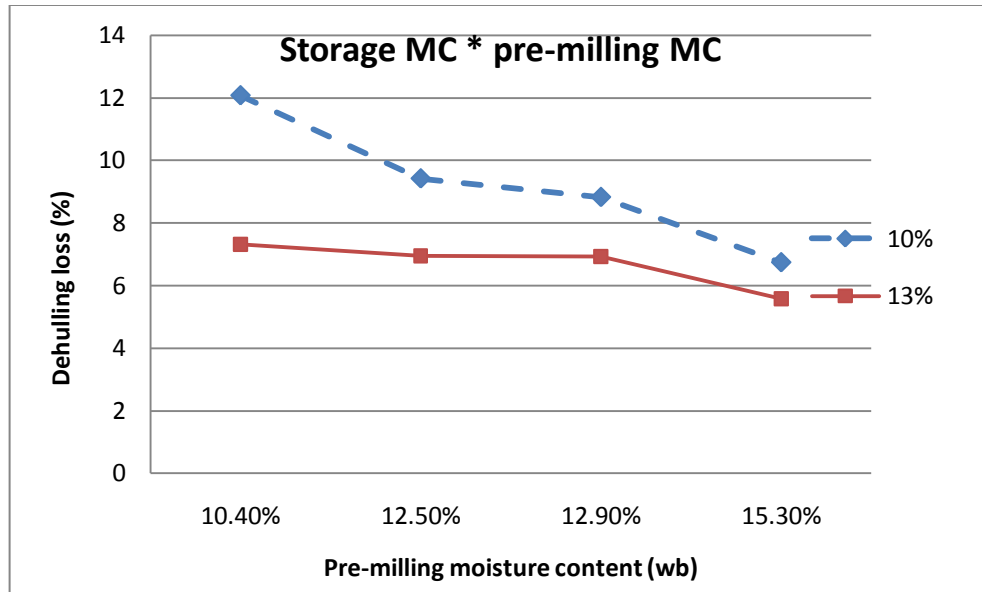
Appendix 44. Least square means plot showing the dehulling loss as affected by storage moisture content and pre-milling moisture content for Redberry 2008 in storage pre-treatment C.



Appendix 45. Least square means plot showing the dehulling loss as affected by storage moisture content and number of cycles for Redberry 2008 in storage pre-treatment C.

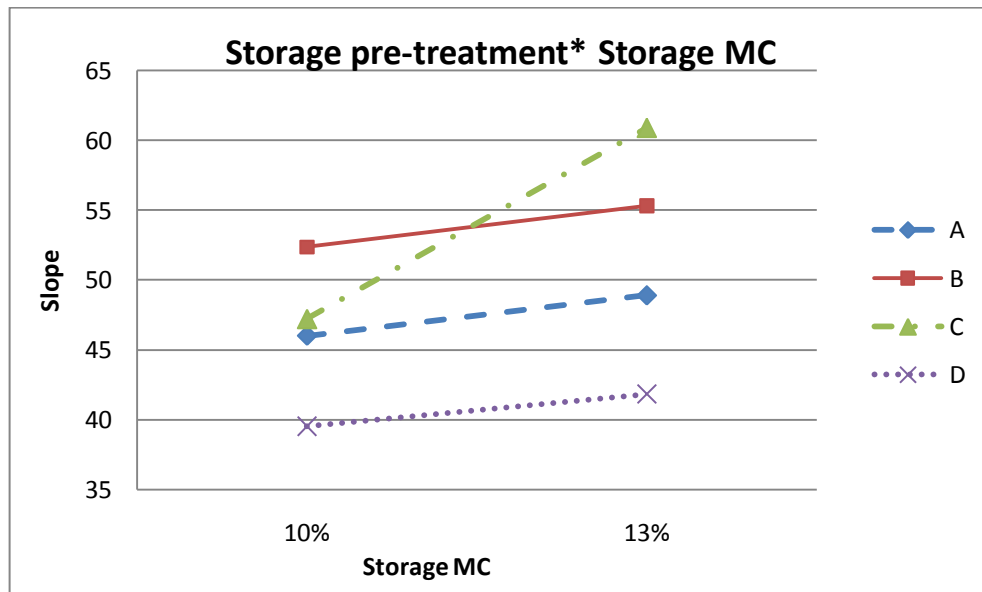


Appendix 46. Least square means plot showing the dehulling loss as affected by storage moisture content and storage time for Redberry 2008 in storage pre-treatment A.

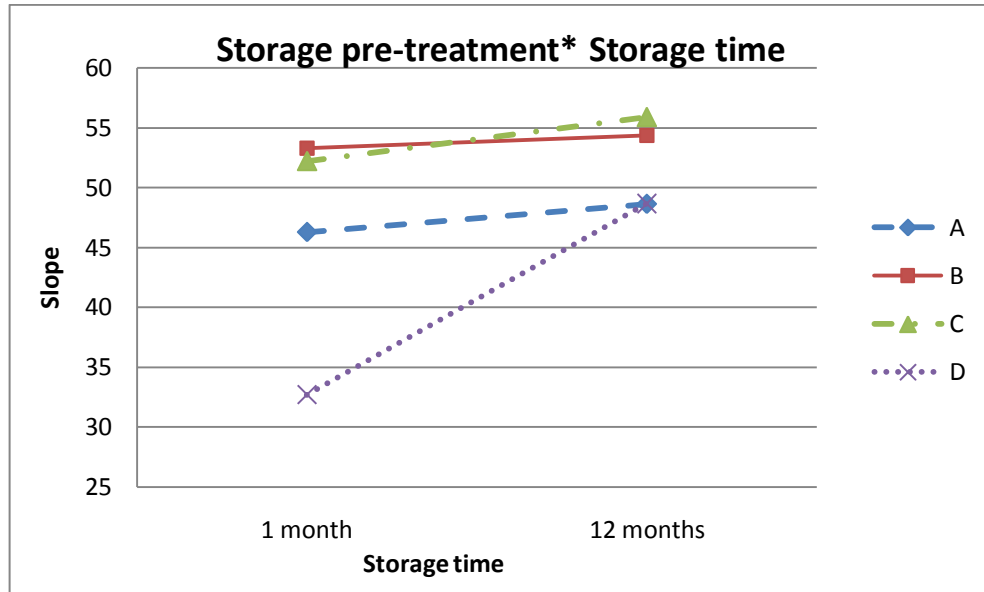


Appendix 47. Least square means plot showing the dehulling loss as affected by storage moisture content and storage time for Redberry 2008 in storage pre-treatment C.

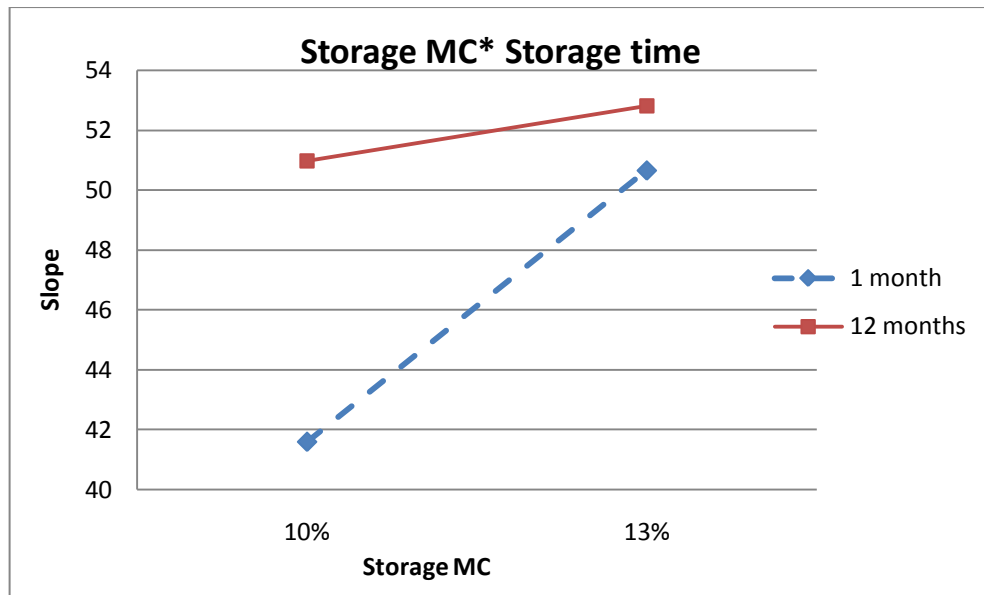
Interactions in the slope of the force-deformation curves of 2007 samples



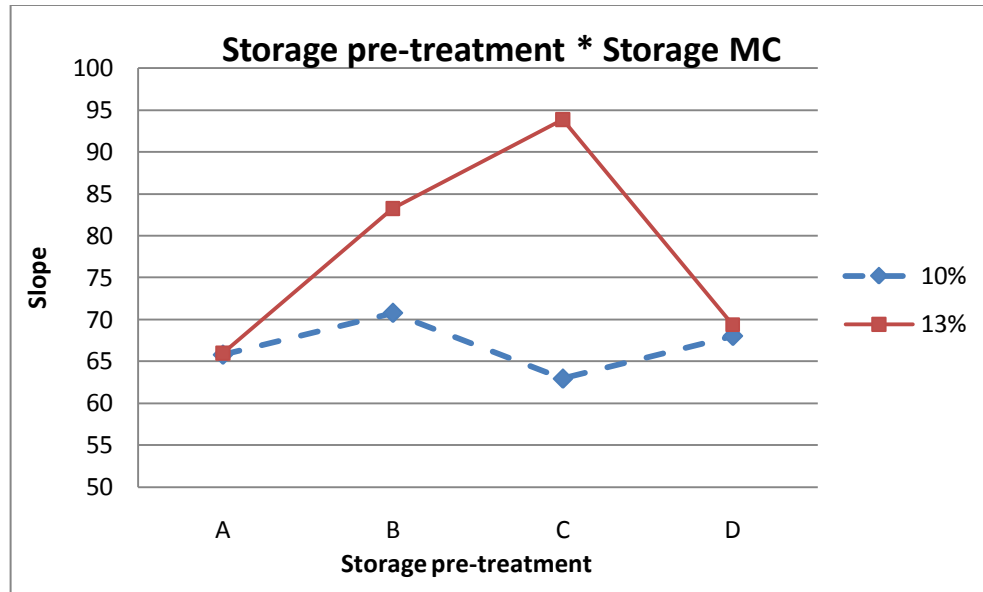
Appendix 48. Least square means plot showing the slope of the force-deformation curves of Redberry 2007 lentils as affected by storage pre-treatment and storage moisture content for samples analyzed with the general factorial design.



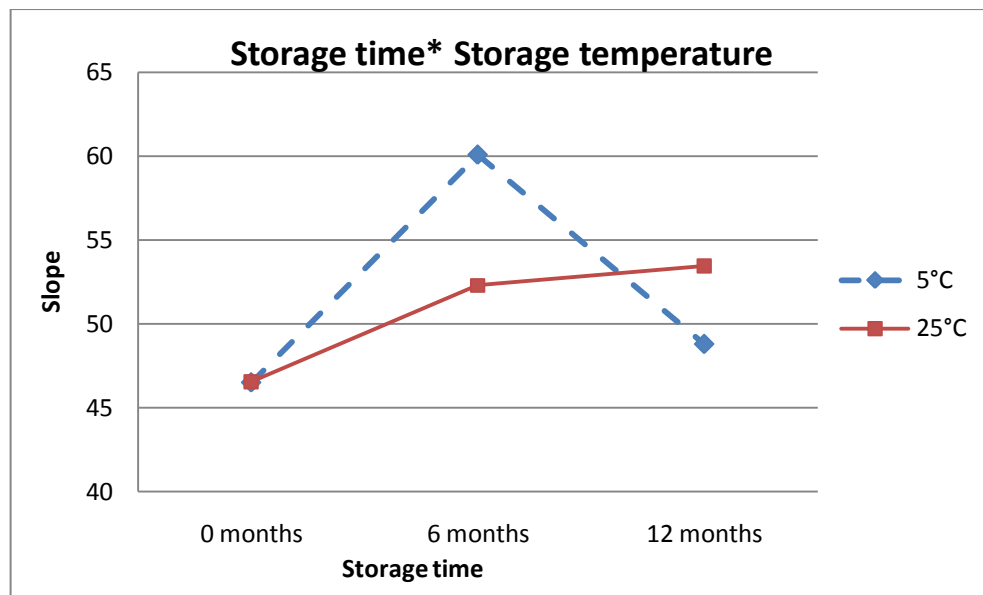
Appendix 49. Least square means plot showing the slope of the force-deformation curves of Redberry 2007 lentils as affected by storage pre-treatment and storage time for samples analyzed with the general factorial design.



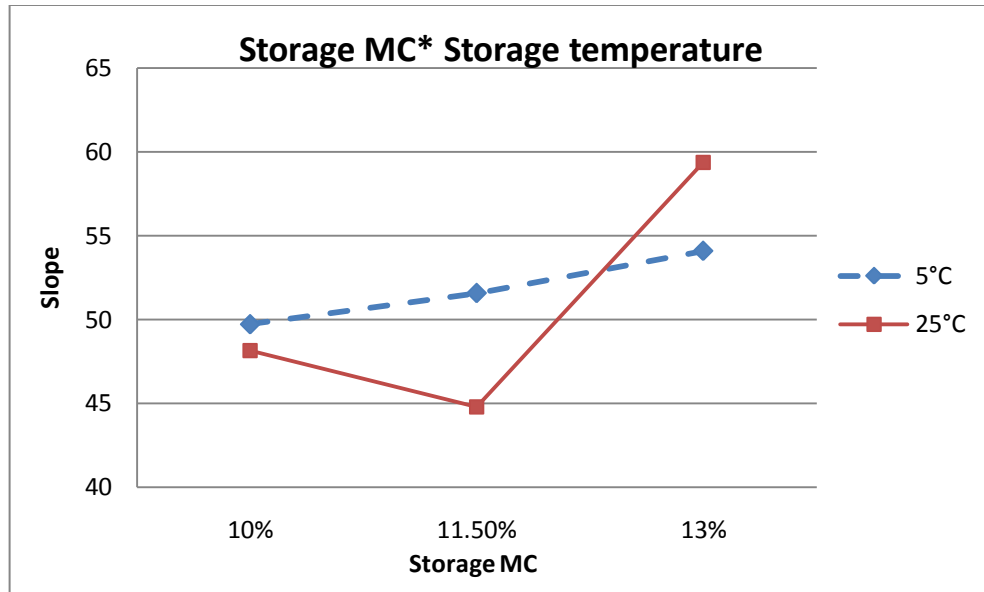
Appendix 50. Least square means plot showing the slope of the force-deformation curves of Redberry 2007 lentils as affected by storage time and storage moisture content for samples analyzed with the general factorial design.



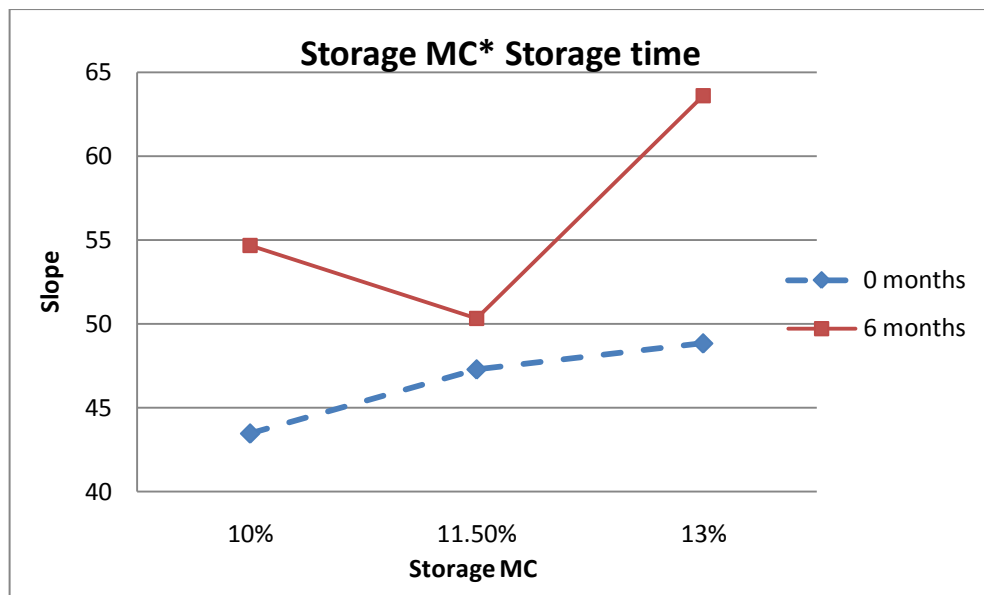
Appendix 51. Least square means plot showing the slope of the force-deformation curves of Impact 2007 lentils as affected by storage pre-treatment and storage moisture content for samples analyzed with the general factorial design.



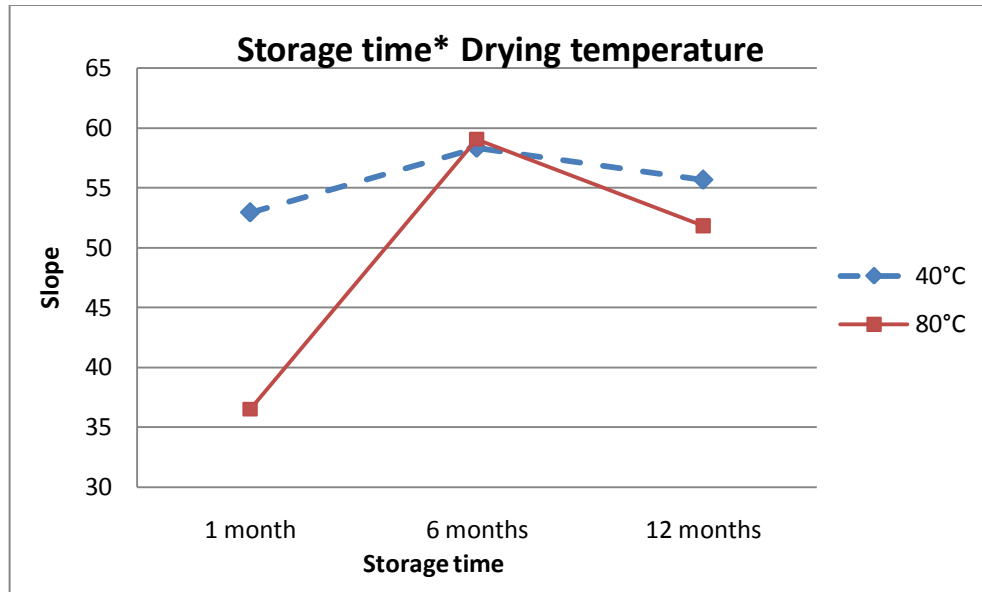
Appendix 52. Least square means plot showing the slope of the force-deformation curves of Redberry 2007 lentils as affected by storage temperature and storage time for samples in storage pre-treatment A.



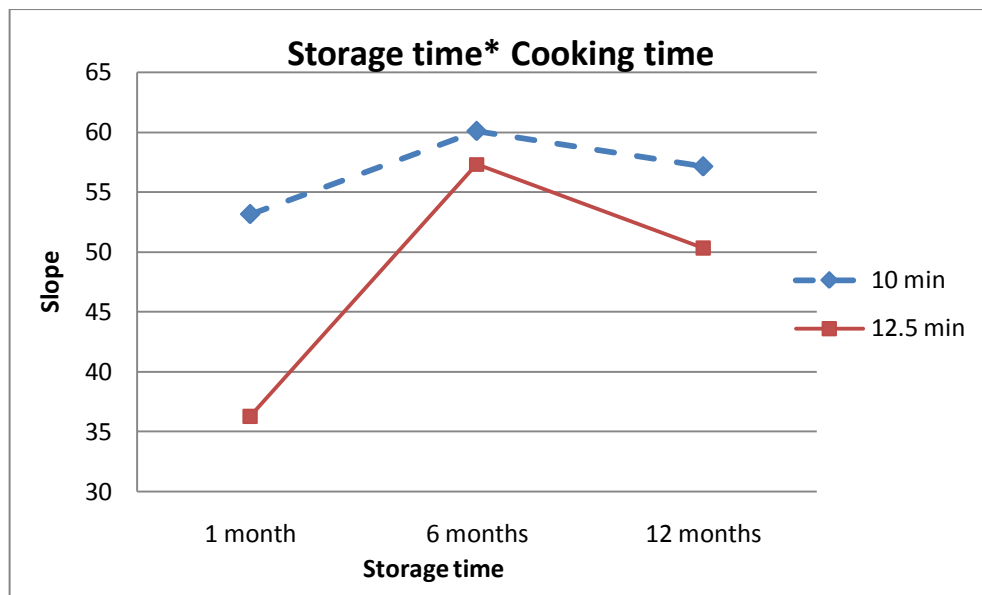
Appendix 53. Least square means plot showing the slope of the force-deformation curves of Redberry 2007 lentils as affected by storage temperature and storage moisture content for samples in storage pre-treatment A.



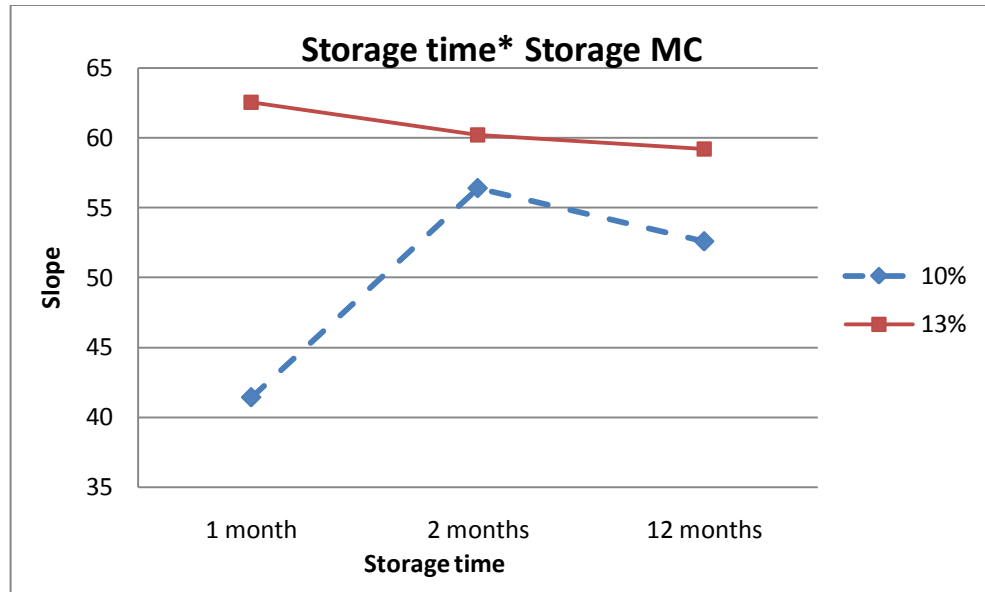
Appendix 54. Least square means plot showing the slope of the force-deformation curves of Redberry 2007 lentils as affected by storage moisture content and storage time for samples in storage pre-treatment A.



