2022 Pulse Quality Evaluation

Lentil

Saskatchewan Food Industry Development Centre Inc.
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Pulse Quality Program—*Mission*

The Pulse Quality Program launched in spring 2022 with a partnership between Saskatchewan Pulse Growers and the Saskatchewan Food Industry Development Centre with the mission to add in best management practices for pulses grown in Western Canada and to help the development of pulse-based ingredients/products in the food industry.

The program aims to develop a comprehensive database of composition, functionality, and nutrition for pulses that provides information to growers, agronomists, breeders, buyers, and end users to make more informed choices. This program implements a genotype by environment (G x E) evaluation of quality parameters of peas, faba beans, lentils, chickpeas, and dry beans.

Phase 1 of the program analyzes up to 3000 samples annually from regional variety trials. The main focus of parameters includes seed quality (i.e., 1000 seed weight, amount of damage, seed size, and seed hardness), nutritional composition (i.e., ash, moisture, and protein content), and physical properties (i.e., colour, particle size, and Hausner ratio). The generated data are compared across pulse varieties, locations, and years. Additional parameters will be considered in future years in Phase 2 and Phase 3.

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2022 Lentil Quality

The **2022** lentil quality evaluation comprised **468** lentil samples harvested from **6** locations, including Elrose, Moose Jaw, Rosthern, Scott, St Brieux, and Swift Current. There were **28** varieties, and three replicates of each variety were cultivated in each location. Table A and Figure A provide the samples' information and locations in detail.

Table A. Description of lentil samples harvested in 2022 for the Pulse Quality Program.

	Type	Variety		Site	Number of samples
Green	Large green	CDC Greenstar CDC Grimm	CDC Lima	Elrose Moose Jaw Rosthern Scott St Brieux Swift Current	468
	Small green	6795-12 6964-4	CDC Jimini CDC Kermit		
Red	Large red	CDC Sublime	CDC Monarch		
	Medium red	7005-3			
	Small red	5929-1 6802-14 CDC 6928 CDC 6956 7014-1 CDC Impulse	CDC Maxim CDC Nimble CDC Proclaim CDC Redmoon CDC Simmie		
	Extra small red	6928-5	6935-3		
Specialty	Spanish brown	7026-13Y	CDC SB-4		
	French green	7333-2-4			

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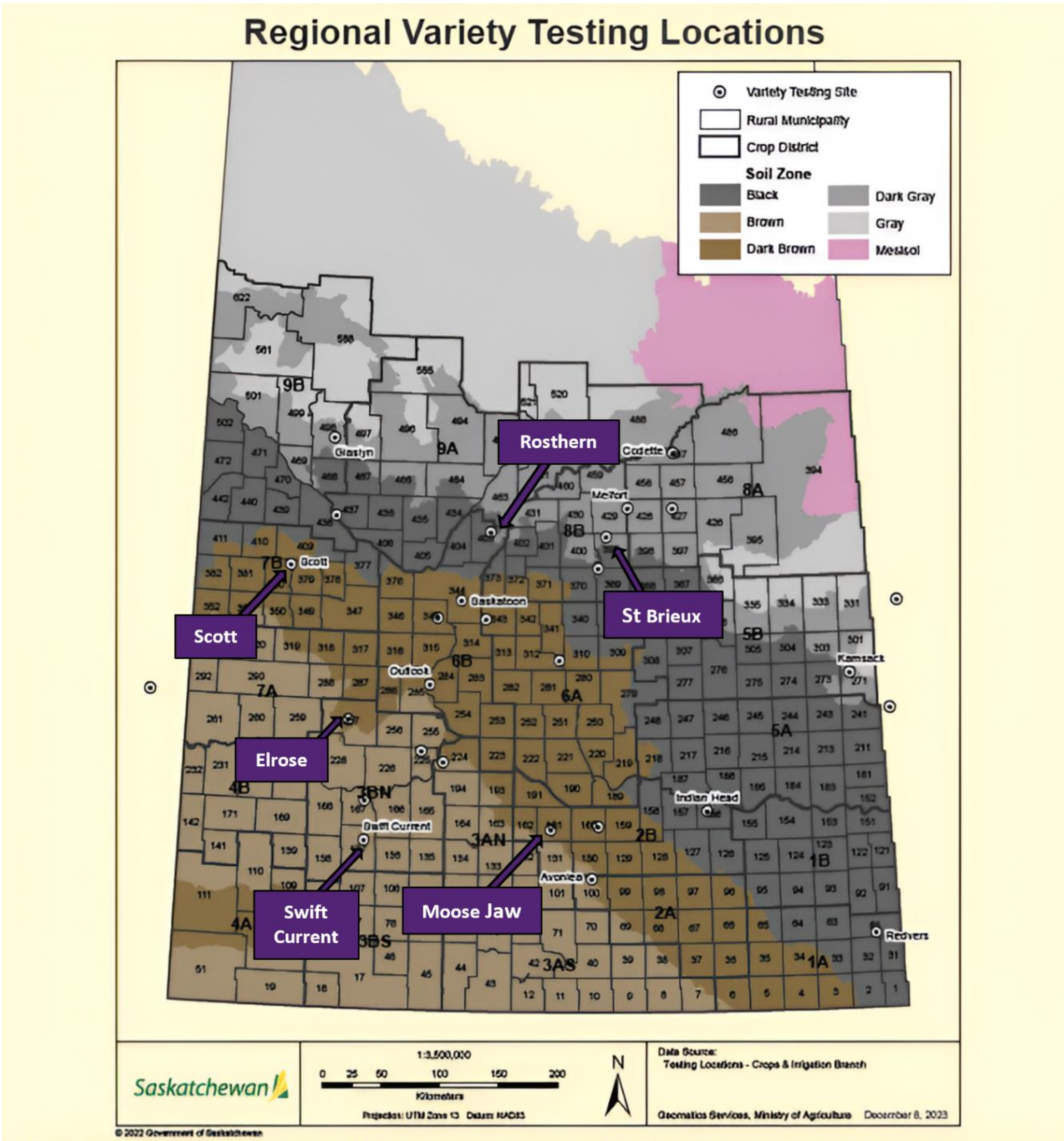