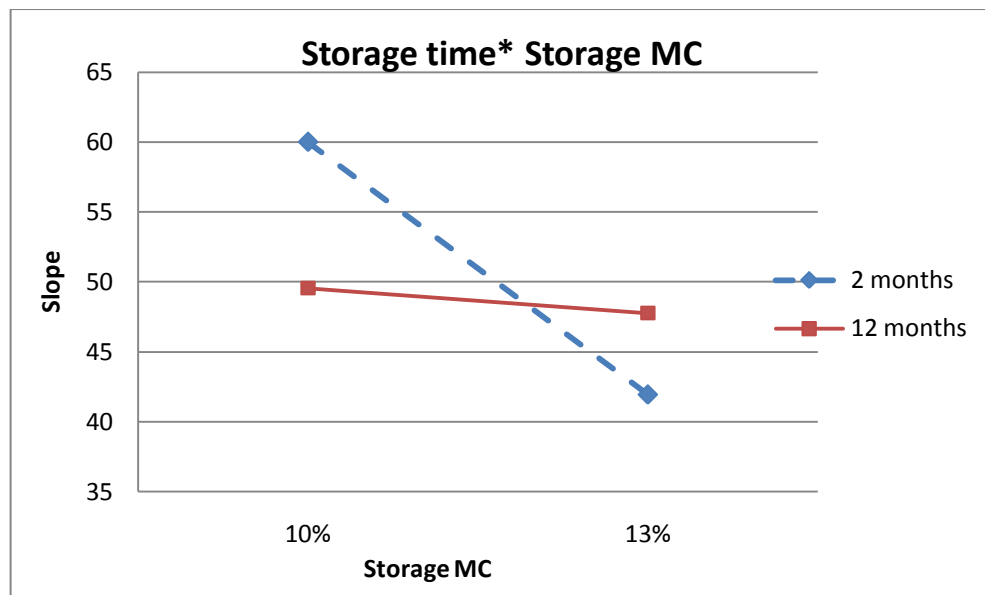
Appendix 55. Least square means plot showing the slope of the force-deformation curves of Redberry 2007 lentils as affected by drying temperature and storage time for samples in storage pre-treatment B.



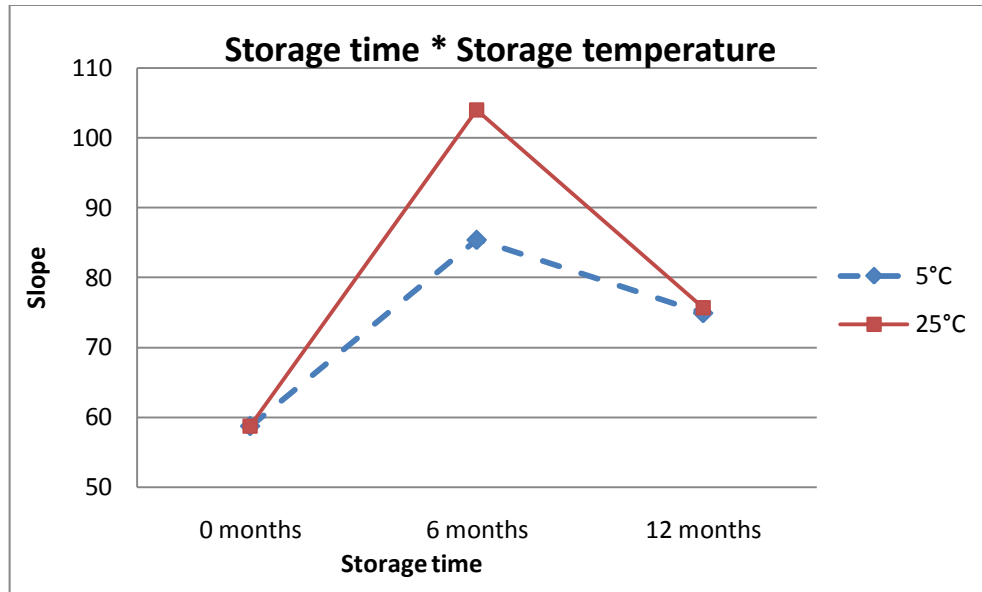
Appendix 56. Least square means plot showing the slope of the force-deformation curves of Redberry 2007 lentils as affected by cooking time and storage time for samples in storage pre-treatment B.



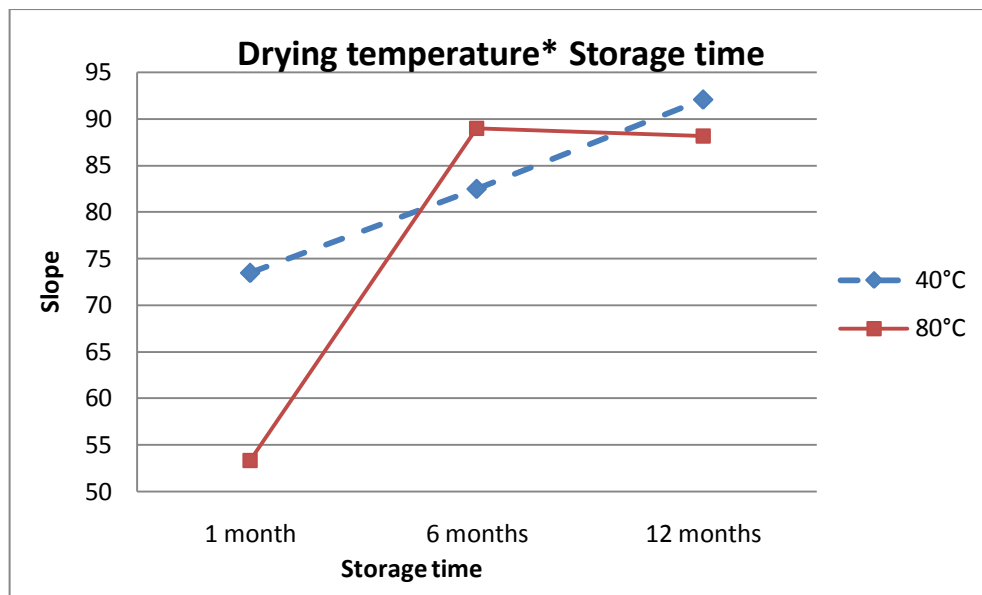
Appendix 57. Least square means plot showing the slope of the force-deformation curves of Redberry 2007 lentils as affected by drying temperature and storage time for samples in storage pre-treatment C.



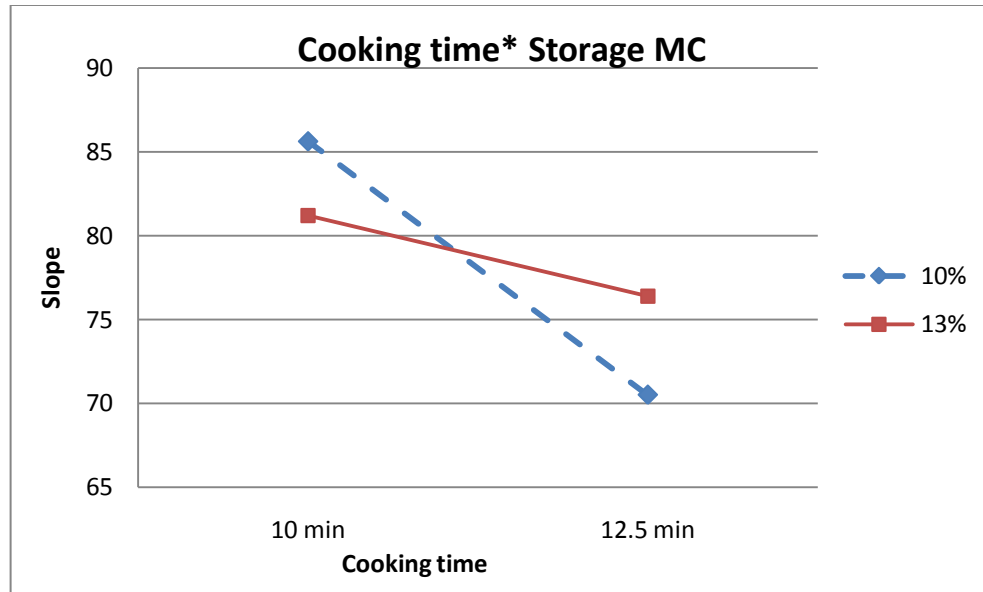
Appendix 58. Least square means plot showing the slope of the force-deformation curves of Redberry 2007 lentils as affected by storage moisture content and storage time for samples in storage pre-treatment D.



Appendix 59. Least square means plot showing the slope of the force-deformation curves of Impact 2007 lentils as affected by storage temperature and storage time for samples in storage pre-treatment A.

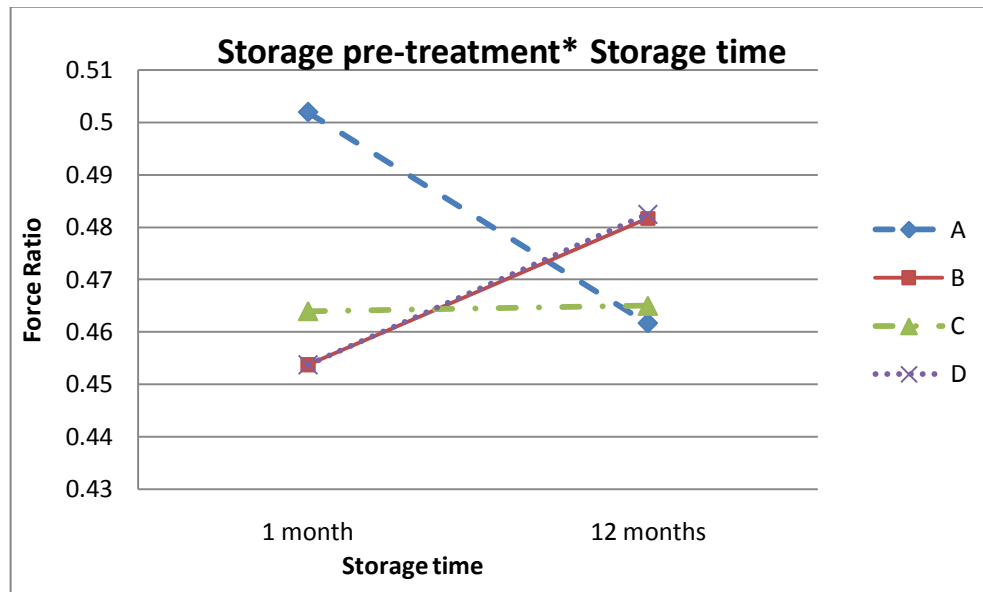


Appendix 60. Least square means plot showing the slope of the force-deformation curves of Impact 2007 lentils as affected by drying temperature and storage time for samples in storage pre-treatment B.

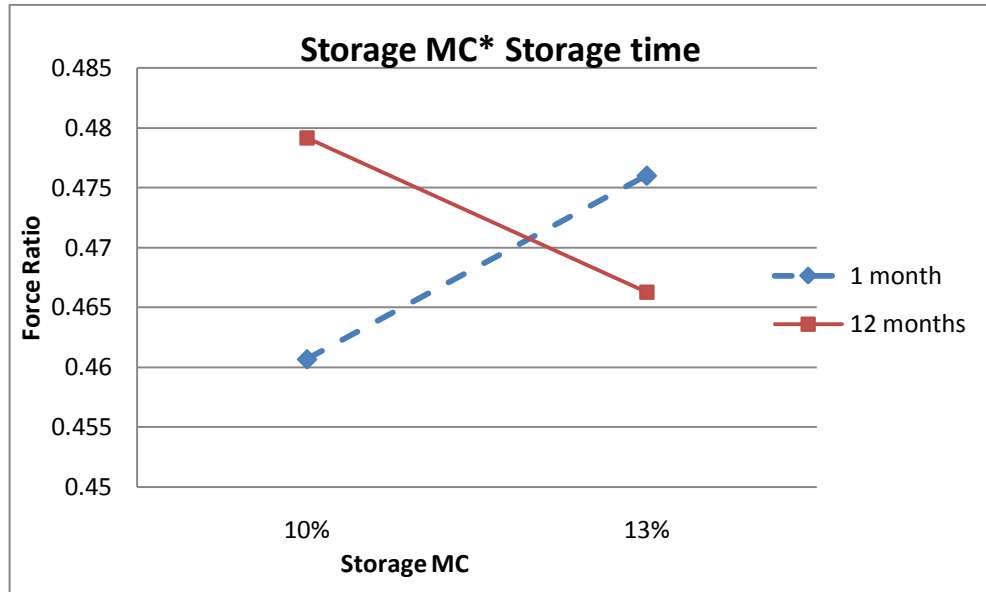


Appendix 61. Least square means plot showing the slope of the force-deformation curves of Impact 2007 lentils as affected by cooking time and storage moisture content for samples in storage pre-treatment D.

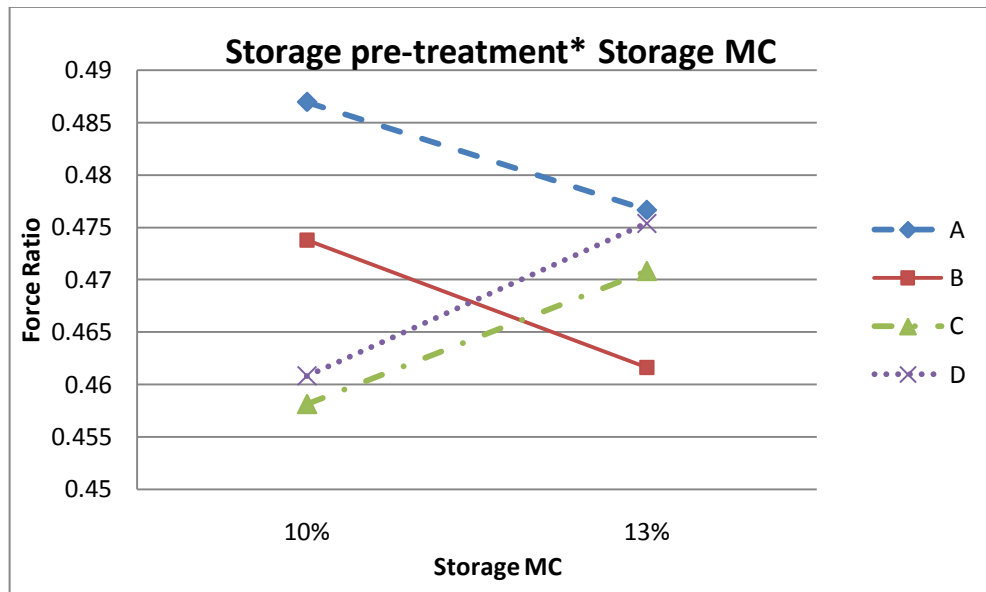
Interactions in the force ratio of 2007 samples



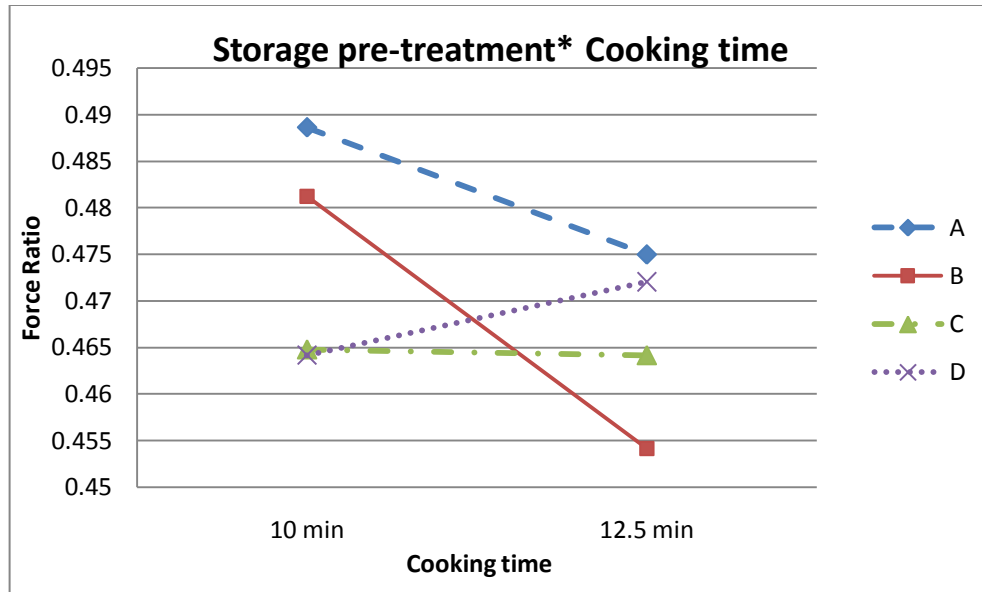
Appendix 62. Least square means plot showing the force ratio of Redberry 2007 lentils as affected by storage time and storage pre-treatment for samples analyzed with the general factorial design.



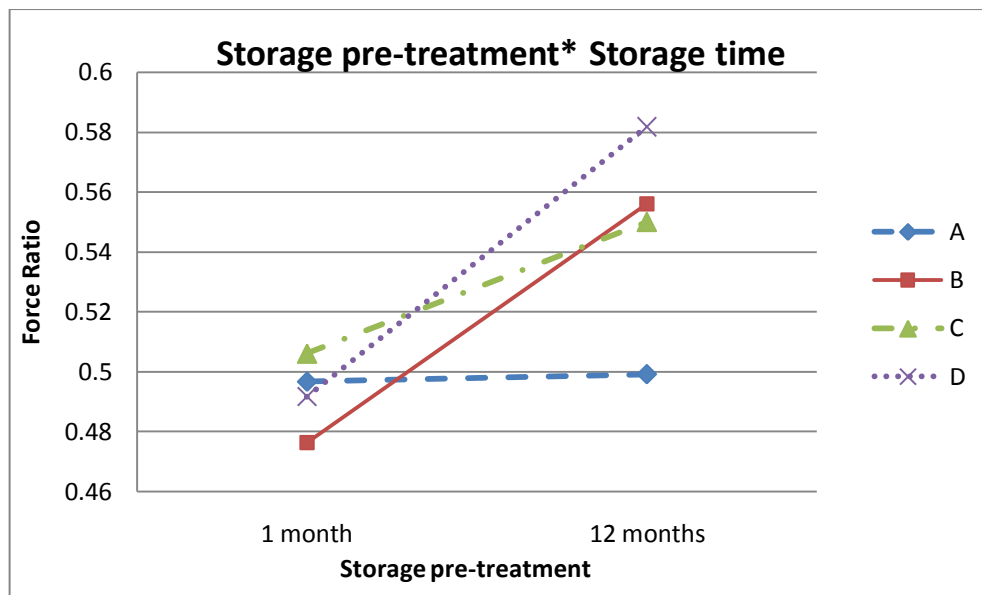
Appendix 63. Least square means plot showing the force ratio of Redberry 2007 lentils as affected by storage time and storage moisture content for samples analyzed with the general factorial design.



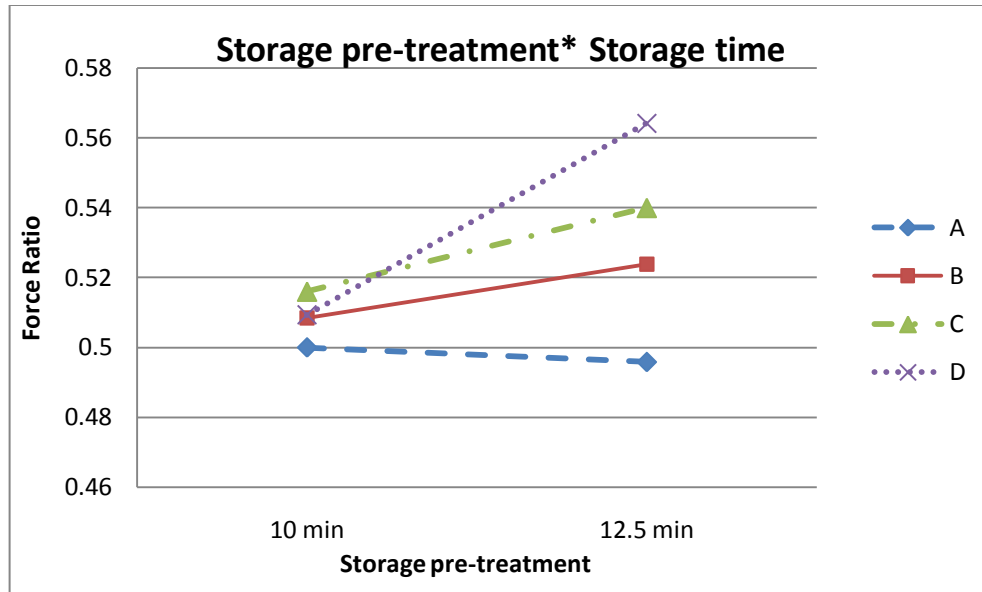
Appendix 64. Least square means plot showing the force ratio of Redberry 2007 lentils as affected by storage pre-treatment and storage moisture content for samples analyzed with the general factorial design.



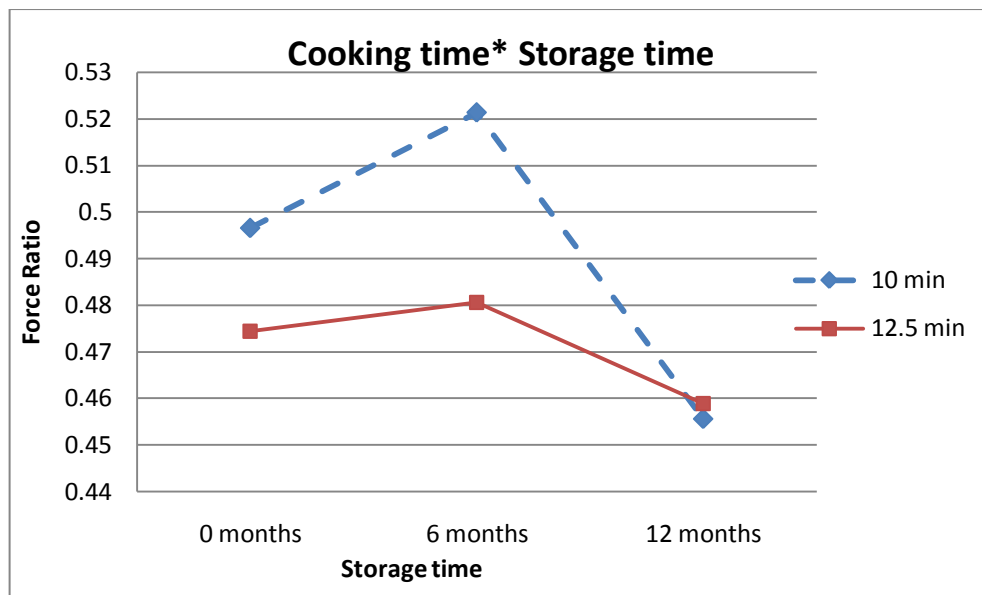
Appendix 65. Least square means plot showing the force ratio of Redberry 2007 lentils as affected by storage pre-treatment and cooking time for samples analyzed with the general factorial design.