The cropland of Saskatchewan has been divided into four areas based roughly on agro-climatic conditions. Crop yields can vary from area to area. In choosing a variety, producers will want to consider the yield data in combination with marketing and agronomic factors.

Area 1: Drought is a definite hazard and high winds are common. Sawfly outbreaks often occur in this area. Cereal rust may be a problem in the southeastern section.

Area 2: Drought and sawfly may be problems in the western and central sections of the area. Cereal rust may be a problem in the southern section.

Area 3: Sawfly can also be a problem. Drought is not as likely to be a problem in this area, particularly in the east. Cereal rust may occur in the eastern portion. The frost-free period can be fairly short in the northern section.

Area 4: Rainfall is usually adequate for crop production. However, early fall frosts and wet harvest conditions are frequent problems.

Note About Dividing Lines:

The dividing lines do not represent distinct changes over a short distance. The change from one area to another is gradual.

Figure A. Locations for lentil quality testing in 2022 and the corresponding soil zones. Figure was modified from material provided by the Saskatchewan Ministry of Agriculture.

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This report includes three sections: **1)** 2022 green lentil varieties, **2)** red lentil varieties, and **3)** specialty lentil varieties. Each section includes ten subsections for the results of the following quality parameters:

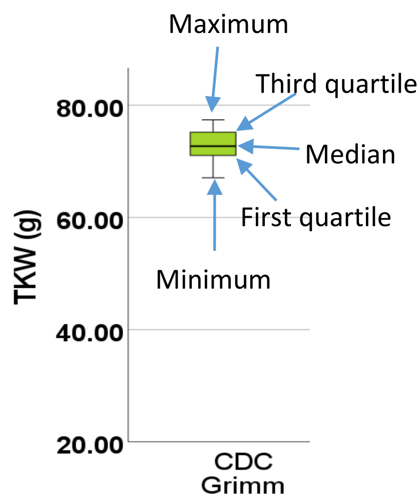
1. 1000 seed weight
2. Seed size distribution
3. Split amount
4. Other damage
5. Hardness of whole seed
6. Ash content
7. Protein content
8. Colour (*L*, a*,* and *b**)
9. Hausner Ratio
10. Particle size

The **method** used to evaluate each quality parameter is provided at the beginning of each subsection.

For the **results**, a **Box and Whisker** plot is first provided to show the full dataset of each variety, where the minimum, median, maximum, first quartile (the median of the lower half of the dataset), and third quartile (the median of the upper half of the dataset).

In addition, a **Bar** graph is included to provide the mean values by variety to show the variety performance and by location to show how the locations differed.

Furthermore, the effects of variety, location, and variety x location on the characteristic are given in a **table**.



For **statistics**, a one-way analysis of variance (ANOVA) along with a post-hoc Tukey test (SPSS, Chicago, IL, USA) was performed to identify the differences in the quality parameters, including TKW, seed size, seed hardness, split + cracked seed coat, other damage, protein, ash, Hausner ratio, colour, and particle size, by variety and by location.

A two-way analysis of variance (ANOVA) was conducted to determine the effects of variety, location, and their interaction on each parameter.