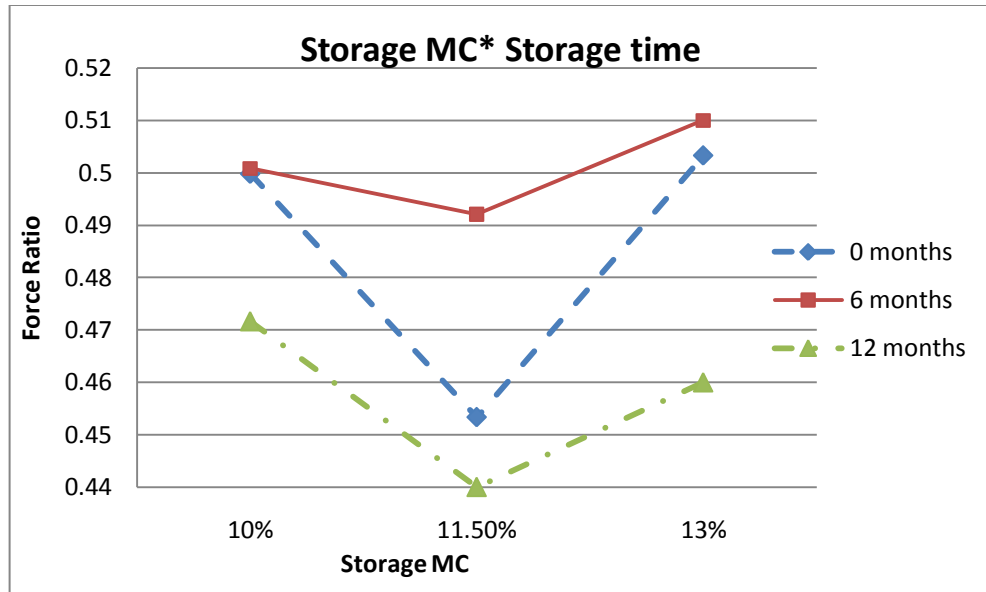
Appendix 66. Least square means plot showing the force ratio of Impact 2007 lentils as affected by storage pre-treatment and storage time for samples analyzed with the general factorial design.



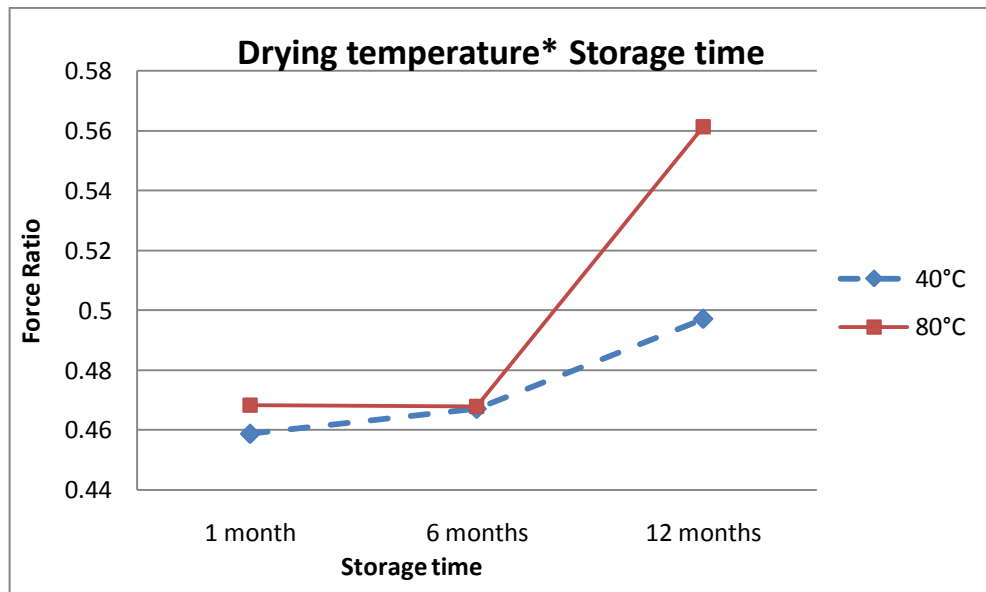
Appendix 67. Least square means plot showing the force ratio of Impact 2007 lentils as affected by storage pre-treatment and storage time for samples analyzed with the general factorial design.



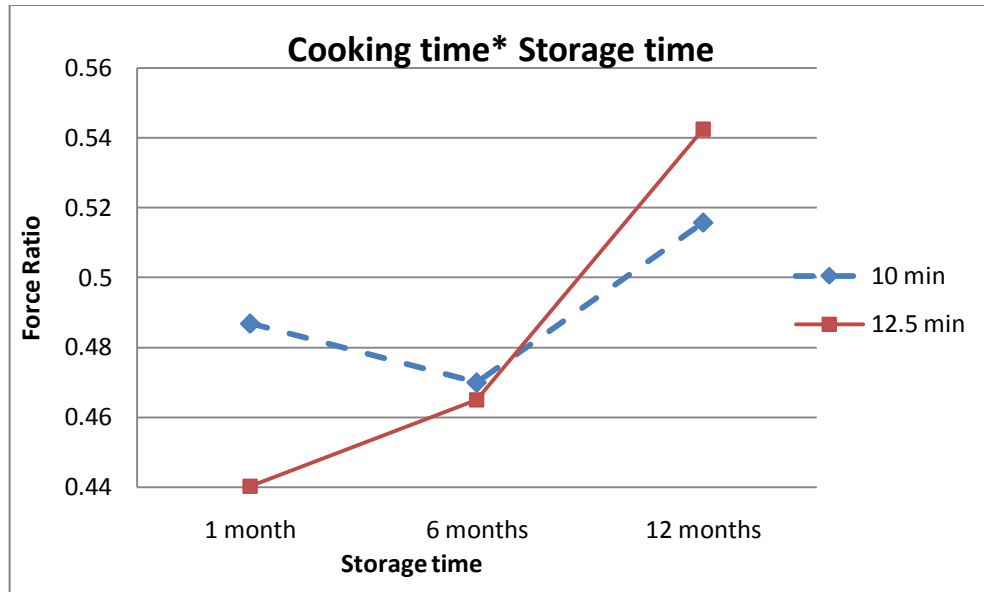
Appendix 68. Least square means plot showing the force ratio of Redberry 2007 lentils as affected by cooking time and storage time for samples in storage pre-treatment A.



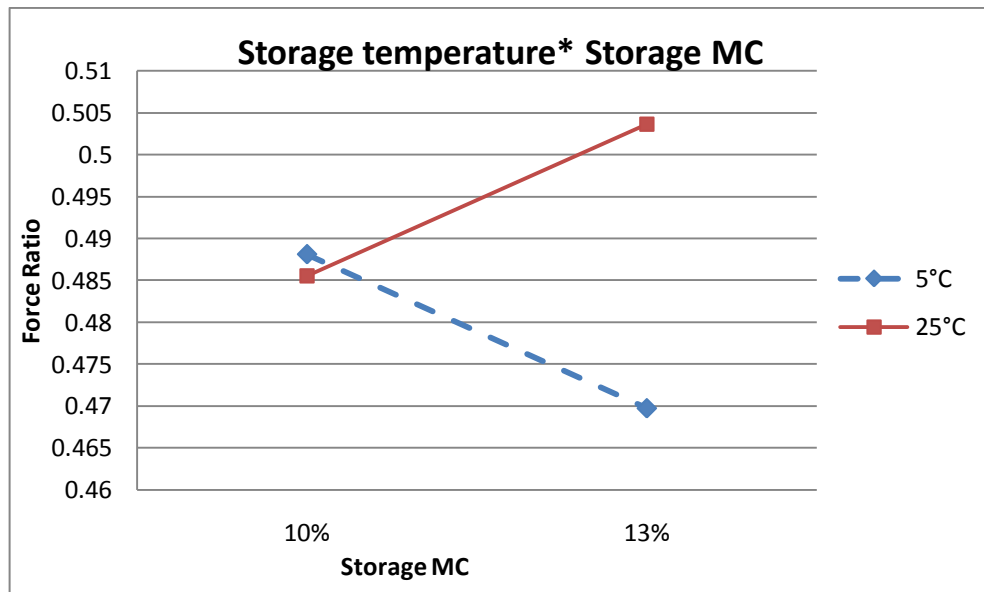
Appendix 69. Least square means plot showing the force ratio of Redberry 2007 lentils as affected by cooking time and storage time for samples in storage pre-treatment A.



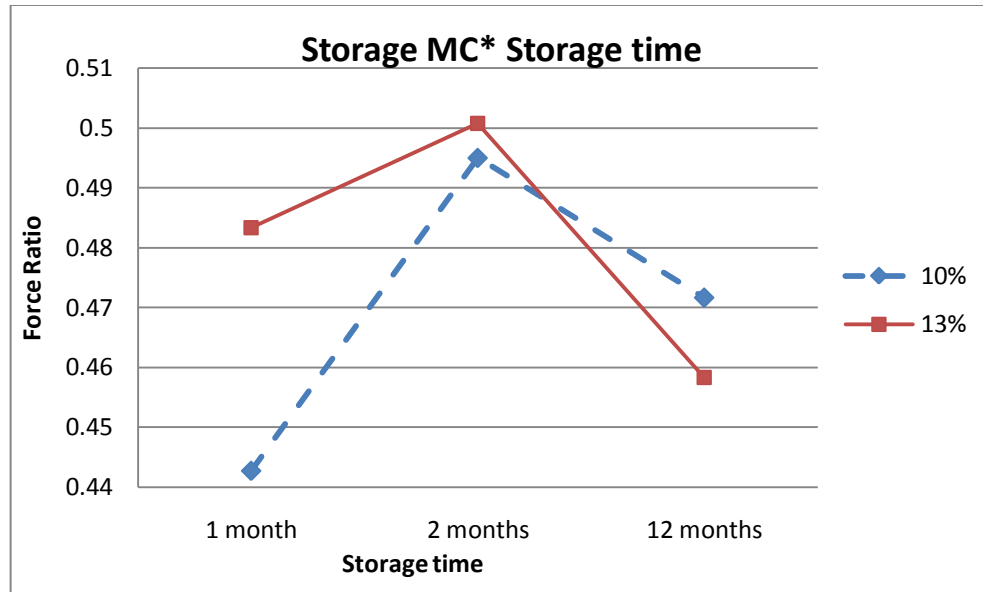
Appendix 70. Least square means plot showing the force ratio of Redberry 2007 lentils as affected by drying temperature and storage time for samples in storage pre-treatment B.



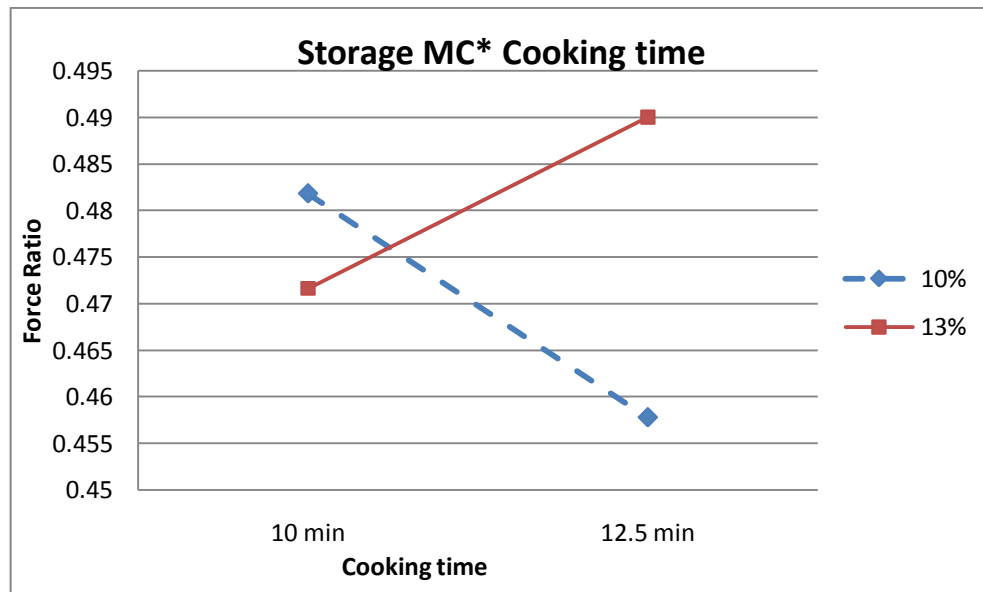
Appendix 71. Least square means plot showing the force ratio of Redberry 2007 lentils as affected by drying temperature and storage time for samples in storage pre-treatment B.



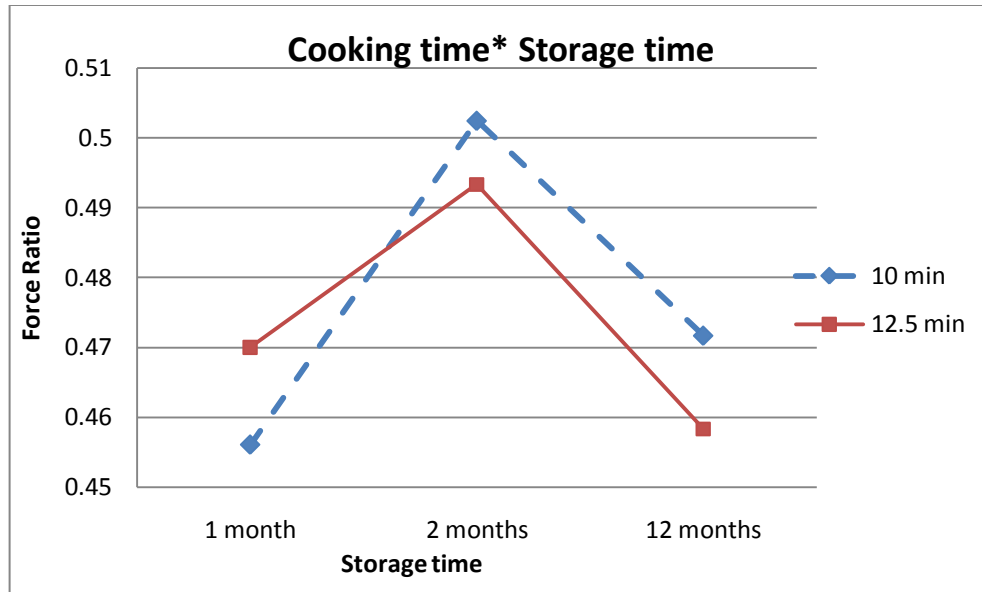
Appendix 72. Least square means plot showing the force ratio of Redberry 2007 lentils as affected by storage temperature and storage moisture content for samples in storage pre-treatment B.



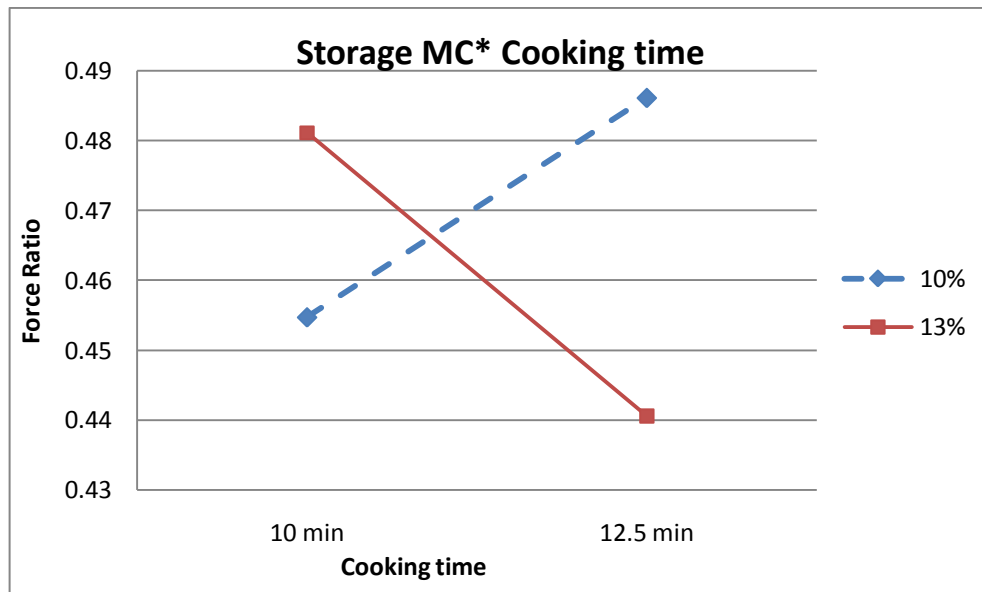
Appendix 73. Least square means plot showing the force ratio of Redberry 2007 lentils as affected by storage time and storage moisture content for samples in storage pre-treatment C.



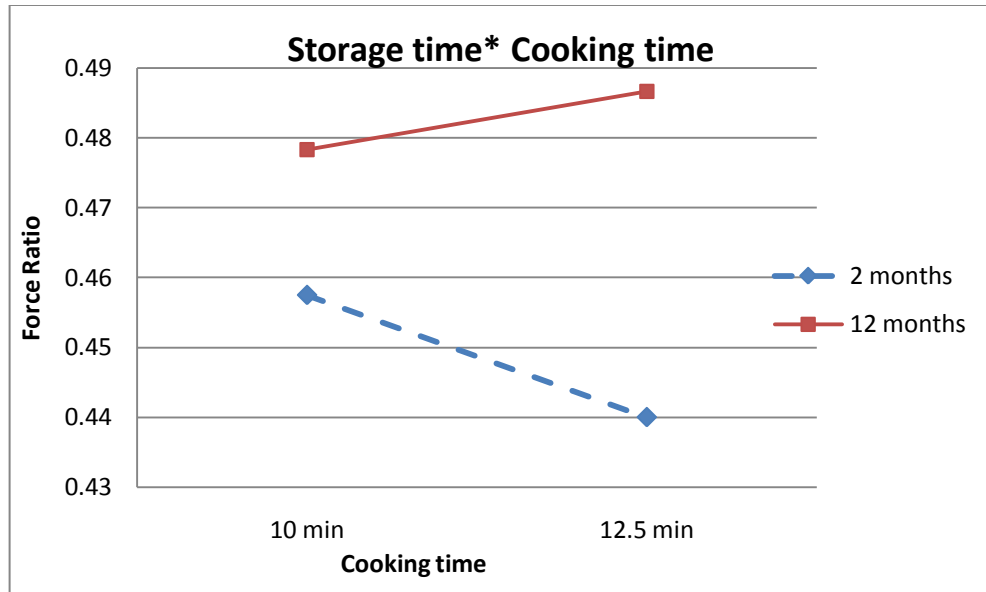
Appendix 74. Least square means plot showing the force ratio of Redberry 2007 lentils as affected by cooking time and storage moisture content for samples in storage pre-treatment C.



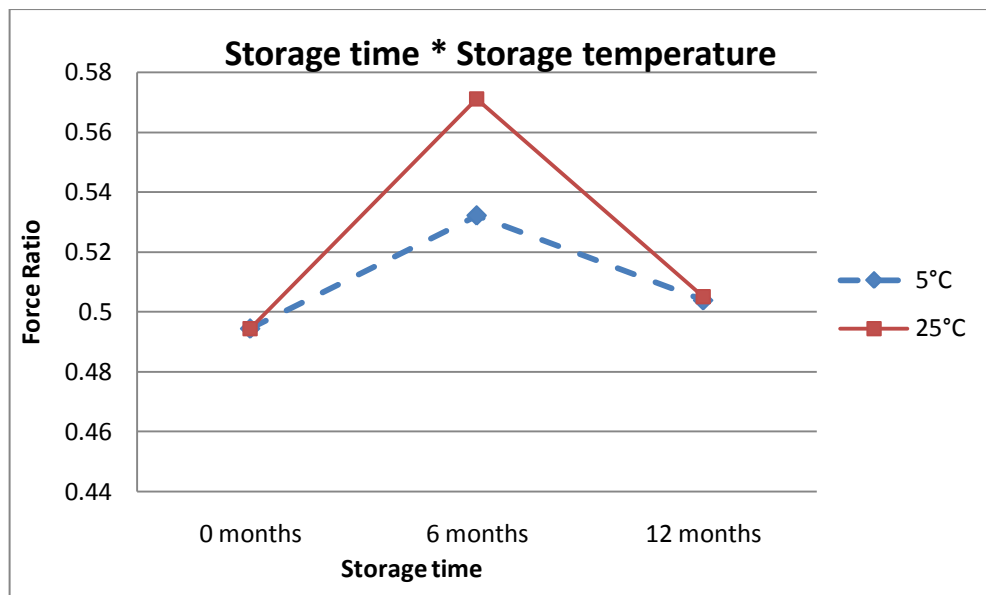
Appendix 75. Least square means plot showing the force ratio of Redberry 2007 lentils as affected by storage time and cooking time for samples in storage pre-treatment C.



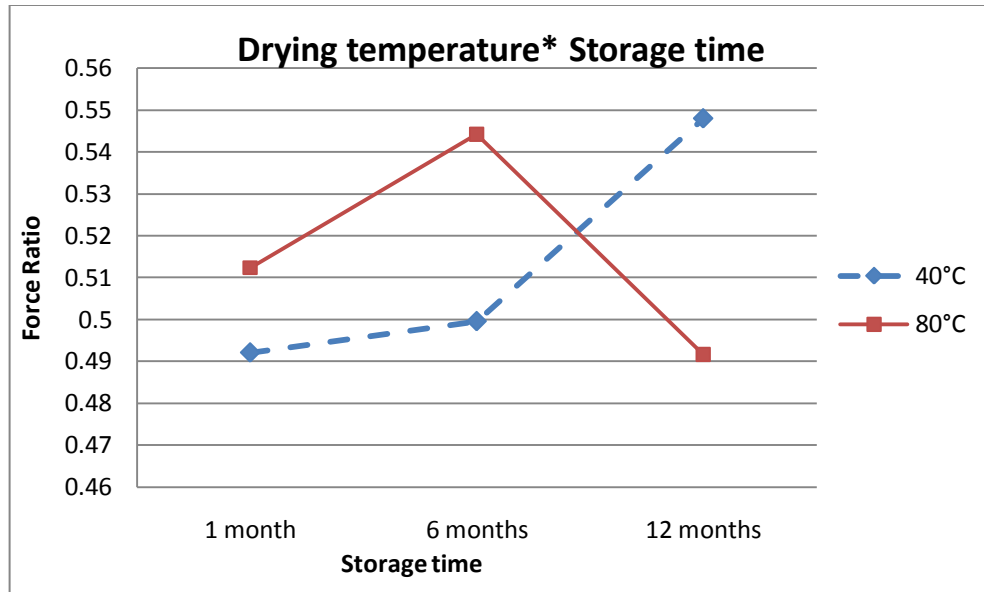
Appendix 76. Least square means plot showing the force ratio of Redberry 2007 lentils as affected by storage moisture content and cooking time for samples in storage pre-treatment D.



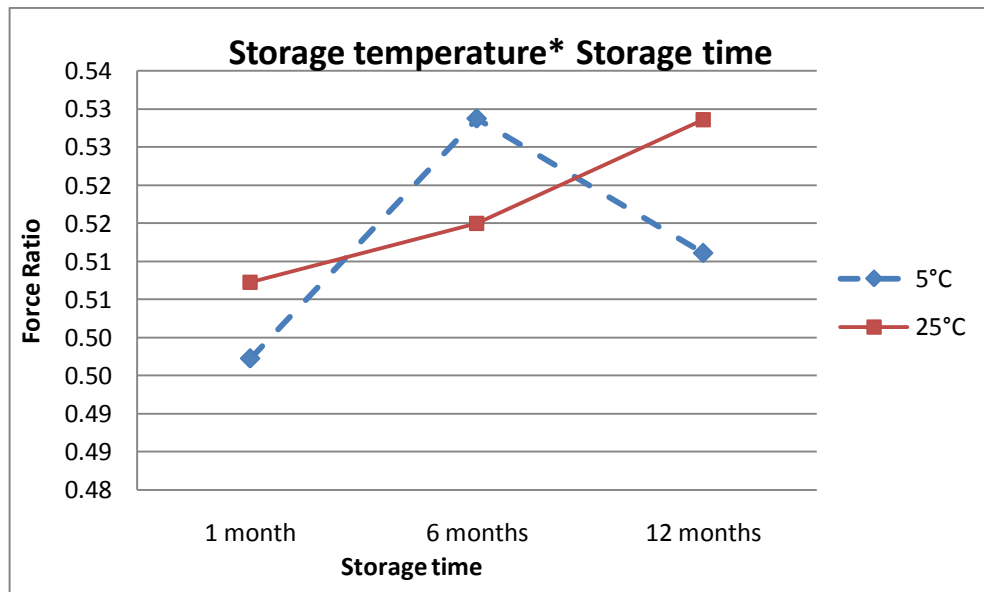
Appendix 77. Least square means plot showing the force ratio of Redberry 2007 lentils as affected by storage moisture content and cooking time for samples in storage pre-treatment D.



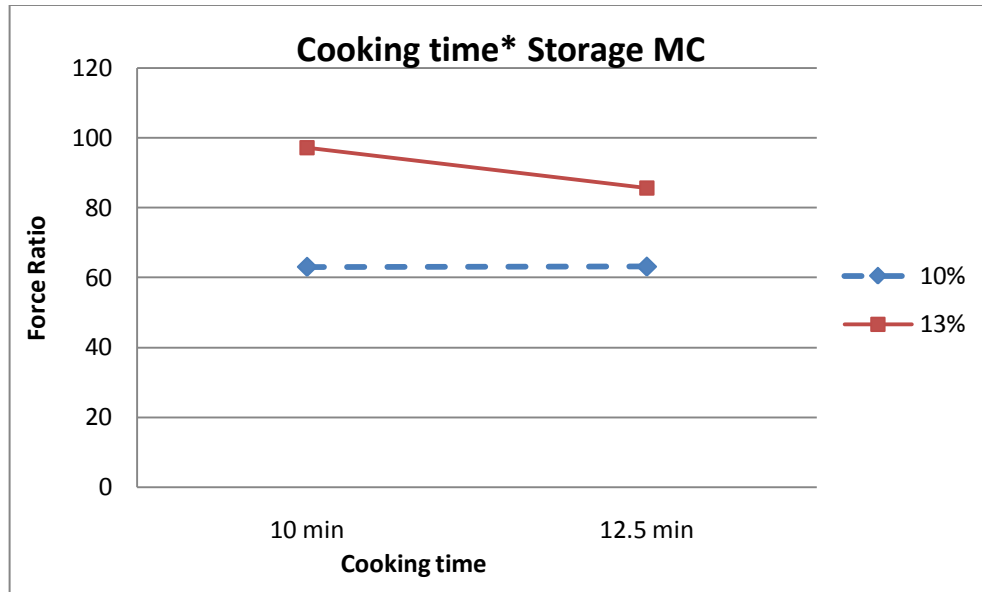
Appendix 78. Least square means plot showing the force ratio of Impact 2007 lentils as affected by storage temperature and storage time for samples in storage pre-treatment A.



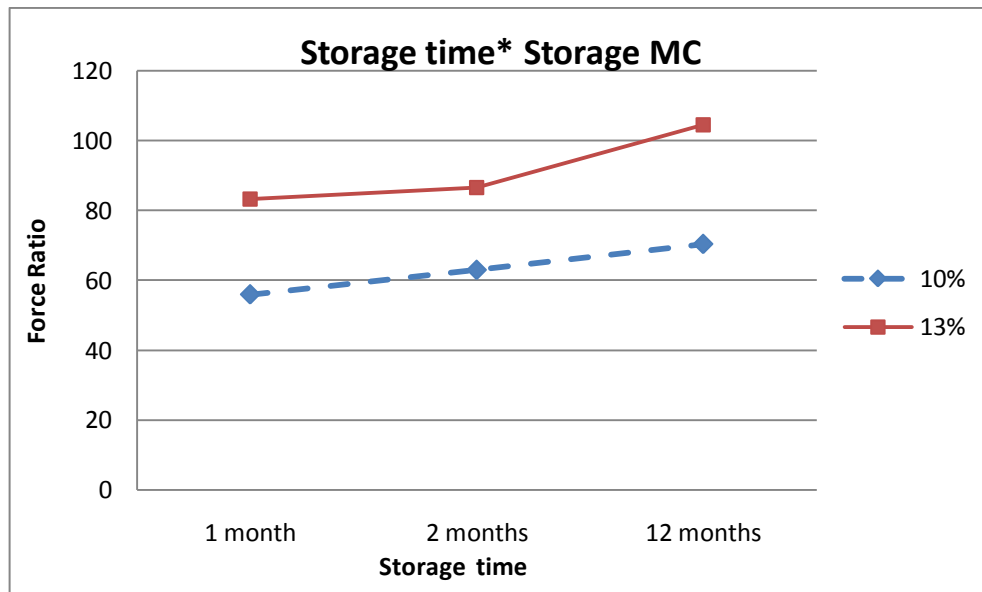
Appendix 79. Least square means plot showing the force ratio of Impact 2007 lentils as affected by drying temperature and storage time for samples in storage pre-treatment B.



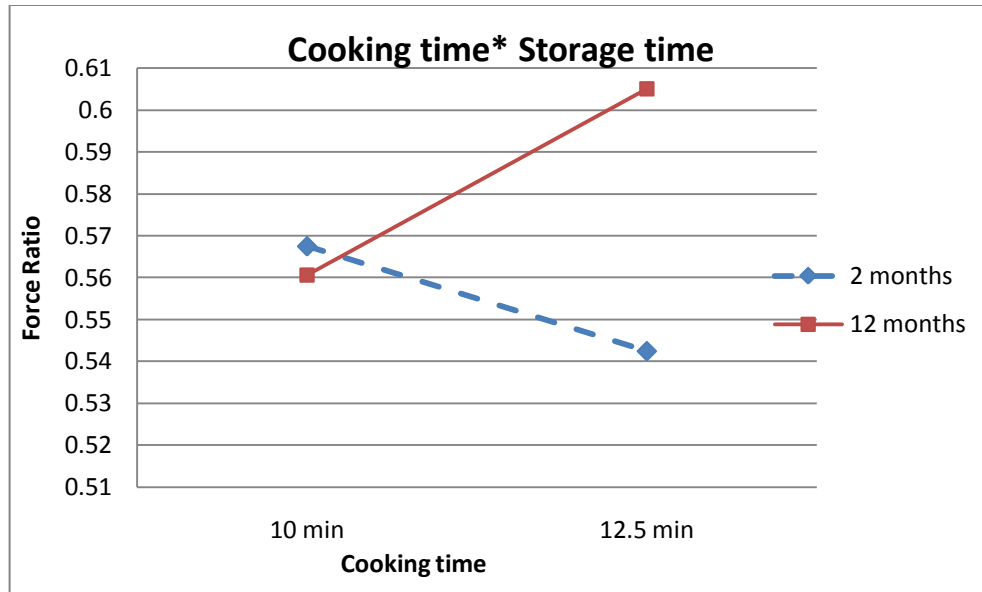
Appendix 80. Least square means plot showing the force ratio of Impact 2007 lentils as affected by storage temperature and storage time for samples in storage pre-treatment B.



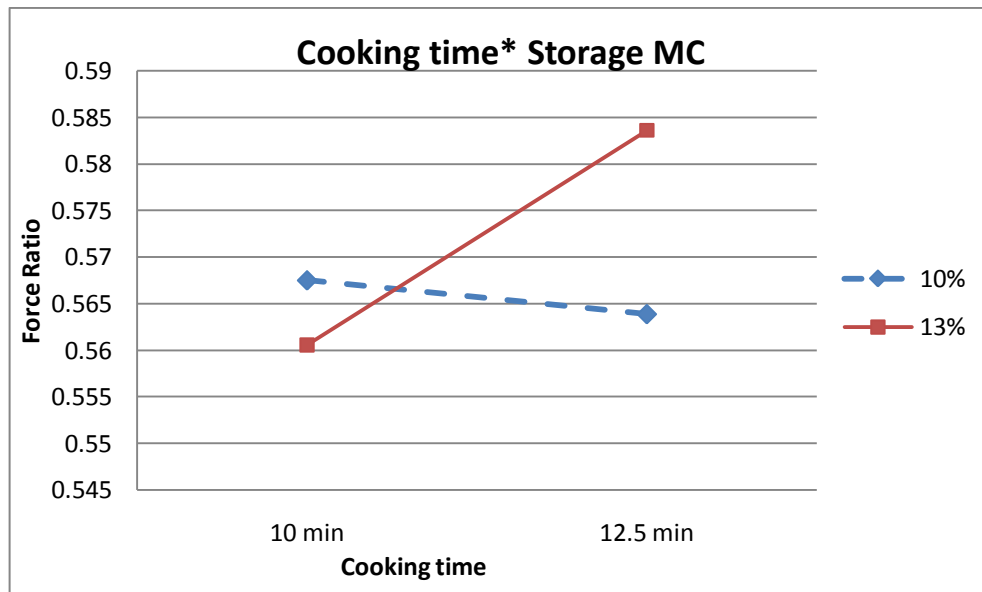
Appendix 81. Least square means plot showing the force ratio of Impact 2007 lentils as affected by storage moisture content and cooking time for samples in storage pre-treatment C.



Appendix 82. Least square means plot showing the force ratio of Impact 2007 lentils as affected by storage moisture content and storage time for samples in storage pre-treatment C.

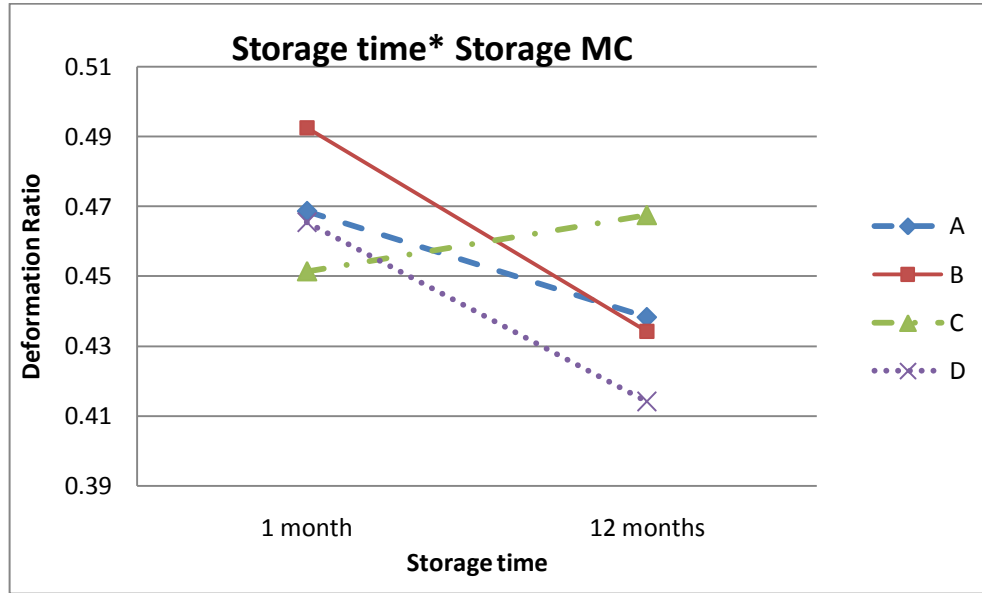


Appendix 83. Least square means plot showing the force ratio of Impact 2007 lentils as affected by cooking time and storage time for samples in storage pre-treatment D.

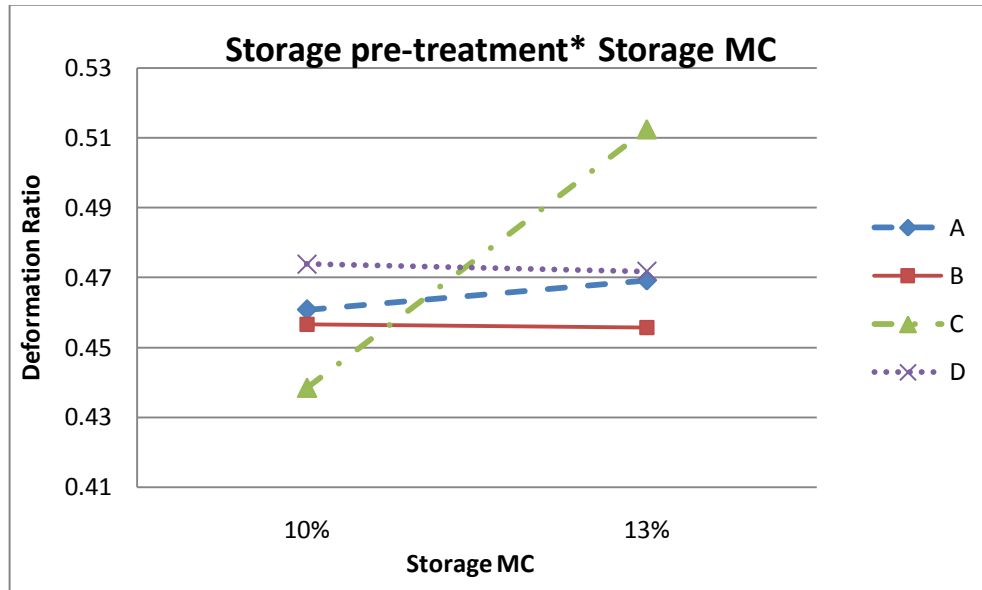


Appendix 84. Least square means plot showing the force ratio of Impact 2007 lentils as affected by cooking time and storage moisture content for samples in storage pre-treatment D.

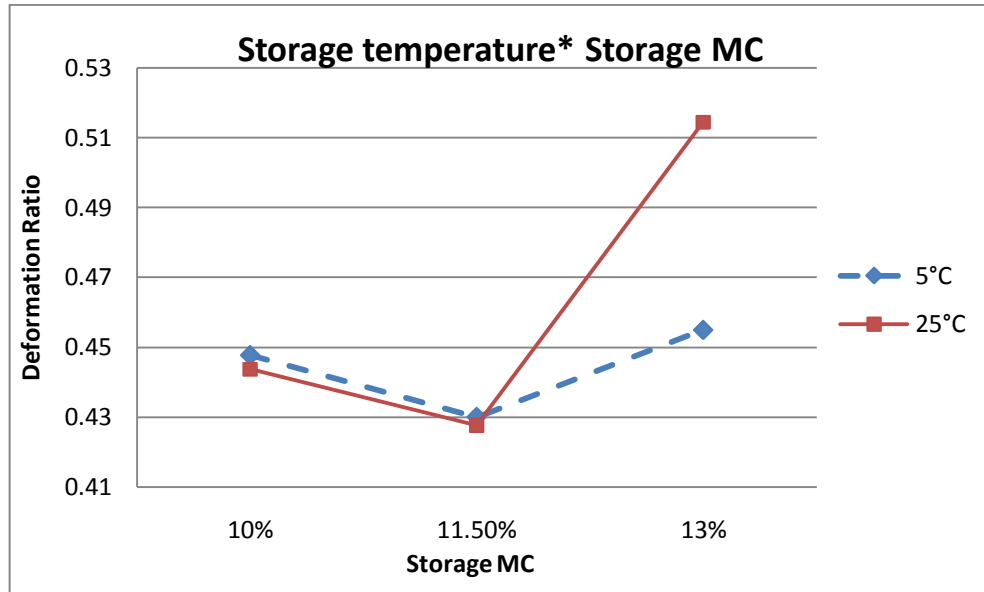
Interactions in the deformation ratio of 2007 samples



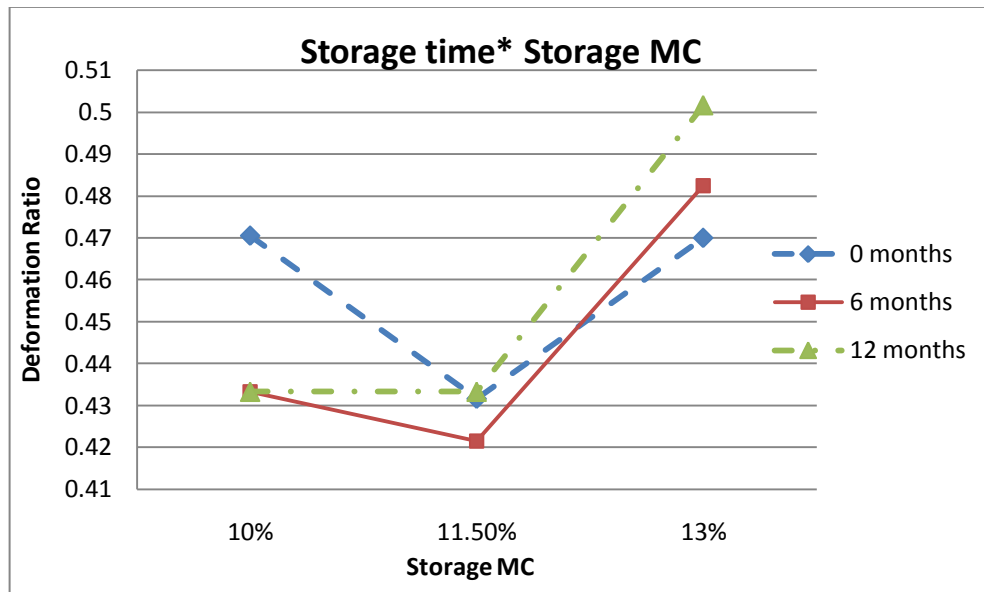
Appendix 85. Least square means plot showing the deformation ratio of Redberry 2007 lentils as affected by storage moisture content and storage time for samples analyzed with the general factorial design.



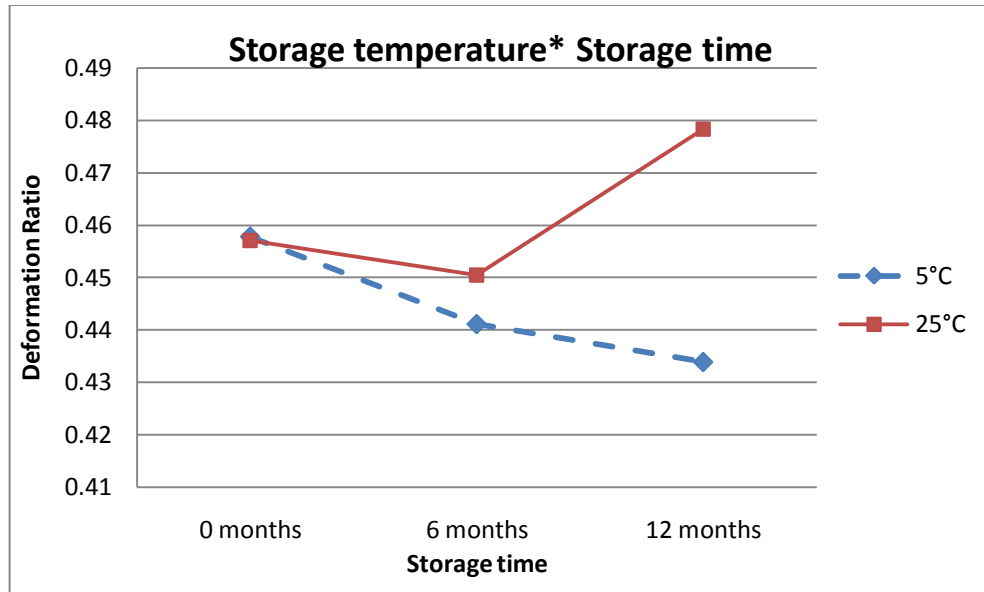
Appendix 86. Least square means plot showing the deformation ratio of Impact 2007 lentils as affected by storage moisture content and storage pre-treatment for samples analyzed with the general factorial design.



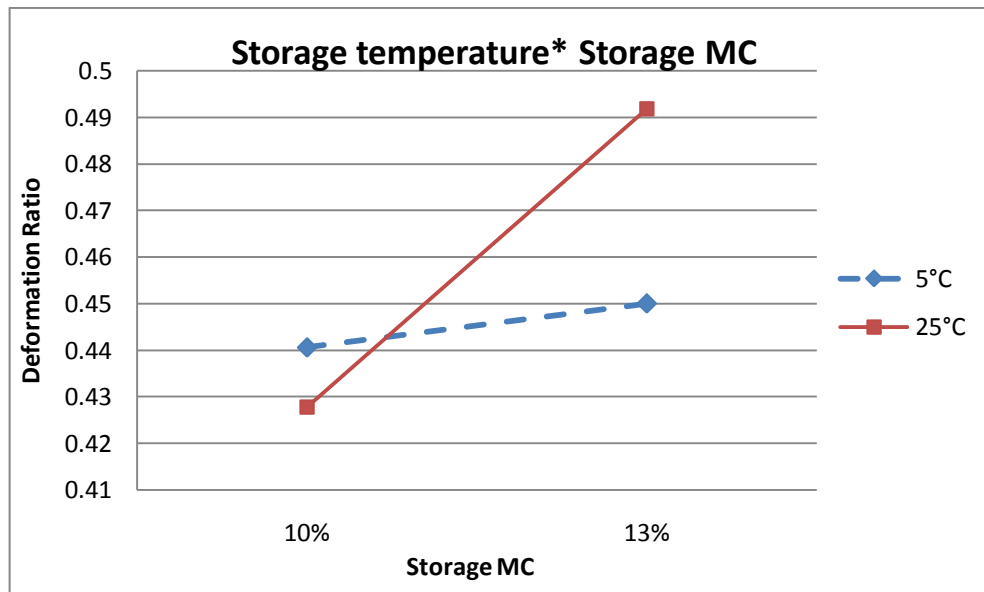
Appendix 87. Least square means plot showing the deformation ratio of Redberry 2007 lentils as affected by storage temperature and storage moisture content for samples in storage pre-treatment A.