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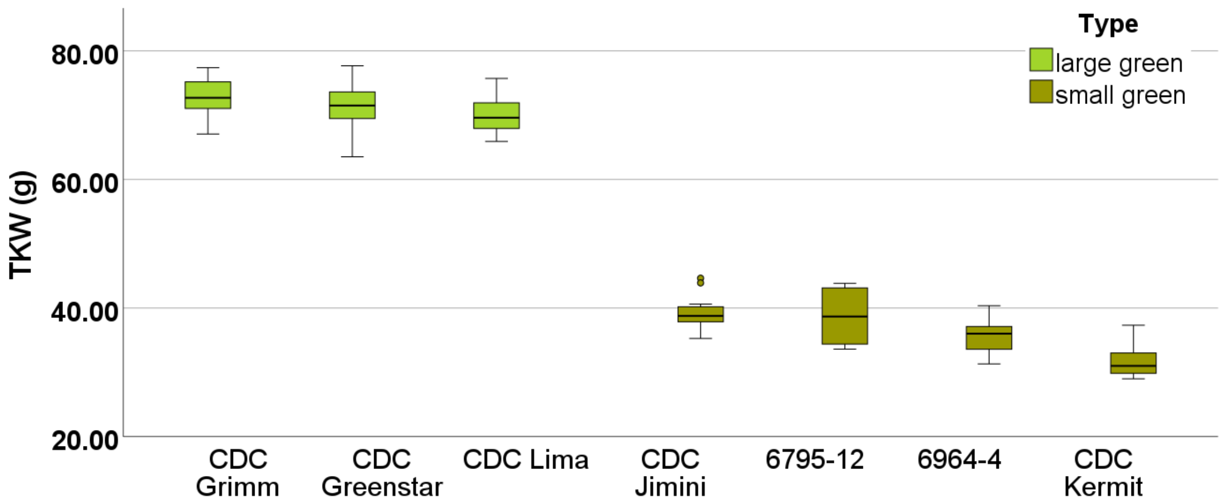
1) 2022 Green Lentil Quality

1. 1000 Seed Weight

Method: Seed weight is an important parameter to indicate seed size and yield production. This test was conducted by weighing 300 seeds with duplicated measurements per sample, and the 1000 seed weight (TKW) was reported.

Results: Figure 1.1.1 Box and Whisker plot of green lentils for TKW resulting from 6 locations. Results by type (large and small lentils) were reported from highest to lowest.



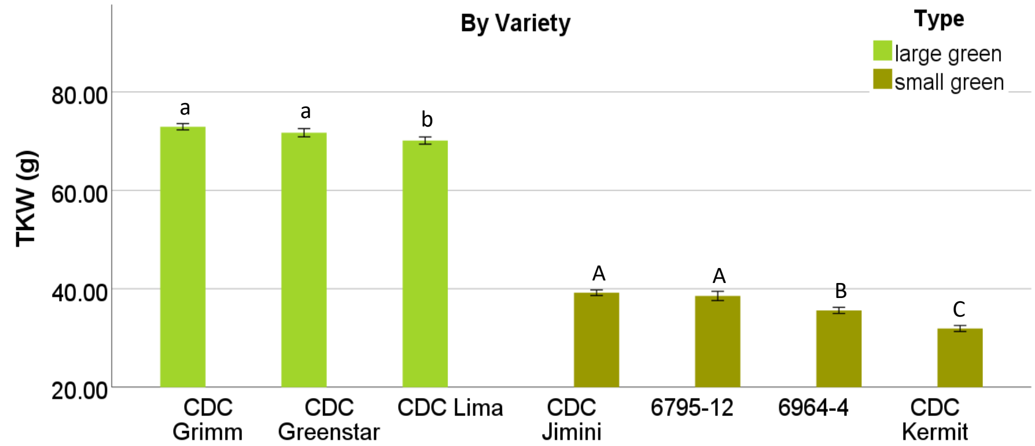
Large green:

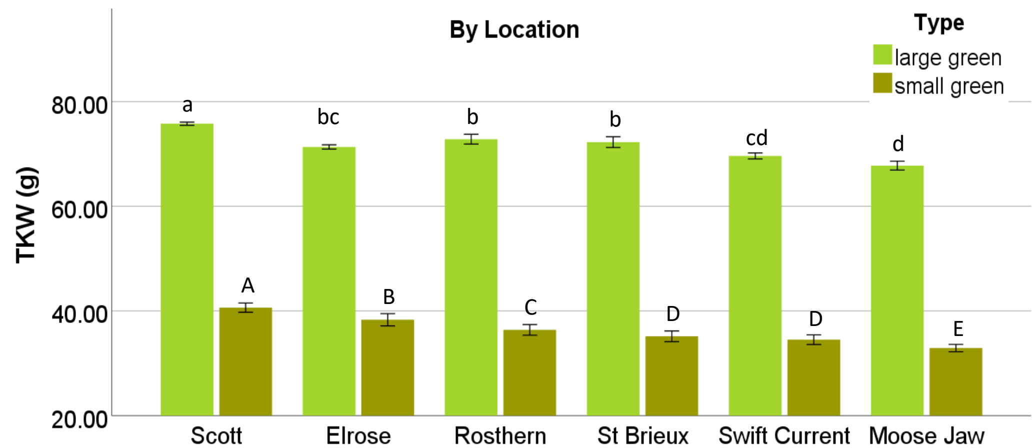
- CDC Grimm had the largest TKW with small variability.
- CDC Greenstar had a larger variability.

Small green:

- CDC Jimini had the largest TKW and a small variability.
- Line 6795-12 had a large variability.
- CDC Kermit was the smallest in TKW.

Figure 1.1.2. Mean TKW of green lentils by variety (top) and by location (bottom). Each bar represents mean ± one standard error.





Note: Small letters indicated significant differences (p<0.05) by large green variety. Capital letters indicated significant differences (p<0.05) by small green variety.

By Variety:

- **Large green:** Means ranged from 70 g to 73 g.
- **Small green:** TKW of CDC Kermit was ~7 g lower than CDC Jimini and line 6795-12.

By Location: An 8 g difference was observed from highest (Scott) to lowest (Moose Jaw) for both large and small green lentils.

Table 1.1. Effects of variety and location.

	Large green	Small green
Variety	***	***
Location	***	***
Variety x Location	*	***

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

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2. Seed Size Distribution

Method: 250 g of seeds were placed on a series of round-hole opening sieves. The weight of seeds retained on each sieve was determined and reported as % of seeds retained. Duplicated measurements were performed.

Sieves used for faba beans:

a. #18R: 7.14 mm
b. #16R: 6.35 mm
c. #14R: 5.56 mm
d. #12R: 4.76 mm
e. #10R: 3.97 mm

Results: Table 1.2. Seed size distribution (%) of each green lentil variety. Data represent mean ± one standard deviation.

Variety	> # 18R (%)	> # 16R (%)	> # 14R (%)	> # 12R (%)	> # 10R (%)	Below # 10R (%)
CDC Greenstar	2.1 ± 1.2[a]	67.1 ± 9.1[a]	26.8 ± 7.8[b]	3.0 ± 1.6[b]	1.0 ± 0.8[a]	0.9 ± 1.0[a]
CDC Grimm	2.4 ± 1.5[a]	68.8 ± 5.2[a]	24.6 ± 5.5[c]	3.1 ± 0.8[b]	1.1 ± 0.6[a]	0.8 ± 0.9[a]
CDC Lima	0.0 ± 0.0[b]	40.3 ± 8.5[b]	52.4 ± 5.6[a]	5.6 ± 2.4[a]	0.8 ± 0.6[a]	0.8 ± 0.7[a]
6795-12	0.0 ± 0.0	0.1 ± 0.3[A]	2.9 ± 1.9[A]	65.0 ± 11.2[A]	32.3 ± 13.9[C]	1.5 ± 0.5[C]
6964-4	0.0 ± 0.0	0.0 ± 0.0[A]	0.1 ± 0.4[B]	44.1 ± 14.2[B]	53.1 ± 13.3[B]	2.7 ± 1.2[B]
CDC Jimini	0.0 ± 0.0	0.0 ± 0.1[A]	0.1 ± 0.2[B]	46.0 ± 12.6[B]	51.3 ± 11.8[B]	2.6 ± 1.2[B]
CDC Kermit	0.0 ± 0.0	0.0 ± 0.0[A]	0.1 ± 0.2[B]	10.8 ± 5.3[C]	80.4 ± 3.8[A]	8.8 ± 4.0[A]

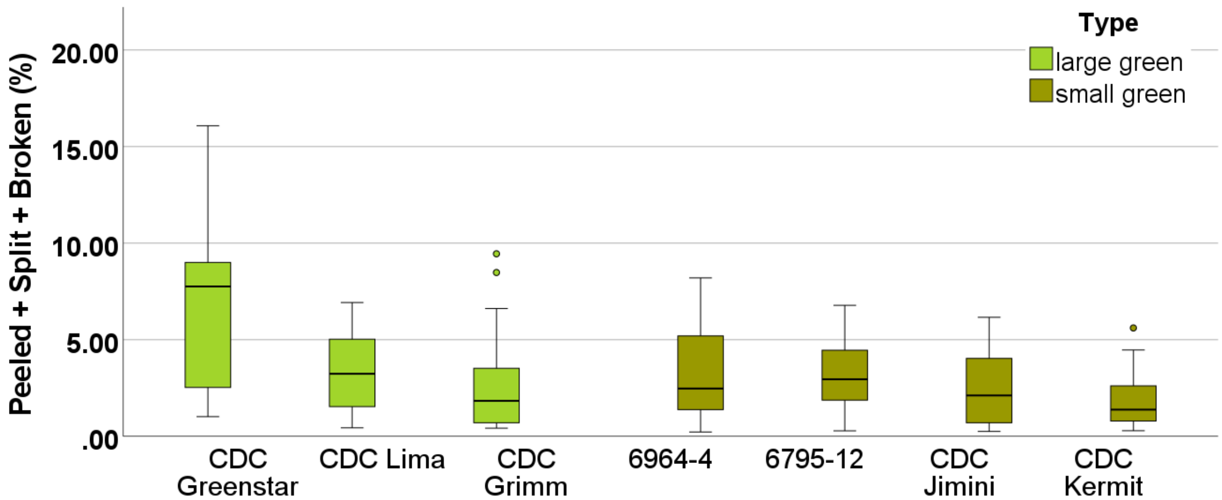
Note: Small letters indicated significant differences ($p<0.05$) between large green varieties. Capital letters indicated significant differences ($p<0.05$) between small green varieties.