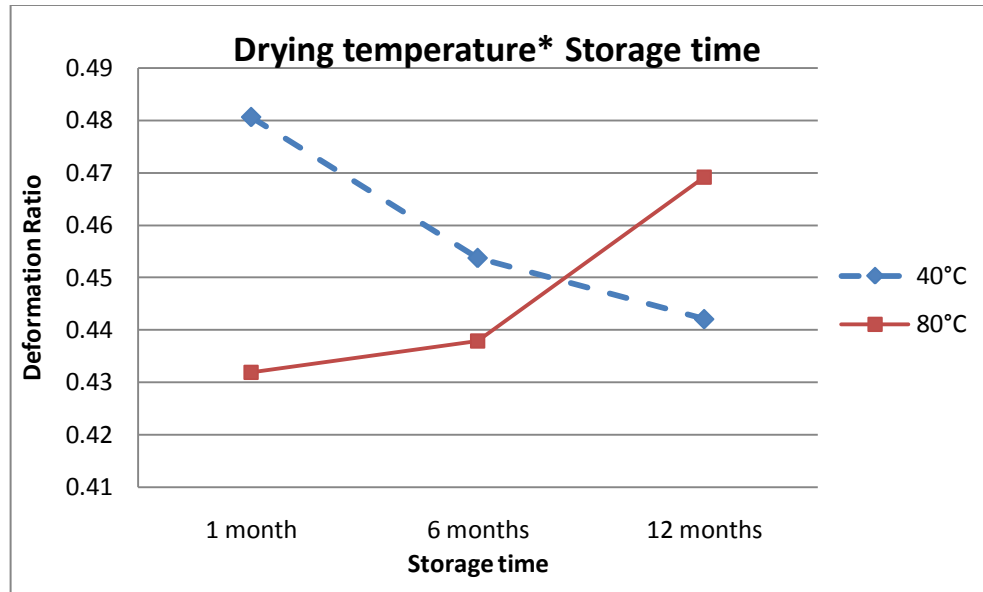
Appendix 88. Least square means plot showing the deformation ratio of Redberry 2007 lentils as affected by storage time and storage moisture content for samples in storage pre-treatment A.



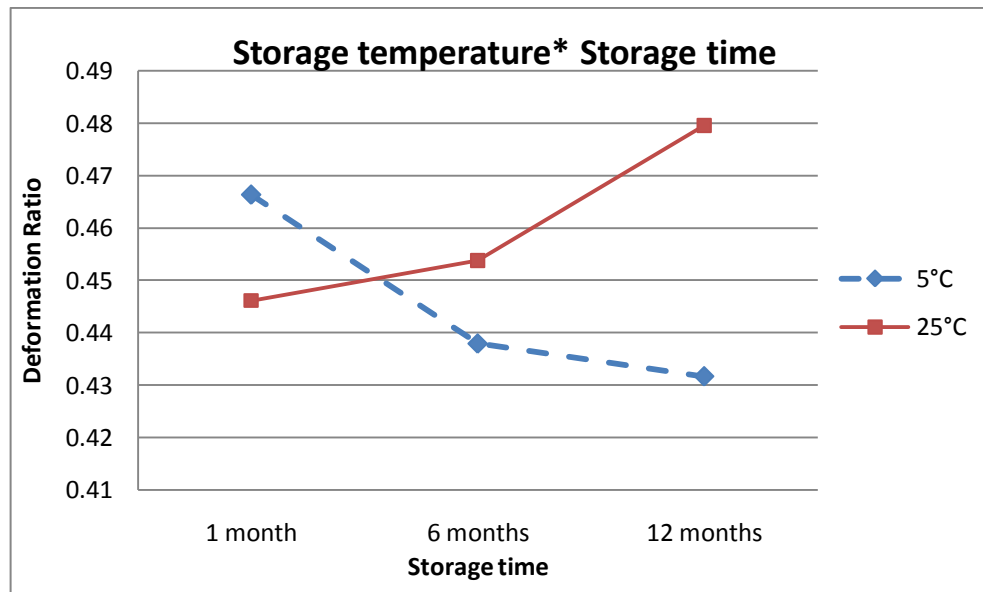
Appendix 89. Least square means plot showing the deformation ratio of Redberry 2007 lentils as affected by storage time and storage temperature for samples in storage pre-treatment A.



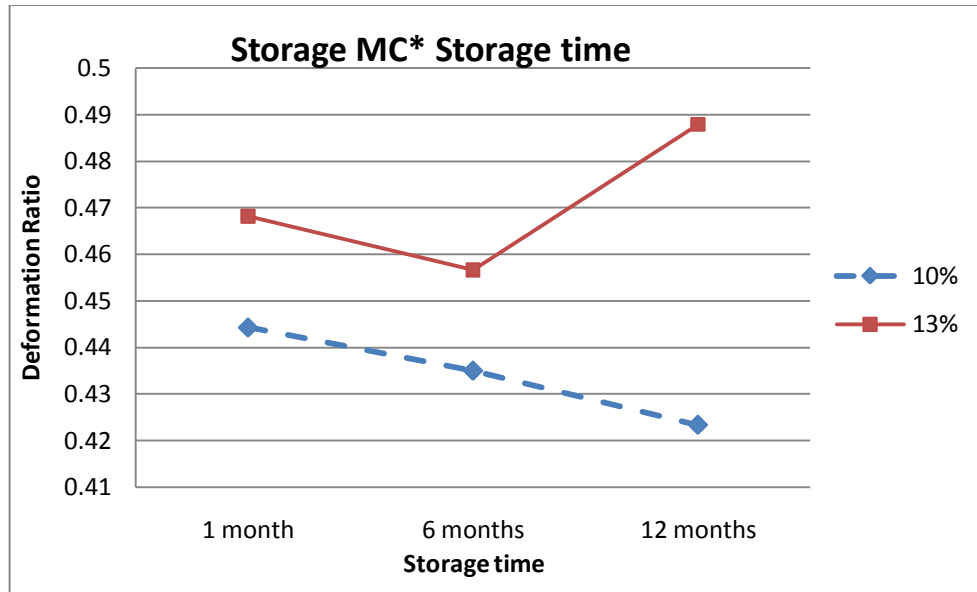
Appendix 90. Least square means plot showing the deformation ratio of Redberry 2007 lentils as affected by storage moisture content and storage temperature for samples in storage pre-treatment B.



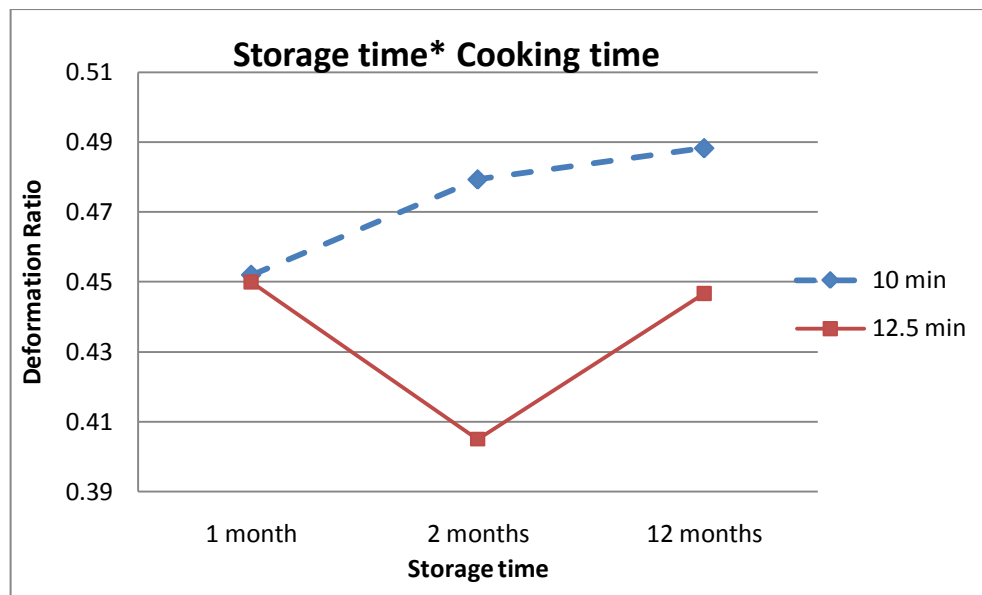
Appendix 91. Least square means plot showing the deformation ratio of Redberry 2007 lentils as affected by storage time and drying temperature for samples in storage pre-treatment B.



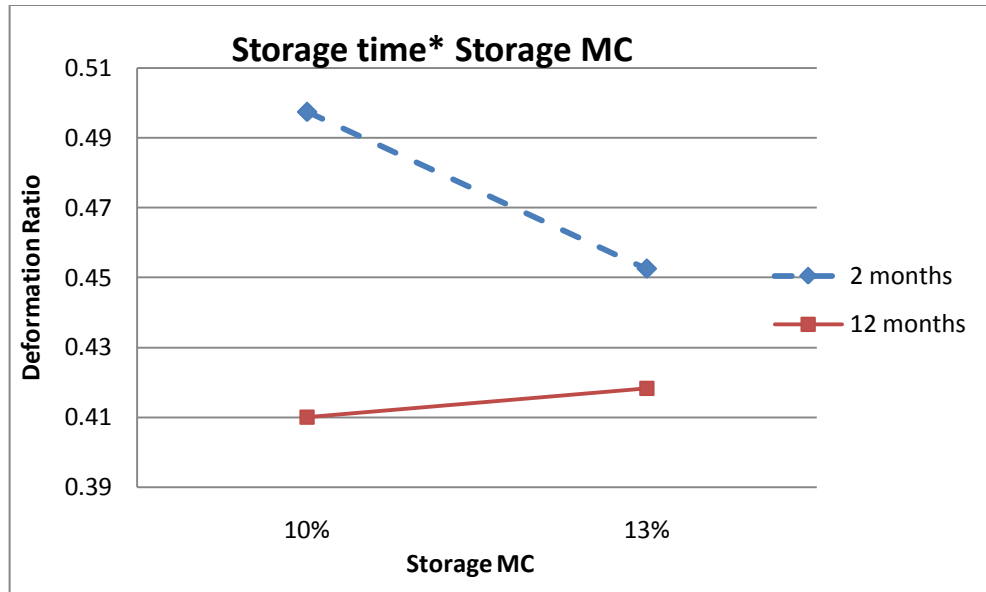
Appendix 92. Least square means plot showing the deformation ratio of Redberry 2007 lentils as affected by storage time and storage temperature for samples in storage pre-treatment B.



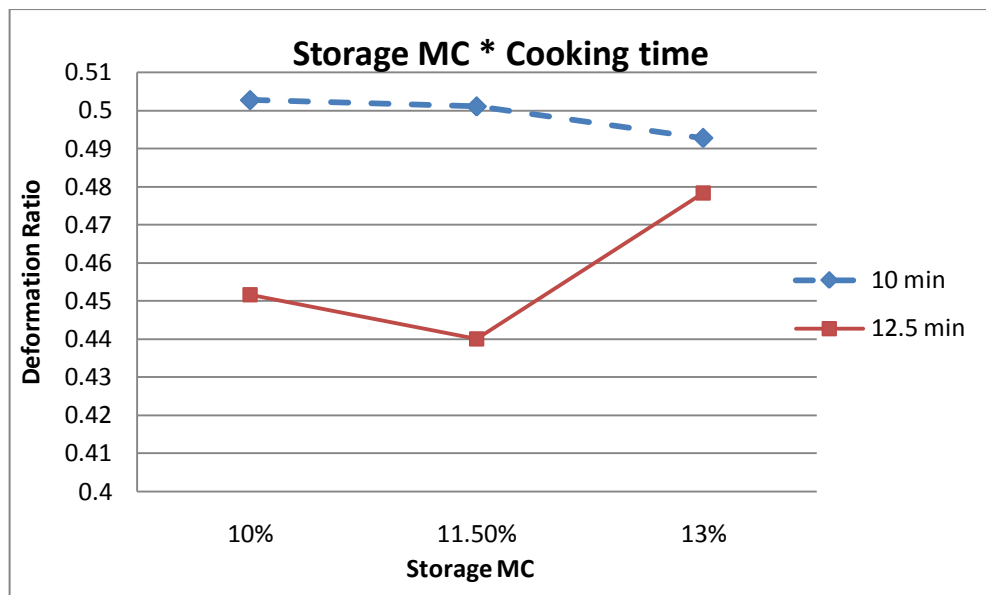
Appendix 93. Least square means plot showing the deformation ratio of Redberry 2007 lentils as affected by storage time and storage moisture content for samples in storage pre-treatment B.



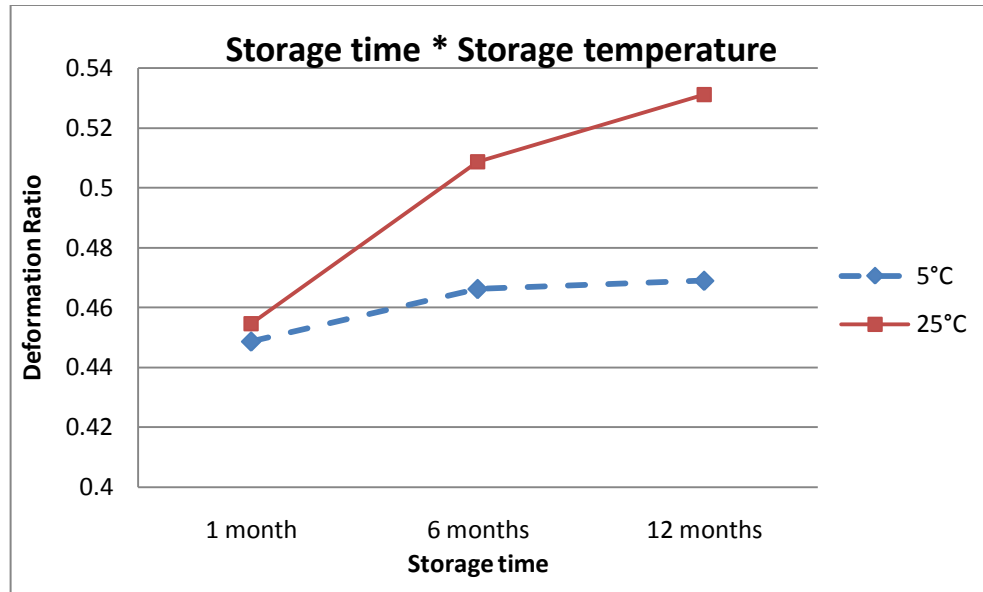
Appendix 94. Least square means plot showing the deformation ratio of Redberry 2007 lentils as affected by storage time and cooking time for samples in storage pre-treatment C.



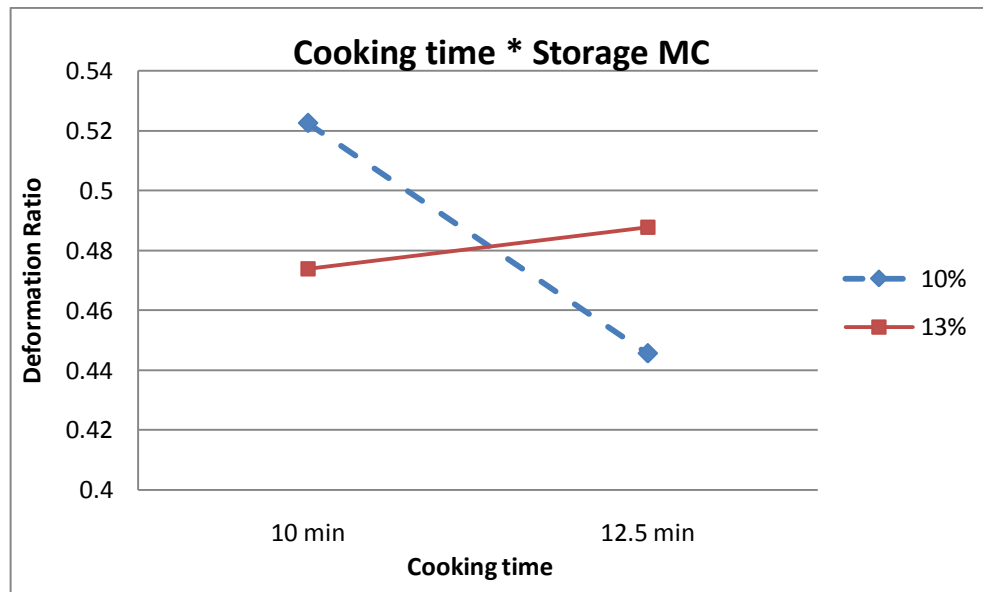
Appendix 95. Least square means plot showing the deformation ratio of Redberry 2007 lentils as affected by storage time and storage moisture content for samples in storage pre-treatment D.



Appendix 96. Least square means plot showing the deformation ratio of Impact 2007 lentils as affected by cooking time and storage moisture content for samples in storage pre-treatment A.

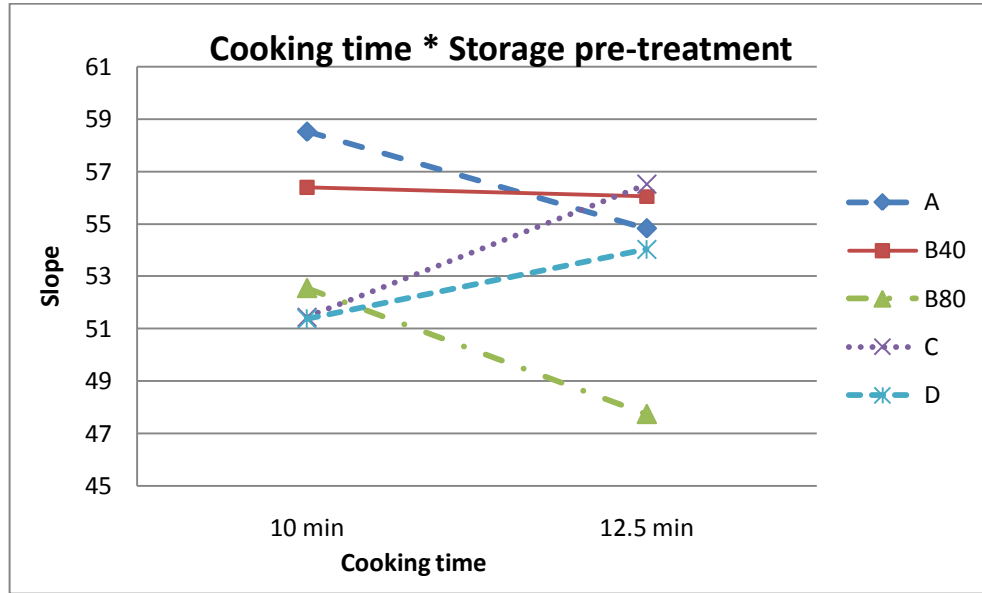


Appendix 97. Least square means plot showing the deformation ratio of Impact 2007 lentils as affected by storage time and storage temperature for samples in storage pre-treatment B.

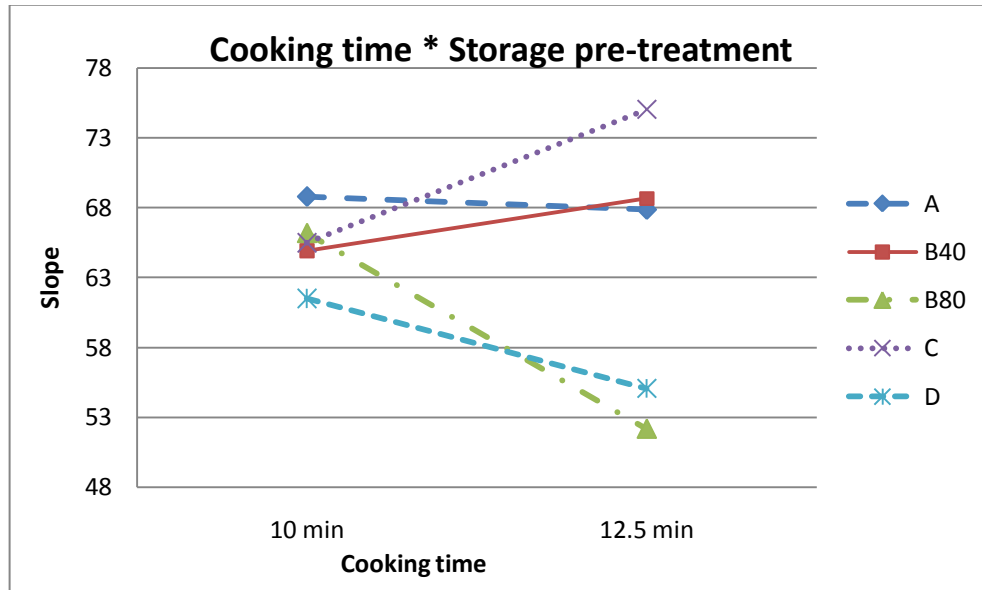


Appendix 98. Least square means plot showing the deformation ratio of Impact 2007 lentils as affected by cooking time and storage moisture content for samples in storage pre-treatment D.

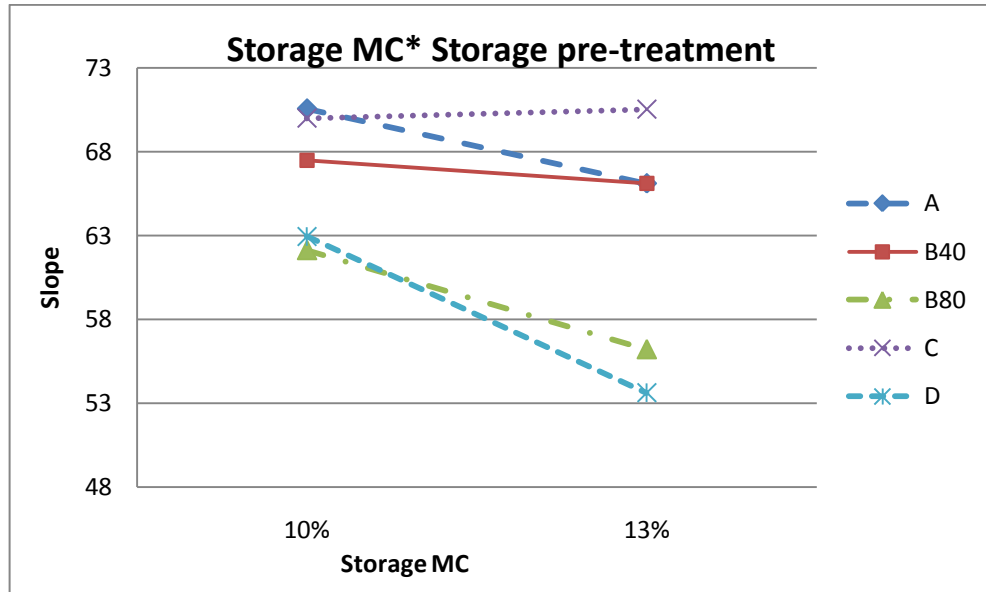
Interactions in the slope of the force-deformation curves of 2008 samples



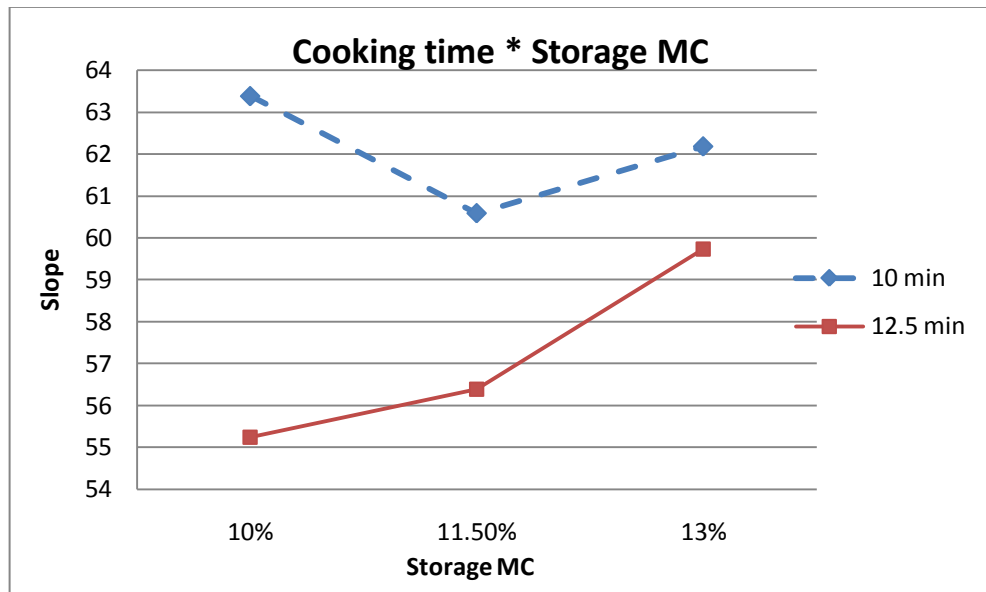
Appendix 99. Least square means plot showing the slope of the force-deformation curves of Redberry 2008 lentils as affected by storage pre-treatment and cooking time for samples analyzed with the general factorial design.