- The majority of large green retained onto sieves #16 and #14.
- The small green tended to fall into #12 and #10 sieves.

3. Peeled + Split + Broken

Method: 50 grams of each sample was used for evaluation, and damaged seeds were selected by hand. Results included splits, cracks, seed coat damage, partially missing hull, and partially missing cotyledon.

Results: Figure 1.3.1. The Box and Whisker plot of the peeled + split + broken green lentils resulting from 6 locations. Results by type (large and small lentils) were reported from highest to lowest.



Large green:

- CDC Greenstar had the most damage with large variability.

Small green:

- CDC Kermit had the smallest damage with the least variability.
- Line 6964-4 had the largest damage with large variability.

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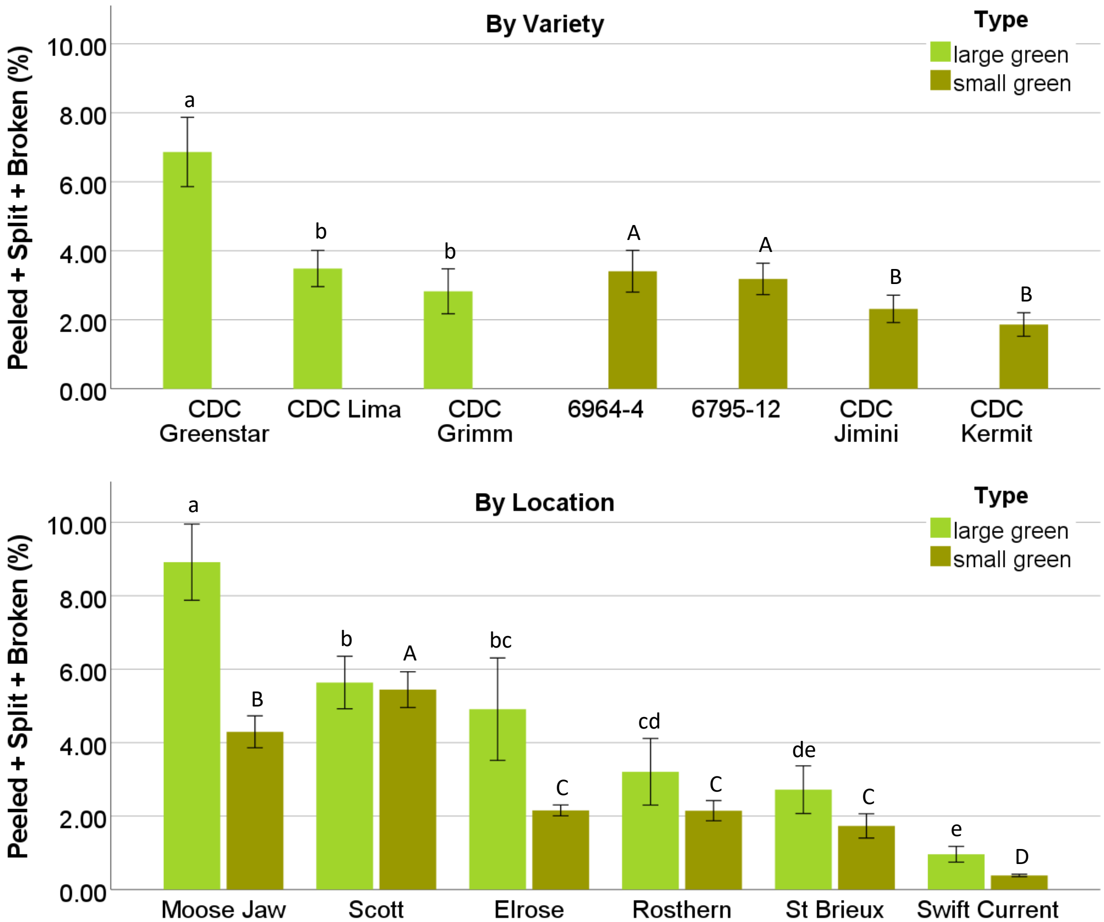
Figure 1.3.2. Mean peeled + split + broken (%) of green lentils by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by large green variety. Capital letters indicated significant differences (p<0.05) by small green variety.

By Variety:

- **Large green:** The amount of peeled + split + broken seeds for CDC Greenstar was dobule of CDC Lima and Grimm.
- **Small green:** CDC Kermit and Jimini were ~1% lower than line 6964-4 and line 6795-12.

By Location:

- **Large green:** The amount of peeled + split + broken was extremely high in Moose Jaw, which was *% higher than Swift Current.
- **Small green:** Swift Current (lowest) was 5% lower than Scott (highest).

Table 1.3. Effects of variety and location.

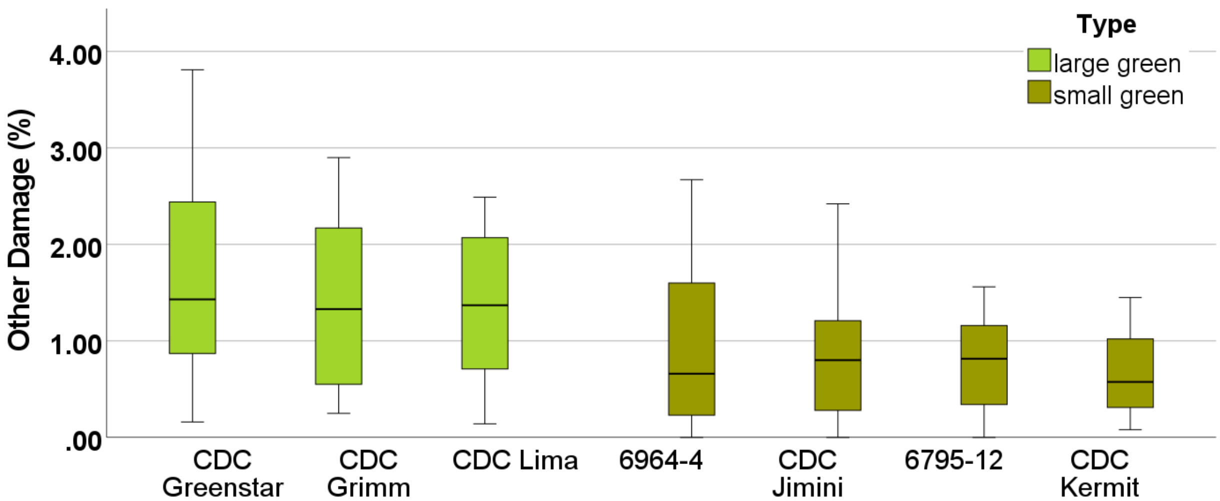
	Large green	Small green
Variety	***	***
Location	***	***
Variety x Location	***	**

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

4. Other Damage

Method: 50 grams of each sample was used for evaluation, and damaged seeds were selected by hand. Other damage included sprouting, distinct immaturity, distinct deterioration or discolouration by weather or disease, insect damage, heat damage, and any other damage that affects appearance.

Results: Figure 1.4.1. Box and Whisker plot of green lentils for other damage resulting from 6 locations. Results by type (large and small lentils) were reported from highest to lowest.