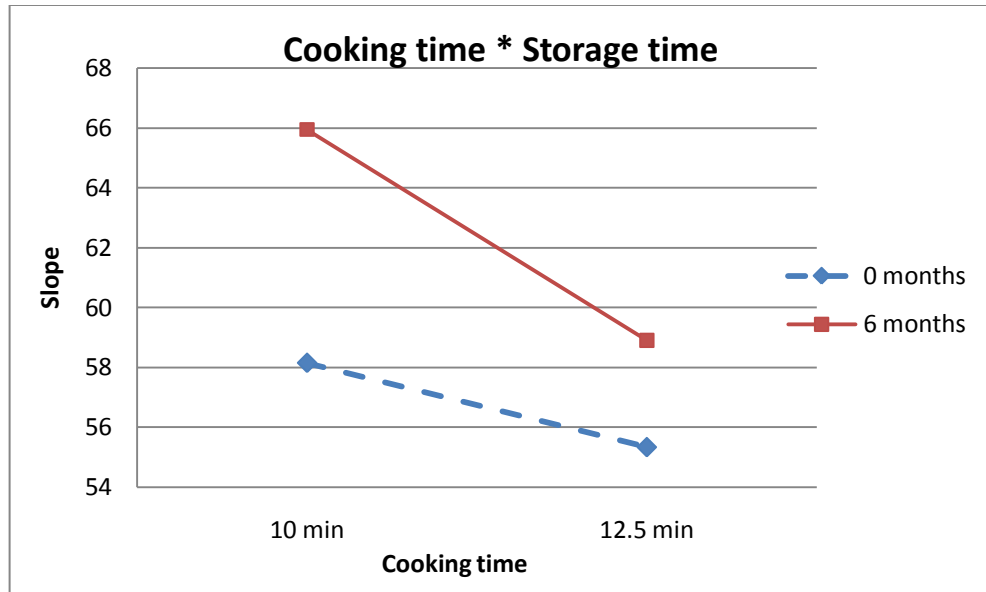
Appendix 100. Least square means plot showing the slope of the force-deformation curves of Impact 2008 lentils as affected by storage pre-treatment and cooking time for samples analyzed with the general factorial design.



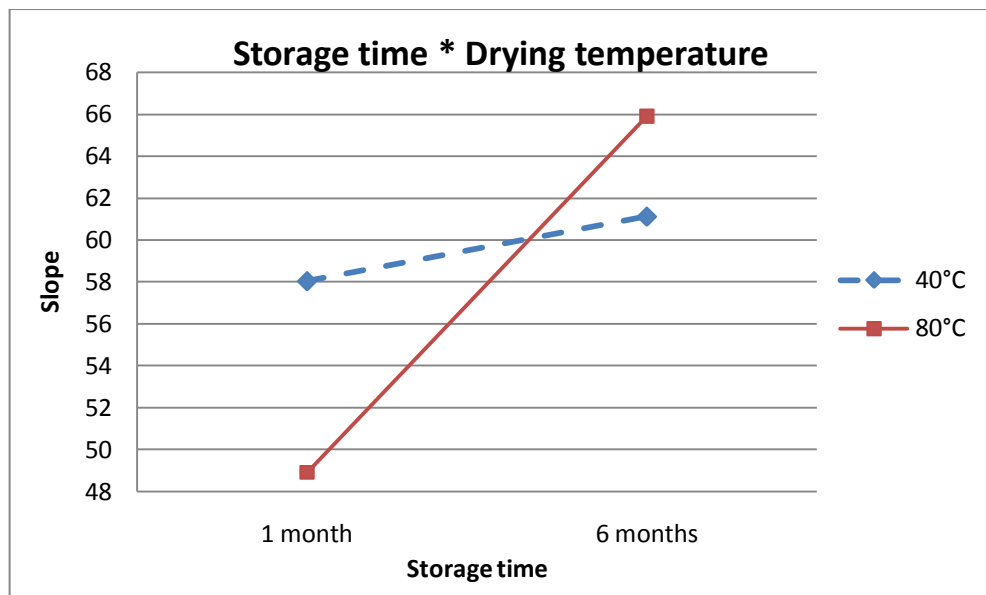
Appendix 101. Least square means plot showing the slope of the force-deformation curves of Impact 2008 lentils as affected by storage pre-treatment and storage moisture content for samples analyzed with the general factorial design.



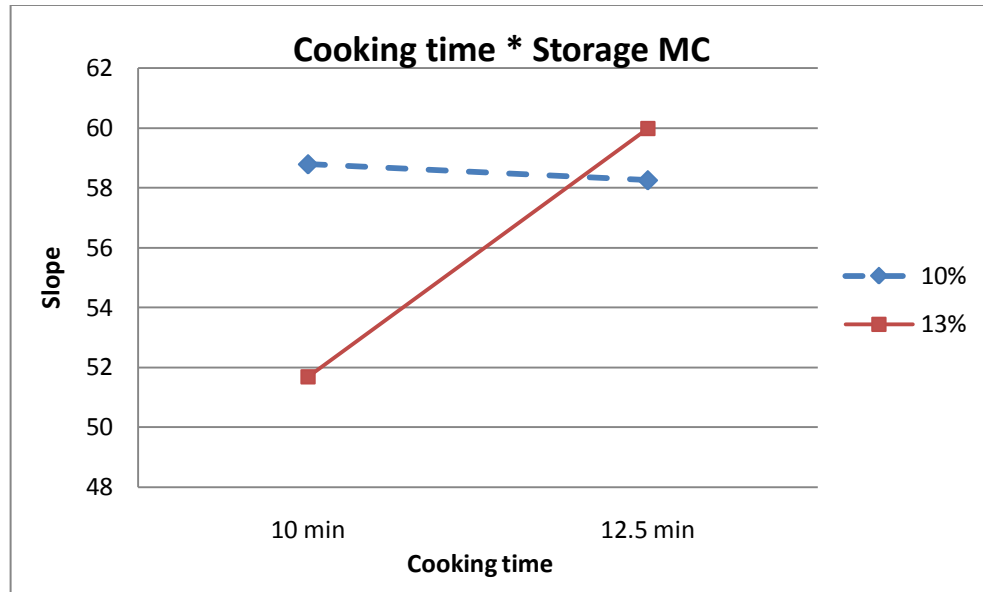
Appendix 102. Least square means plot showing the slope of the force-deformation curves of Redberry 2008 lentils as affected by storage moisture content and cooking time for samples in storage pre-treatment A.



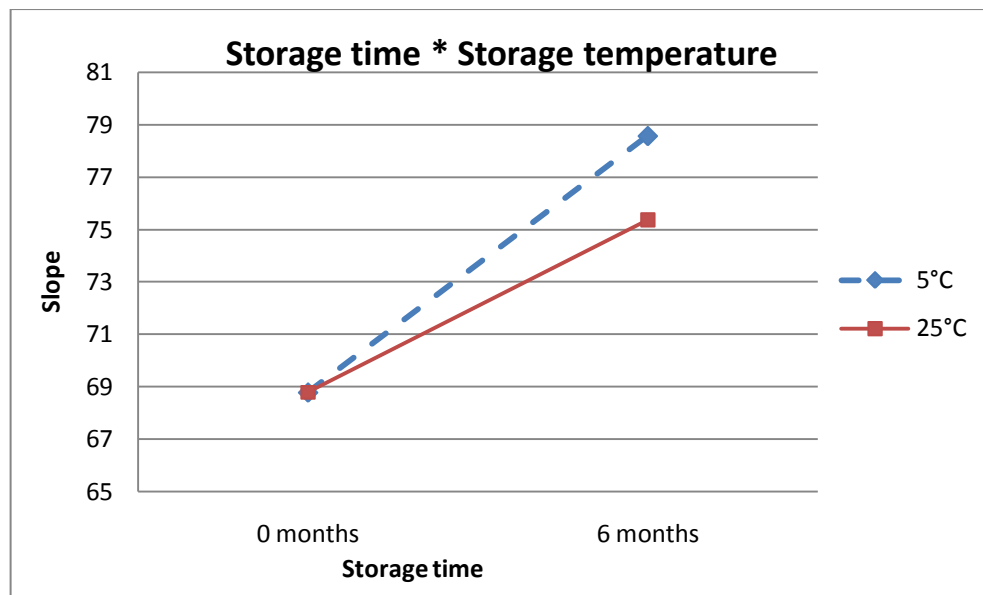
Appendix 103. Least square means plot showing the slope of the force-deformation curves of Redberry 2008 lentils as affected by storage time and cooking time for samples in storage pre-treatment A.



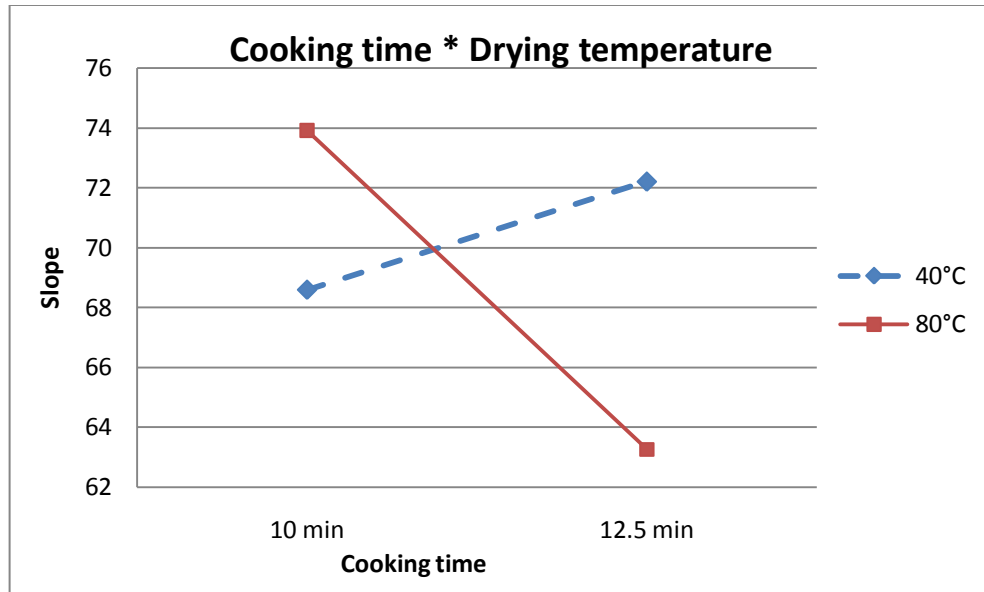
Appendix 104. Least square means plot showing the slope of the force-deformation curves of Redberry 2008 lentils as affected by storage time and drying temperature for samples in storage pre-treatment B.



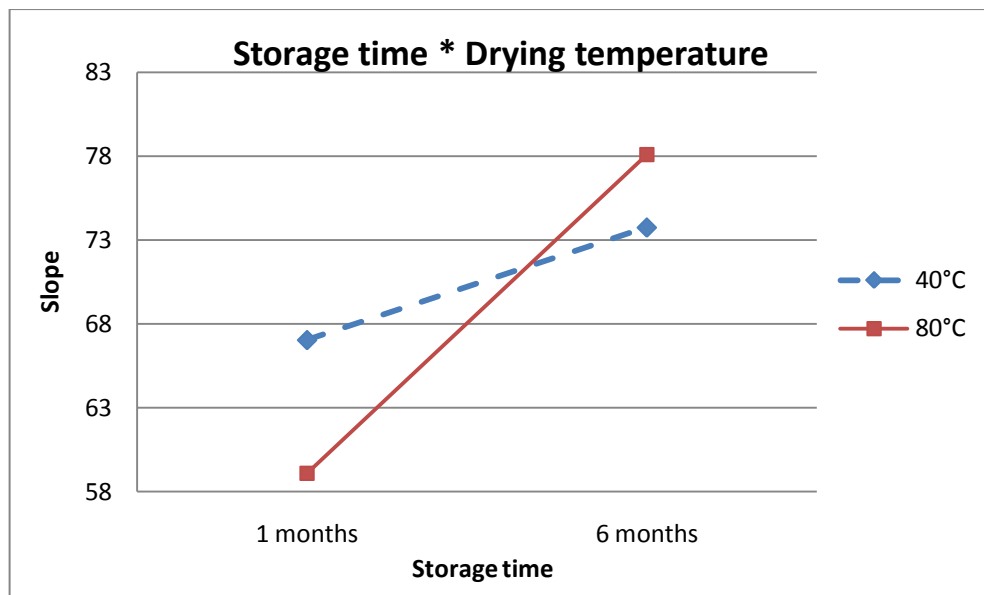
Appendix 105. Least square means plot showing the slope of the force-deformation curves of Redberry 2008 lentils as affected by storage moisture content and cooking time for samples in storage pre-treatment C.



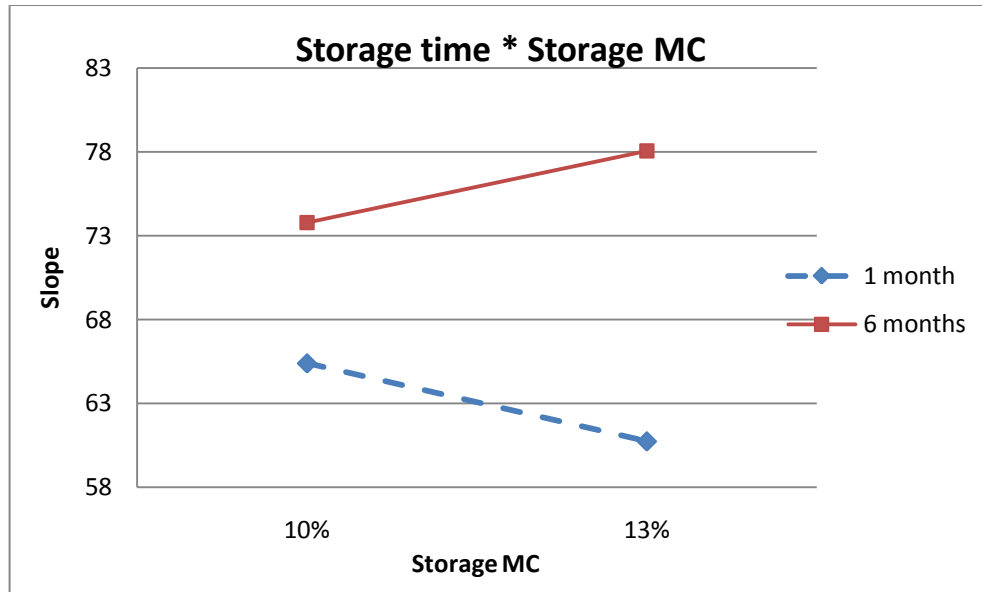
Appendix 106. Least square means plot showing the slope of the force-deformation curves of Impact 2008 lentils as affected by storage temperature and storage time for samples in storage pre-treatment A.



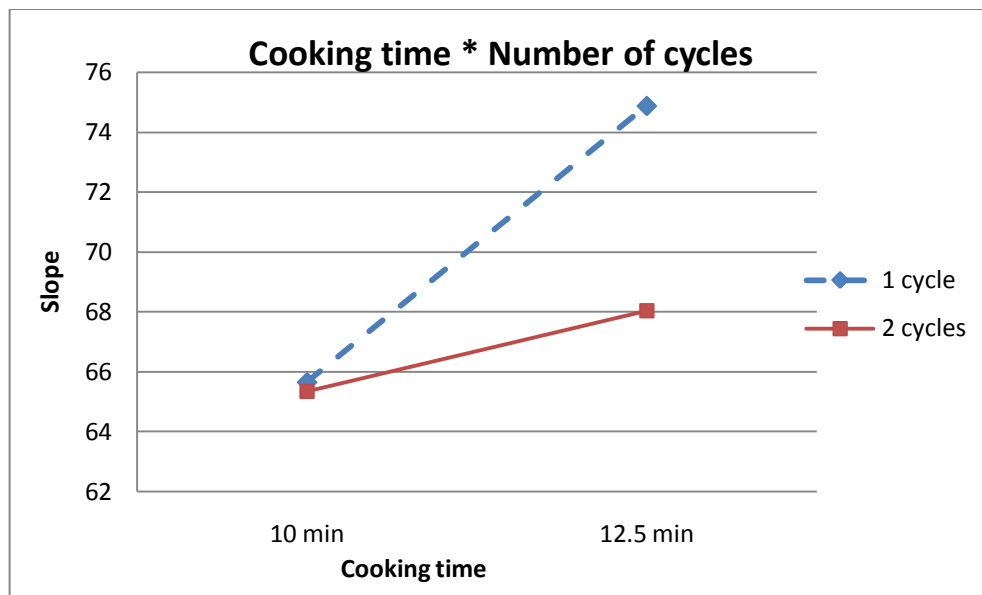
Appendix 107. Least square means plot showing the slope of the force-deformation curves of Impact 2008 lentils as affected by drying temperature and cooking time for samples in storage pre-treatment B.



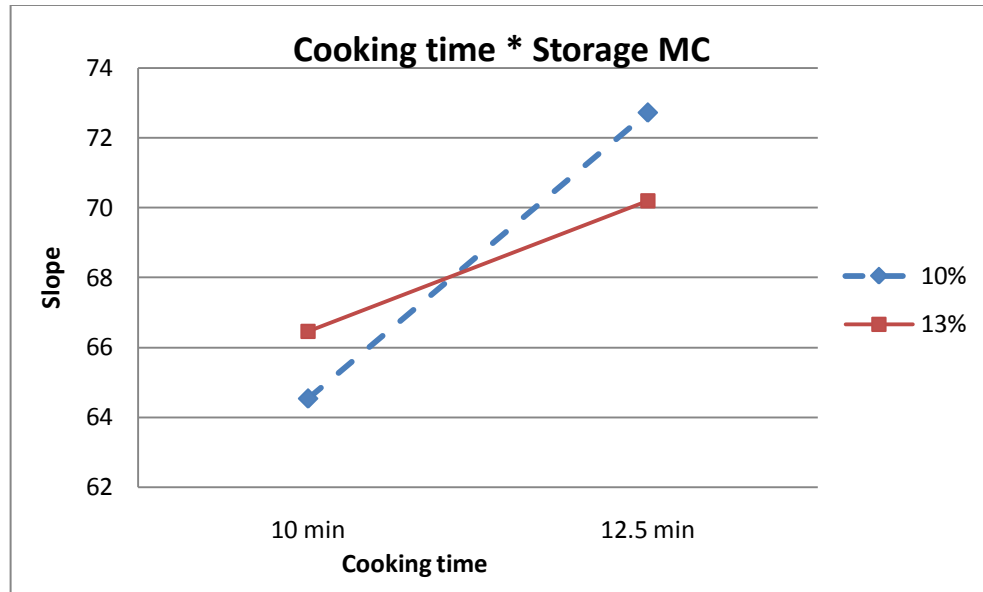
Appendix 108. Least square means plot showing the slope of the force-deformation curves of Impact 2008 lentils as affected by drying temperature and storage time for samples in storage pre-treatment B.



Appendix 109. Least square means plot showing the slope of the force-deformation curves of Impact 2008 lentils as affected by storage time and storage moisture content for samples in storage pre-treatment B.

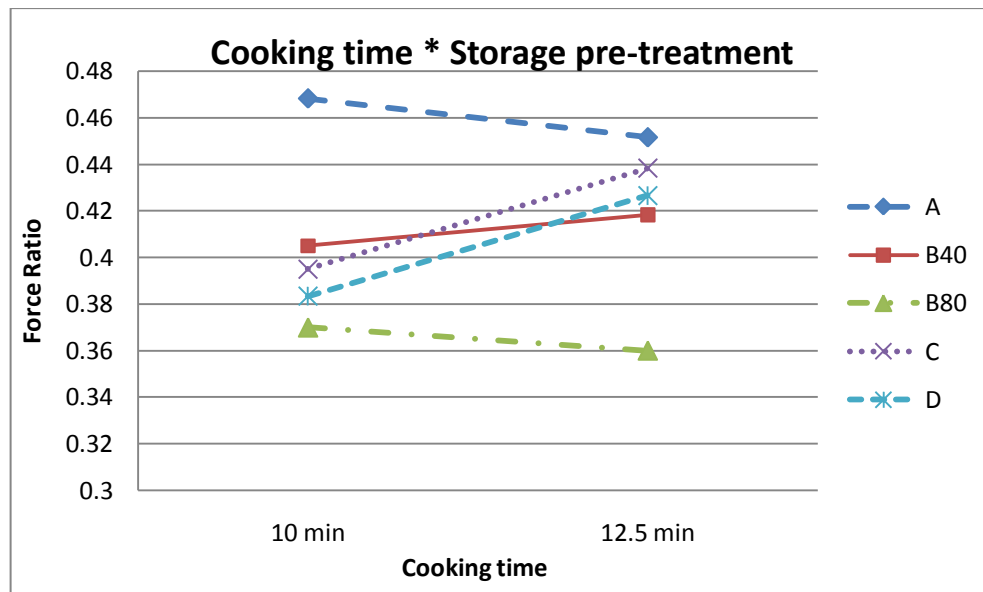


Appendix 110. Least square means plot showing the slope of the force-deformation curves of Impact 2008 lentils as affected by cooking time and number of cycles for samples in storage pre-treatment C.

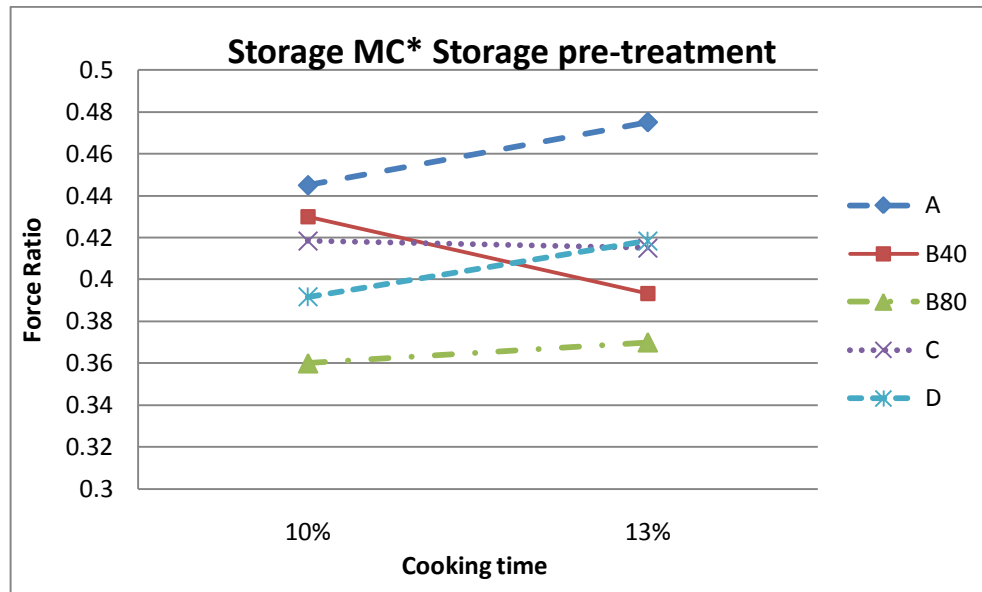


Appendix 111. Least square means plot showing the slope of the force-deformation curves of Impact 2008 lentils as affected by cooking time and storage moisture content for samples in storage pre-treatment C.

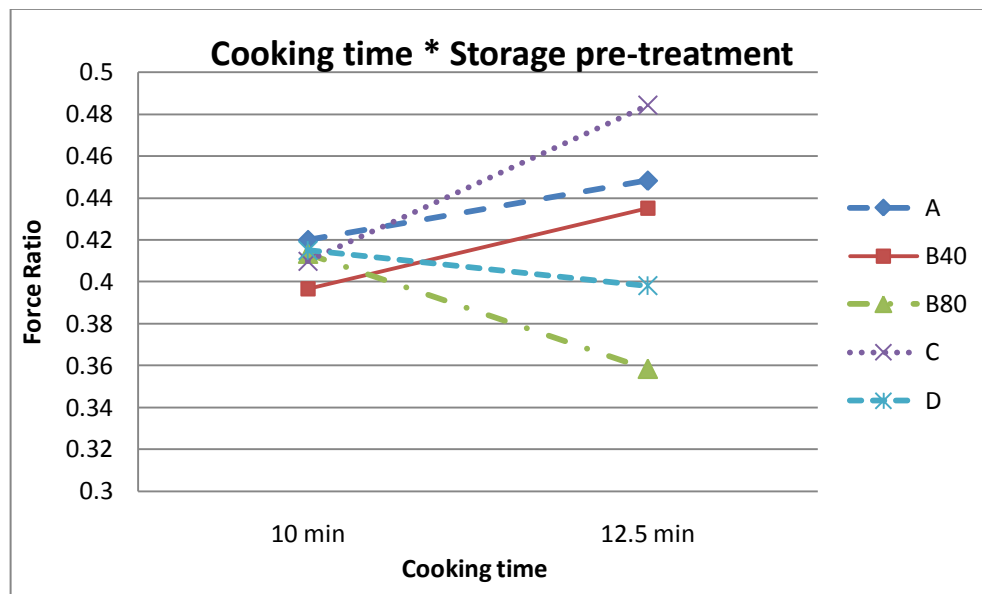
Interactions in the force ratio of 2008 samples



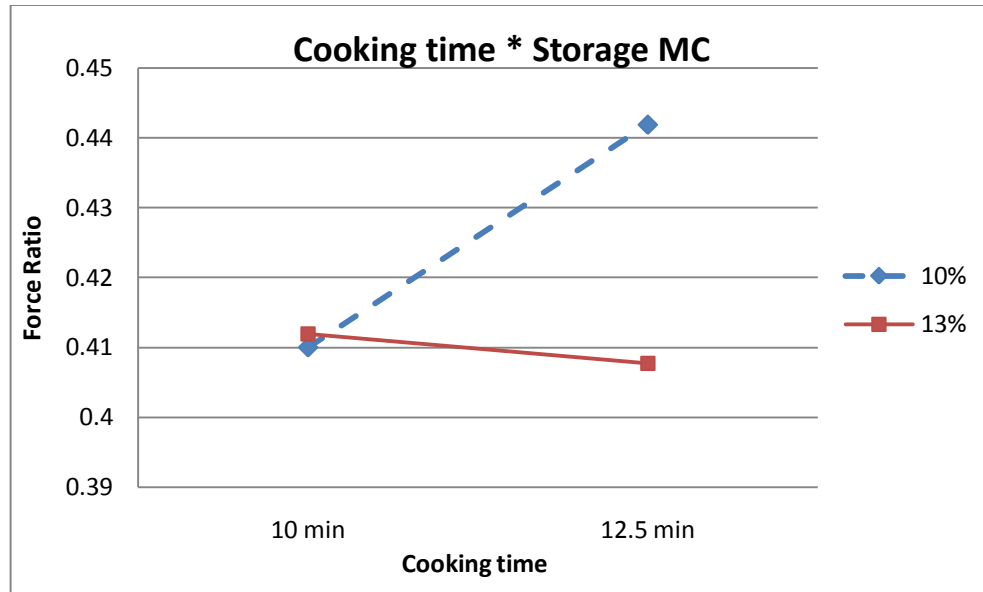
Appendix 112. Least square means plot showing the force ratio of Redberry 2008 lentils as affected by cooking time and storage pre-treatment for samples analyzed with the general factorial design.



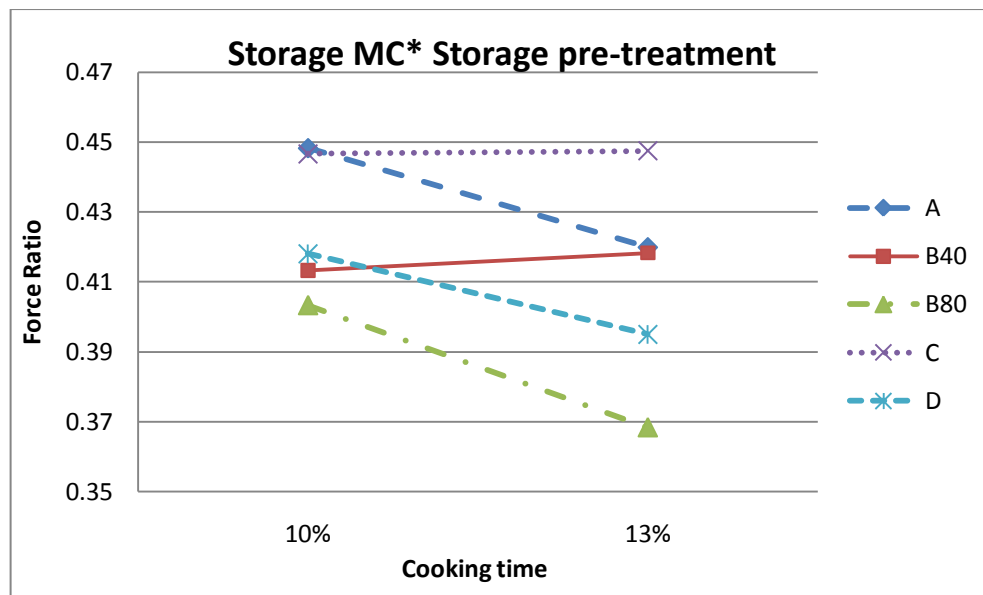
Appendix 113. Least square means plot showing the force ratio of Redberry 2008 lentils as affected by storage moisture content and storage pre-treatment for samples analyzed with the general factorial design.



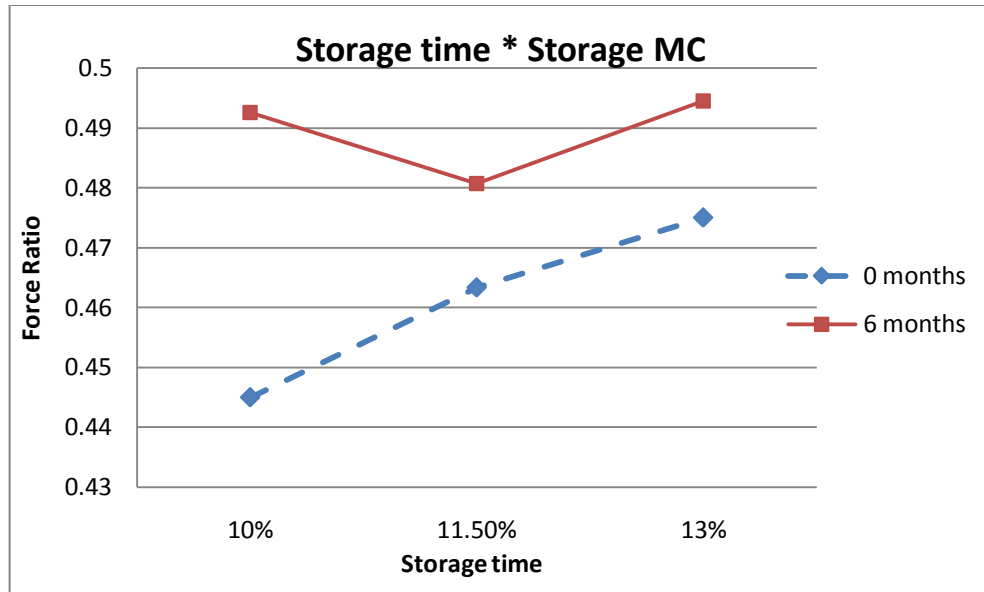
Appendix 114. Least square means plot showing the force ratio of Impact2008 lentils as affected by cooking time and storage pre-treatment for samples analyzed with the general factorial design.



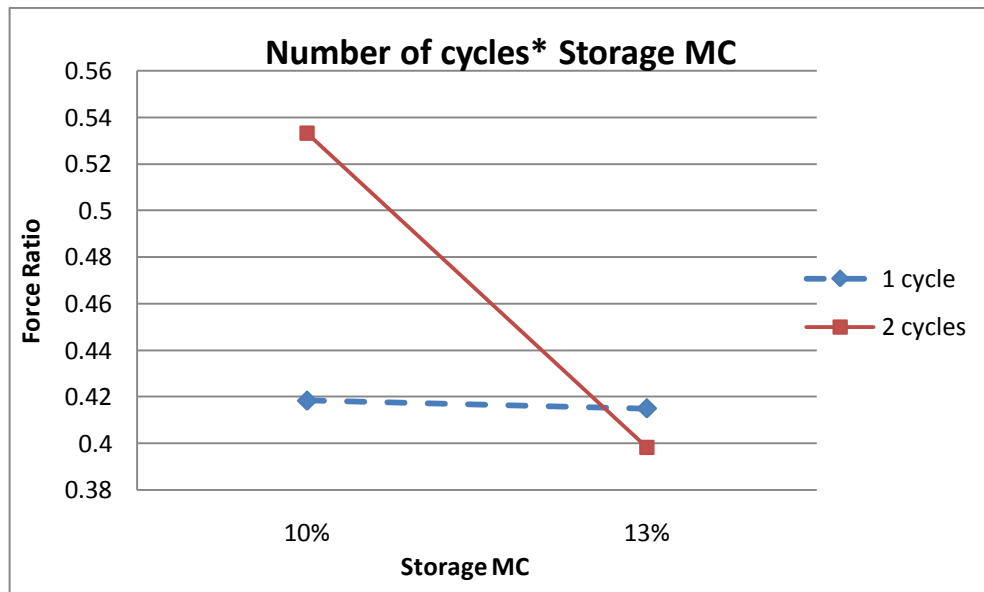
Appendix 115. Least square means plot showing the force ratio of Impact2008 lentils as affected by cooking time and storage moisture content for samples analyzed with the general factorial design.



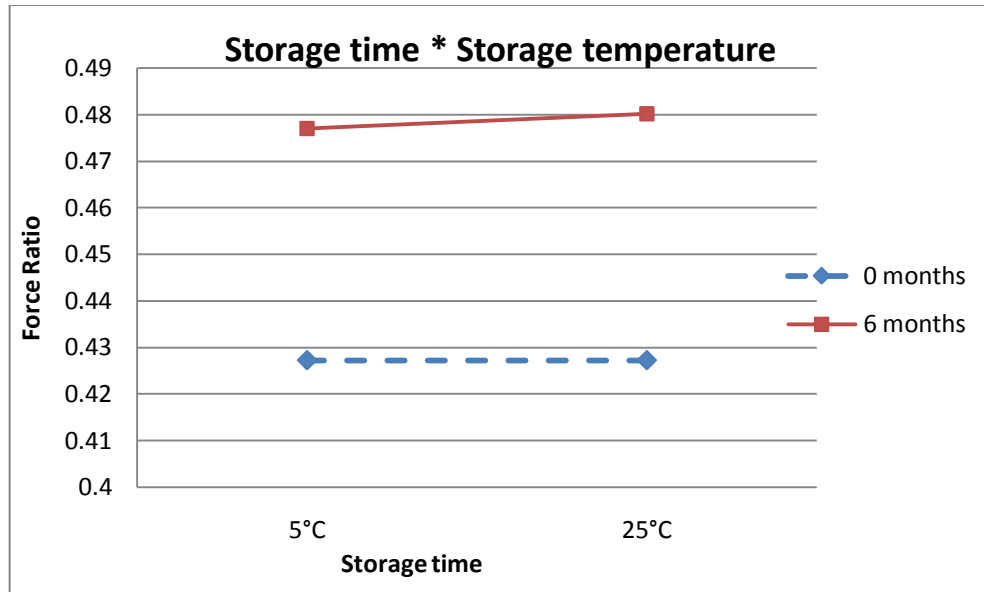
Appendix 116. Least square means plot showing the force ratio of Impact2008 lentils as affected by storage moisture content and storage pre-treatment for samples analyzed with the general factorial design.



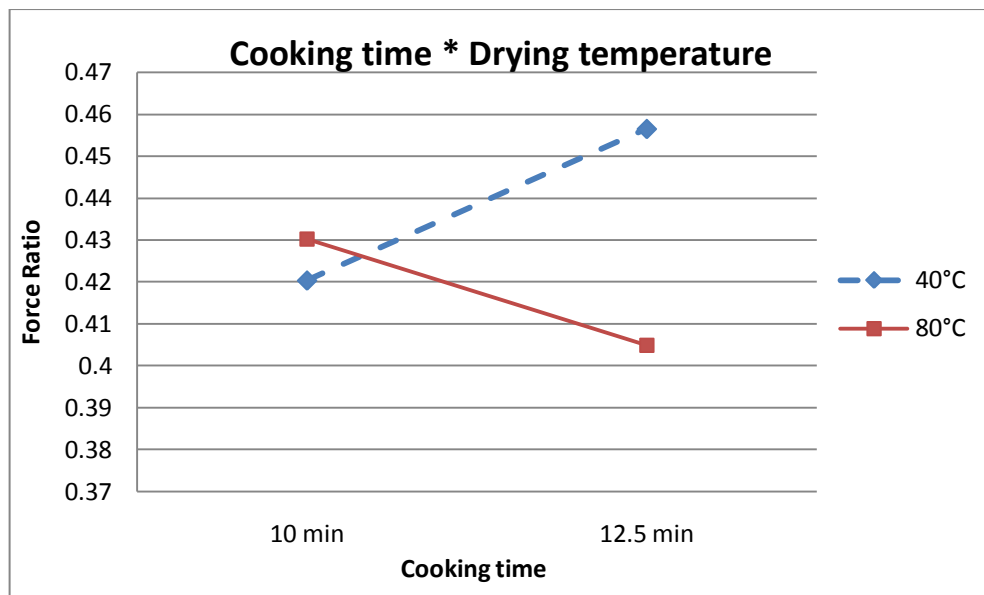
Appendix 117. Least square means plot showing the force ratio of Redberry2008 lentils as affected by storage moisture content and storage time for samples in storage pre-treatment A.



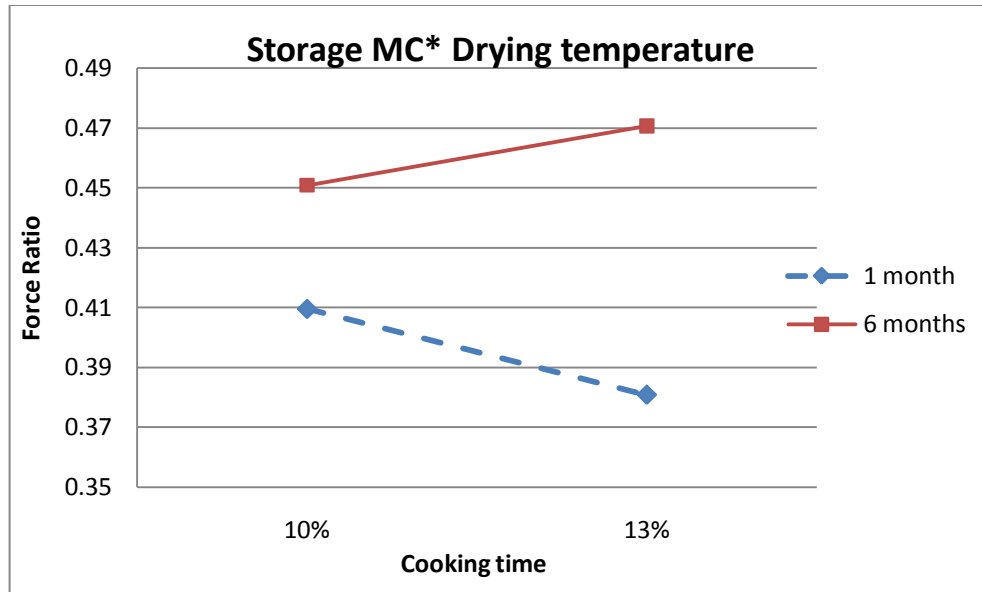
Appendix 118. Least square means plot showing the force ratio of Redberry2008 lentils as affected by storage moisture content and number of cycles for samples in storage pre-treatment C.



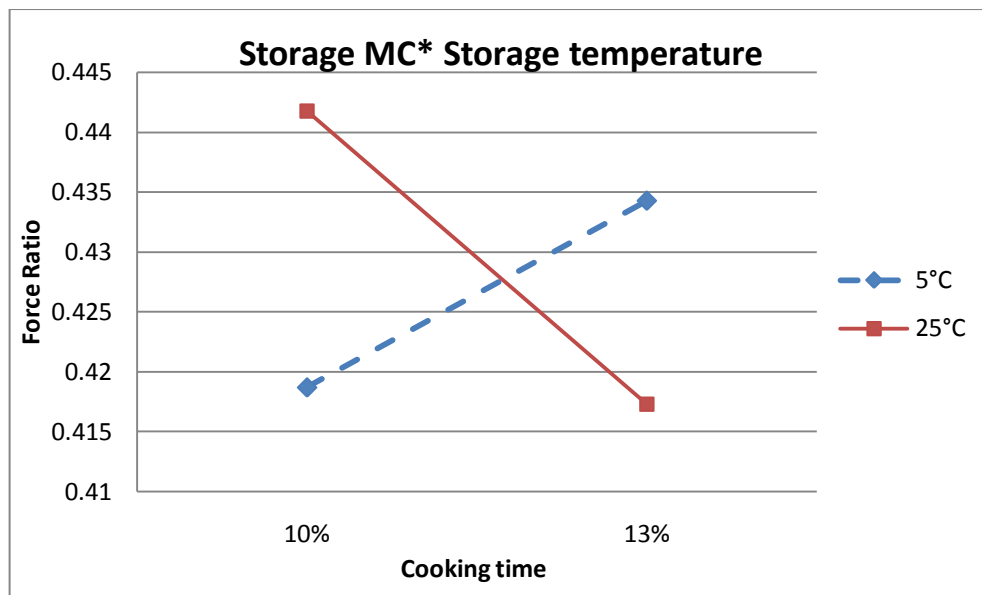
Appendix 119. Least square means plot showing the force ratio of Impact 2008 lentils as affected by storage temperature content and storage time for samples in storage pre-treatment A.



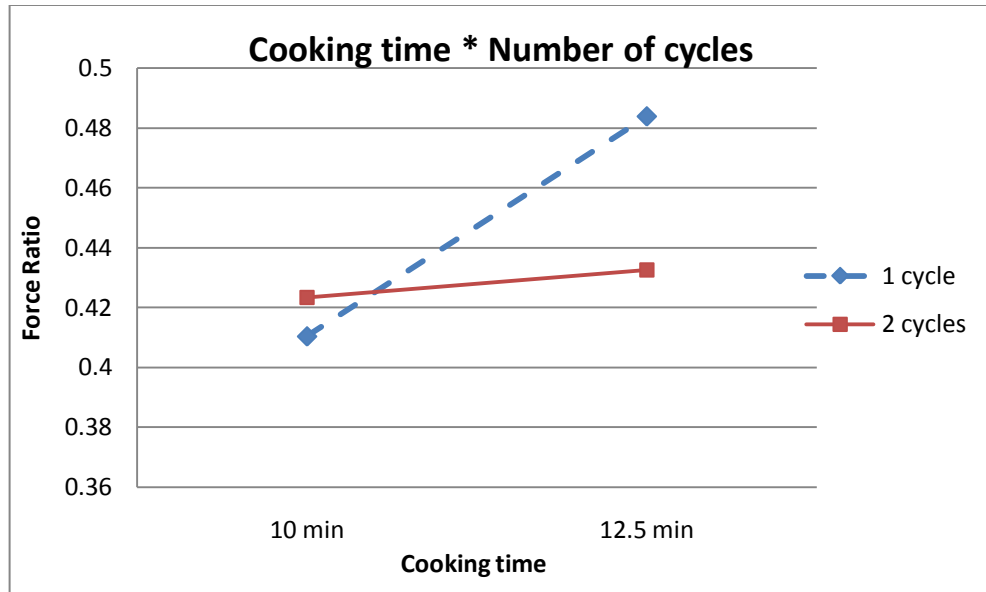
Appendix 120. Least square means plot showing the force ratio of Impact 2008 lentils as affected by drying temperature and cooking time for samples in storage pre-treatment B.