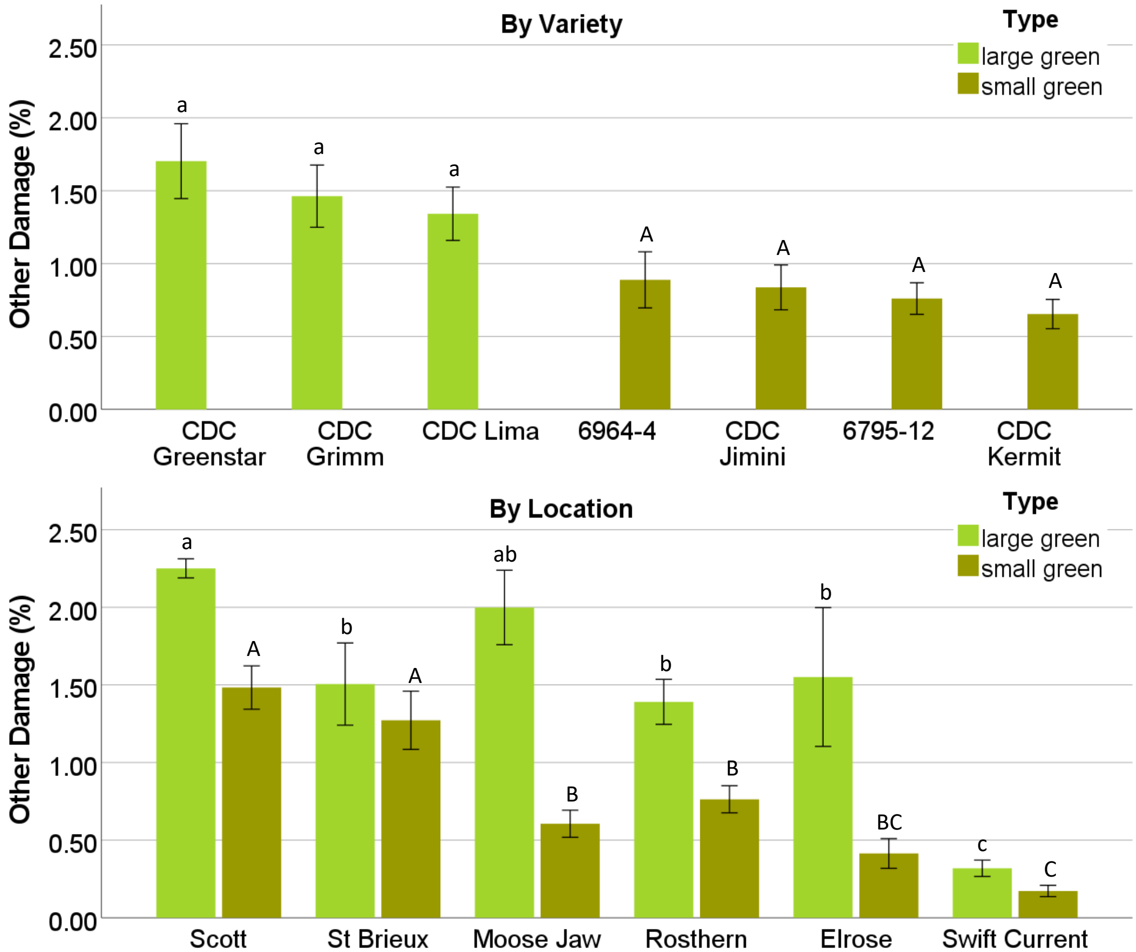
Large green:

- CDC Lima had the lowest other damage.

Small green:

- CDC Kermit and Line 6795-12 were similar.

Figure 1.4.2. Mean other damage of green lentils by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by large green variety. Capital letters indicated significant differences (p<0.05) by small green variety.

By Variety: Large green in general had a higher other damage than small green.

By Location: Swift Current had the lowest other damage for both seed types.

- **Large green:** Scott and Moose Jaw had a high other damage amount.
- **Small green:** high in Scott and St Brieux.

Table 1.4. Effects of variety and location.

	Large green	Small green
Variety	*NS*	*NS*
Location	***	***
Variety x Location	***	**

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

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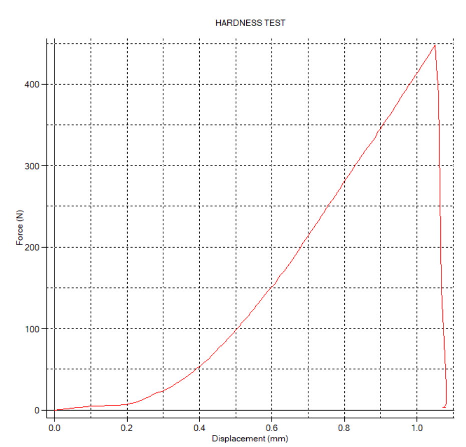
5. Hardness of Whole Seed

Seed hardness is an important parameter to indicate milling yield and cooking quality. Seed hardness is affected by seed size, shape, density, composition, etc.