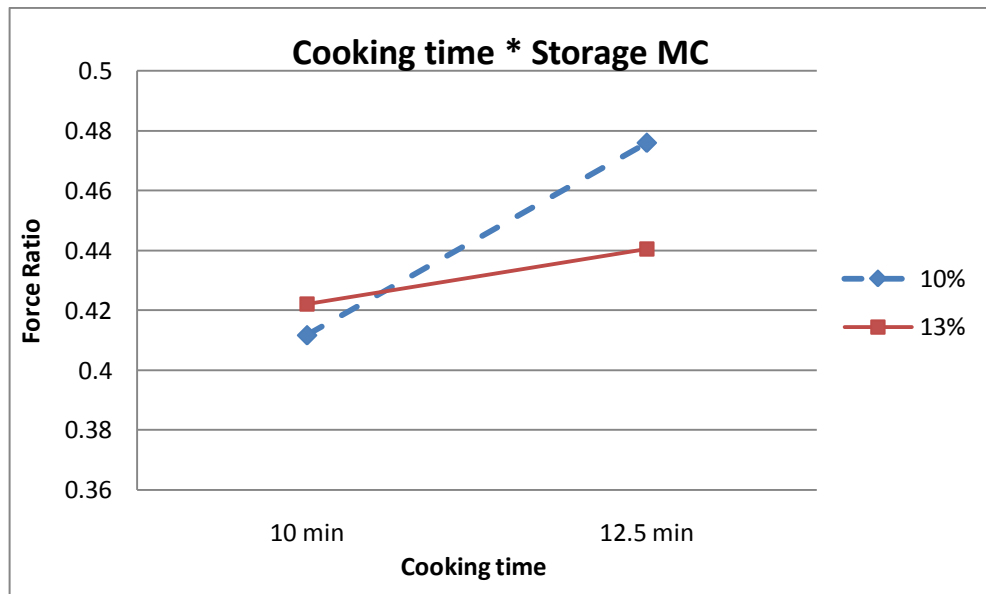
Appendix 121. Least square means plot showing the force ratio of Impact 2008 lentils as affected by drying temperature and storage moisture content for samples in storage pre-treatment B.



Appendix 122. Least square means plot showing the force ratio of Impact 2008 lentils as affected by storage temperature and storage moisture content for samples in storage pre-treatment B.

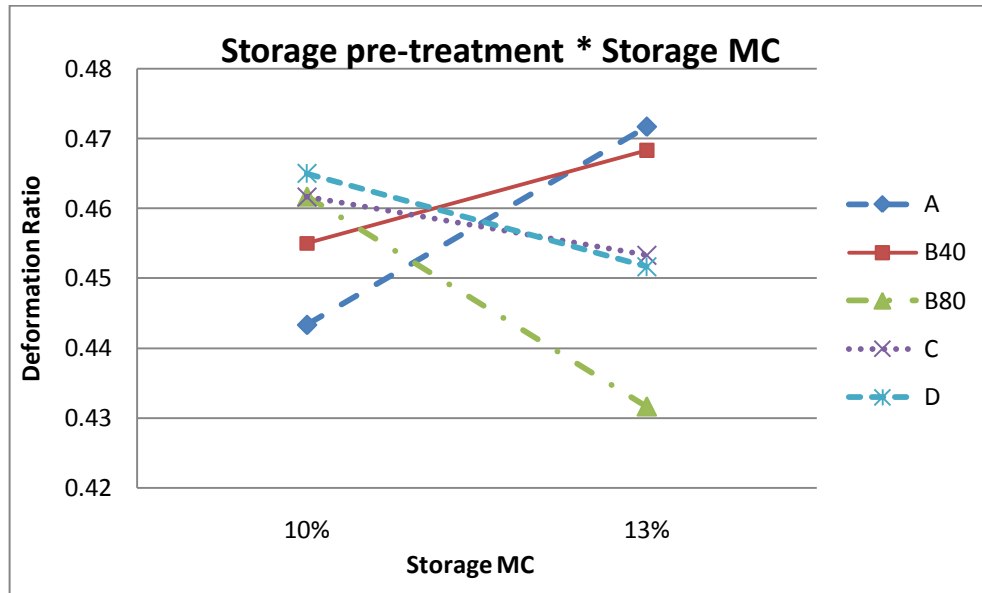


Appendix 123. Least square means plot showing the force ratio of Impact 2008 lentils as affected by cooking time and number of cycles for samples in storage pre-treatment C.

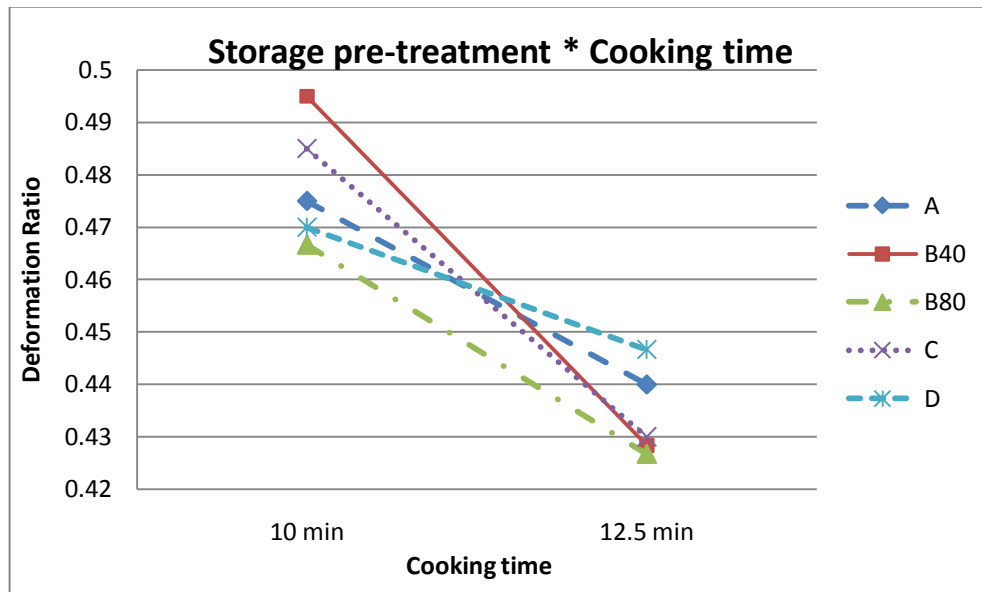


Appendix 124. Least square means plot showing the force ratio of Impact 2008 lentils as affected by cooking time and storage moisture content for samples in storage pre-treatment C.

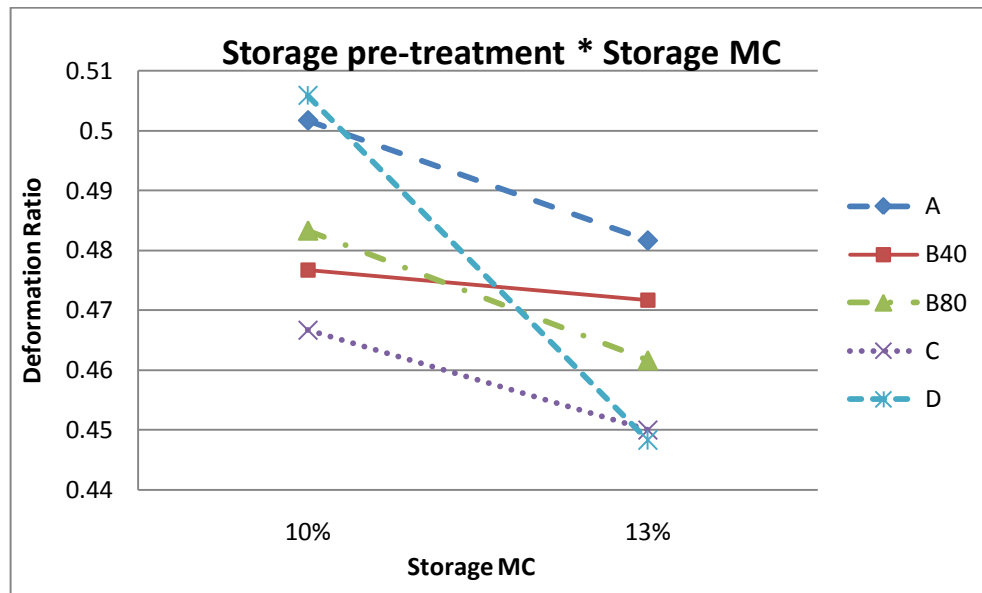
Interactions in the deformation ratio of 2008 samples



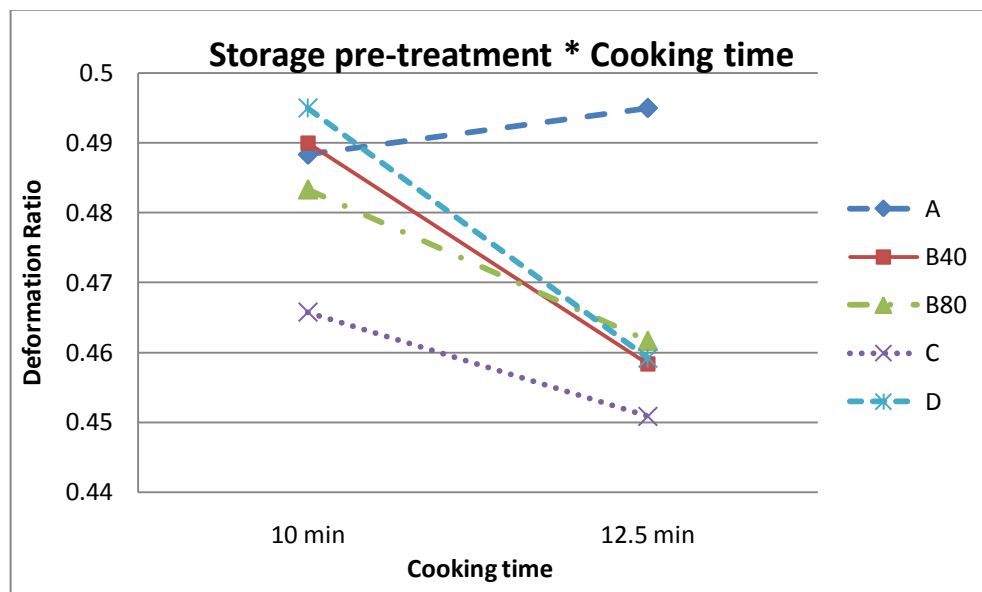
Appendix 125. Least square means plot showing the deformation ratio of Redberry 2008 lentils as affected by storage moisture content and storage pre-treatment for samples analyzed with the general factorial design.



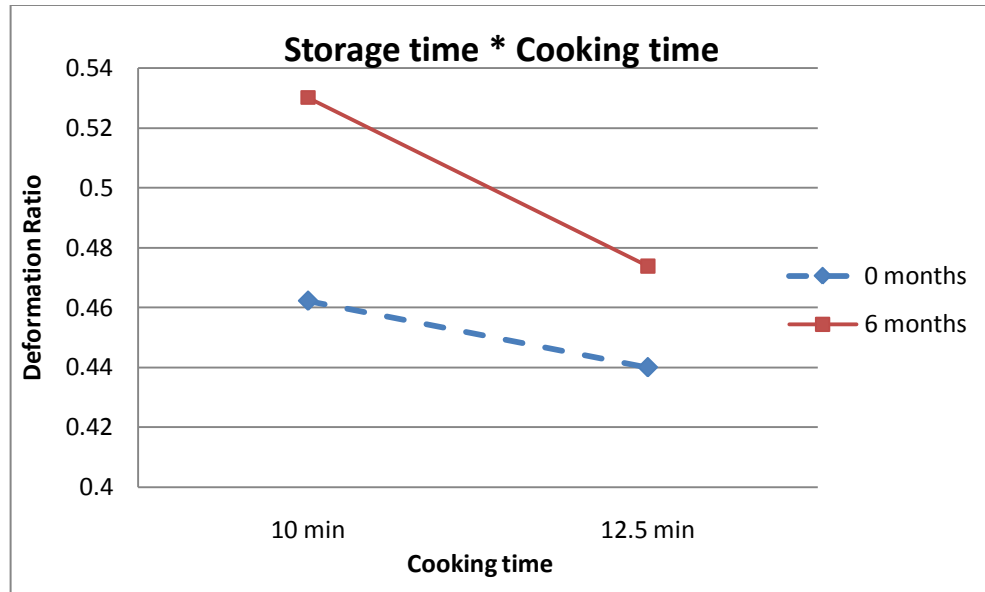
Appendix 126. Least square means plot showing the deformation ratio of Redberry 2008 lentils as affected by cooking time and storage pre-treatment for samples analyzed with the general factorial design.



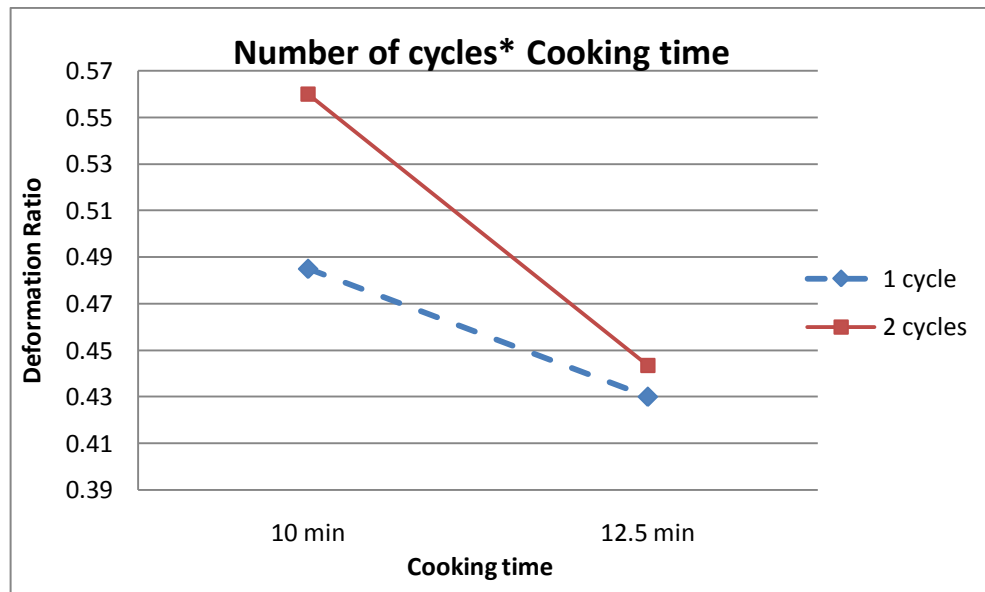
Appendix 127. Least square means plot showing the deformation ratio of Impact 2008 lentils as affected by storage moisture content and storage pre-treatment for samples analyzed with the general factorial design.



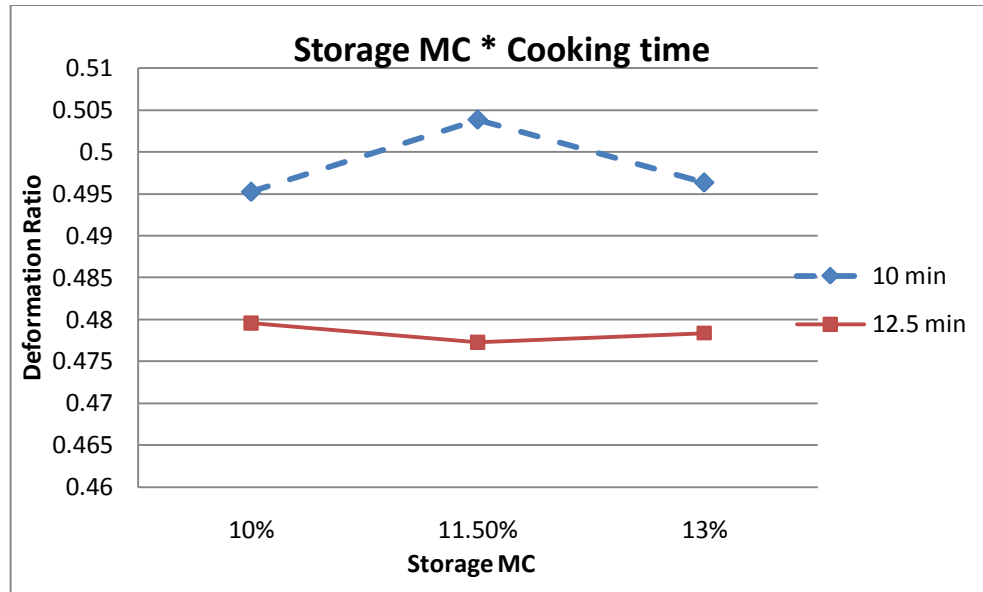
Appendix 128. Least square means plot showing the deformation ratio of Impact 2008 lentils as affected by cooking time and storage pre-treatment for samples analyzed with the general factorial design.



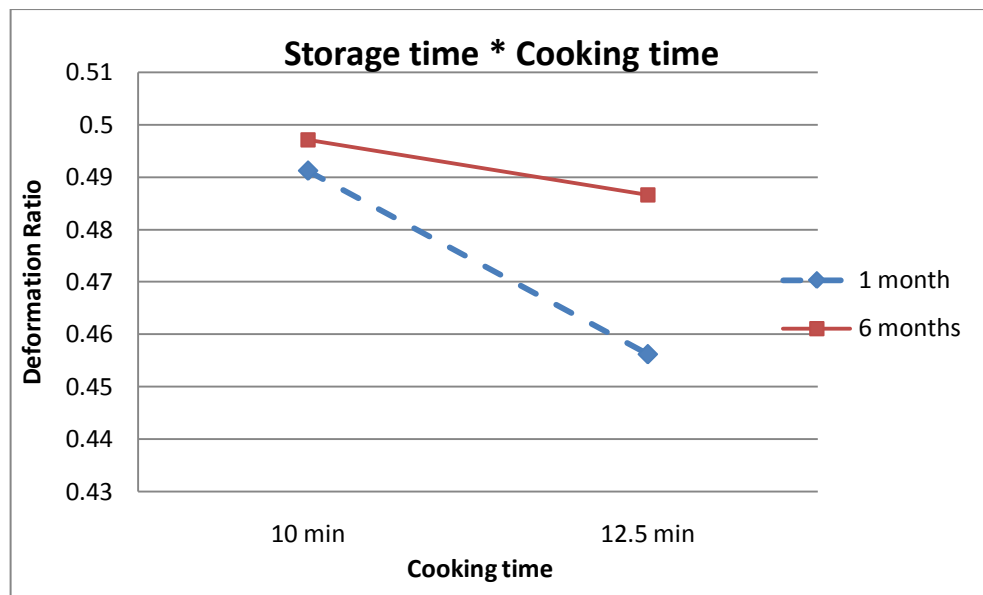
Appendix 129. Least square means plot showing the deformation ratio of Redberry 2008 lentils as affected by cooking time and storage time for samples in storage pre-treatment A.



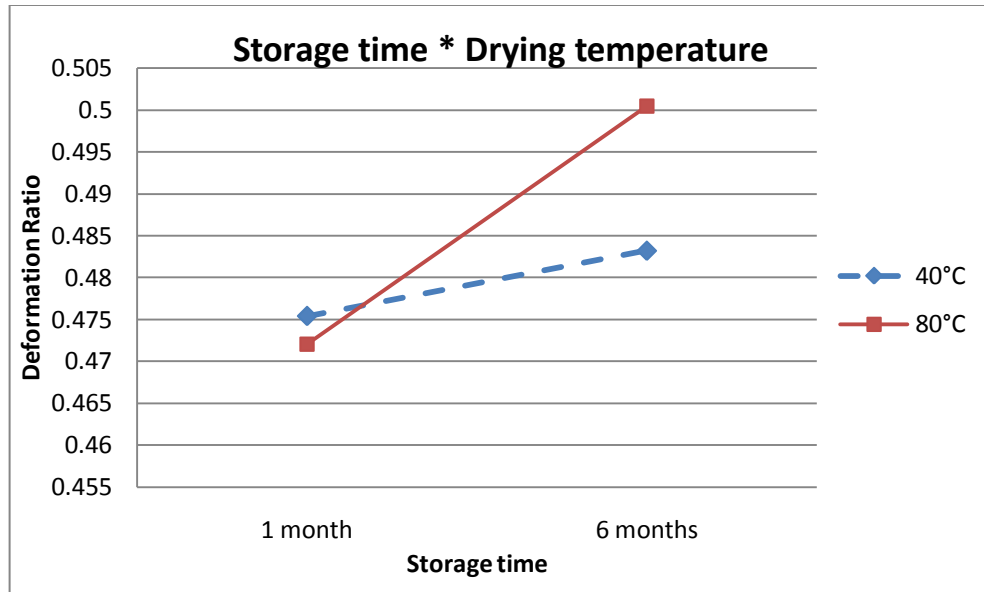
Appendix 130. Least square means plot showing the deformation ratio of Redberry 2008 lentils as affected by cooking time and number of cycles for samples in storage pre-treatment C.



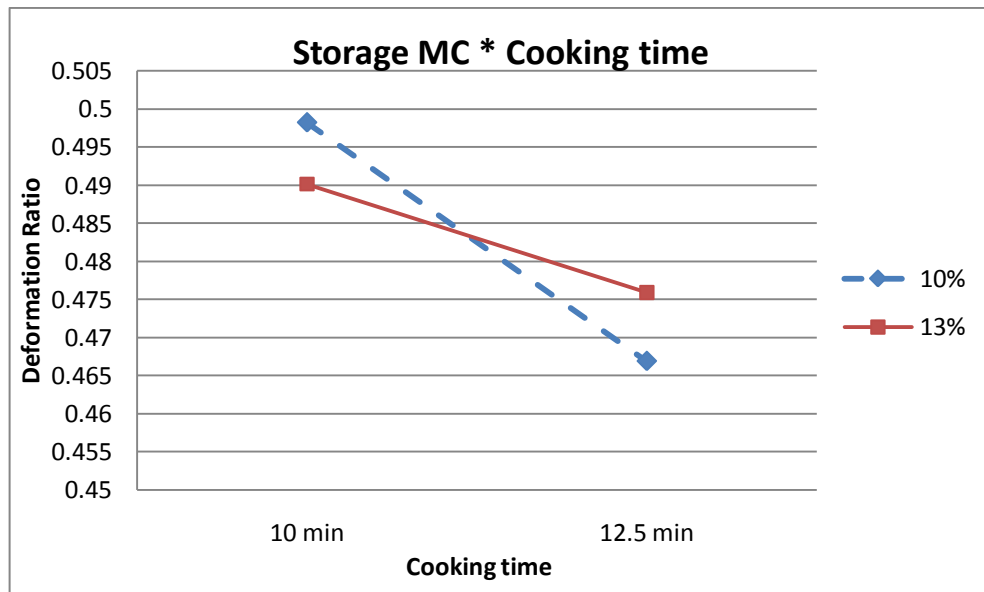
Appendix 131. Least square means plot showing the deformation ratio of Impact 2008 lentils as affected by cooking time and storage moisture content for samples in storage pre-treatment A.



Appendix 132. Least square means plot showing the deformation ratio of Impact 2008 lentils as affected by cooking time and storage time for samples in storage pre-treatment B.



Appendix 133. Least square means plot showing the deformation ratio of Impact 2008 lentils as affected by drying temperature and storage time for samples in storage pre-treatment B.



Appendix 134. Least square means plot showing the deformation ratio of Impact 2008 lentils as affected by cooking time and storage moisture content for samples in storage pre-treatment B.