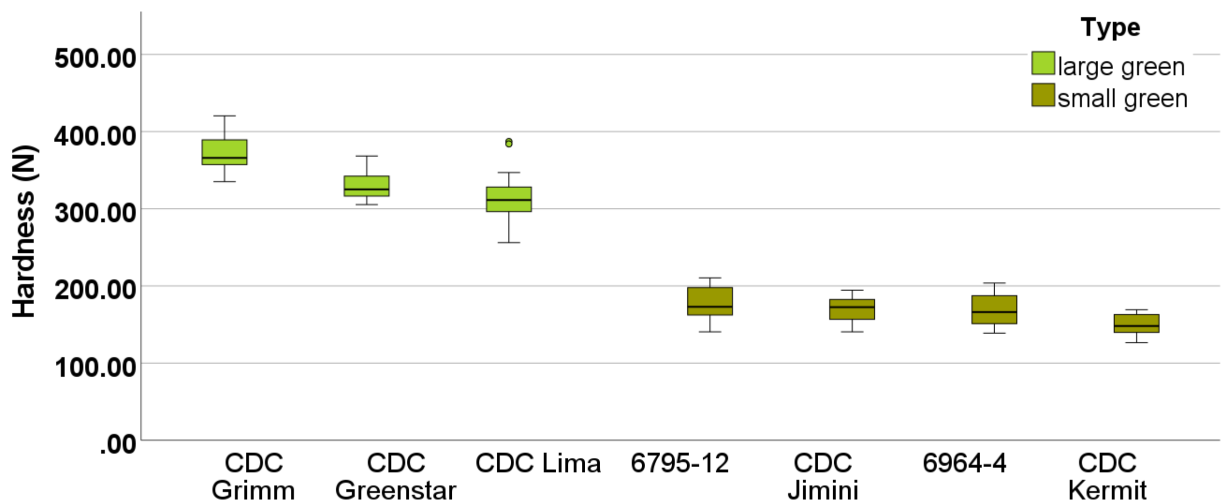


Method:

Seed hardness was determined by measuring the force of breaking a seed using a texture analyzer (TMS-Pro, Food Technology Corporation, USA) equipped with a 2500 N load cell with a modified method from Karami et al. (2017) and Lovas-Kiss (2020)[1].

In brief, a seed was placed under the 10 mm cylinder probe that was lowered with a speed of 50 mm/min. The forces to lower the probe till a seed was broken were monitored. The mean peak force (N) of 10 seeds was reported.

Results: Figure 1.5.1. Box and Whisker plot of green lentils for seed hardness (N) resulting from 6 locations. Results by type (large and small lentils) were reported from highest to lowest.

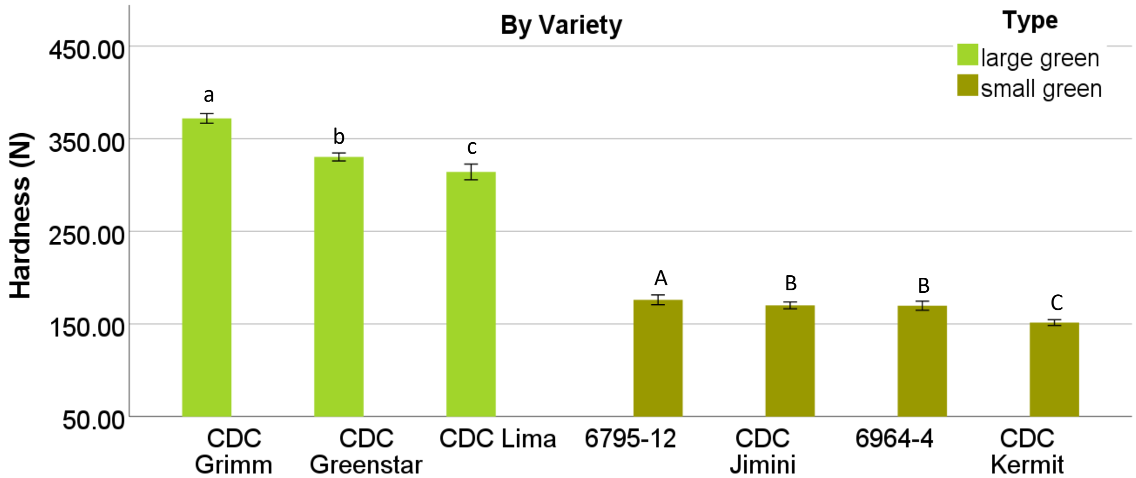


Large green: CDC Grimm had the largest hardness. CDC lima was smallest but had a larger variability.
Small green: CDC 1089 had the lowest hardness with small variability.

[1] Karami, S., Sabzalian, M. R., Rahimmalek, M., Saeidi, G., & Ghasemi, S. (2017). Interaction of seed coat color and seed hardness: An effective relationship which can be exploited to enhance resistance to the safflower fly (Acanthiophilus helianthi) in Carthamus spp. Crop Protection, 98, 267-275.

Lovas‐Kiss, Á., Vincze, O., Kleyheeg, E., Sramkó, G., Laczkó, L., Fekete, R., ... & Green, A. J. (2020). Seed mass, hardness, and phylogeny explain the potential for endozoochory by granivorous waterbirds. Ecology and Evolution, 10(3), 1413-1424.

Figure 1.5.2. Mean seed hardness of green lentils by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by large green variety. Capital letters indicated significant differences (p<0.05) by small green variety.

By Variety: Hardness of large green was higher than small green.

- **Large green:** Hardness of CDC Grimm was 57 N higher than CDC Lima.
- **Small green:** Line 6795-12 was 25 N higher than CDC Kermit.

By Location:

- **Large green:** Swift Current was 57 N higher than Moose Jaw.
- **Small green:** Scott was 45 N higher than Moose Jaw.

Table 1.5. Effects of variety and location.

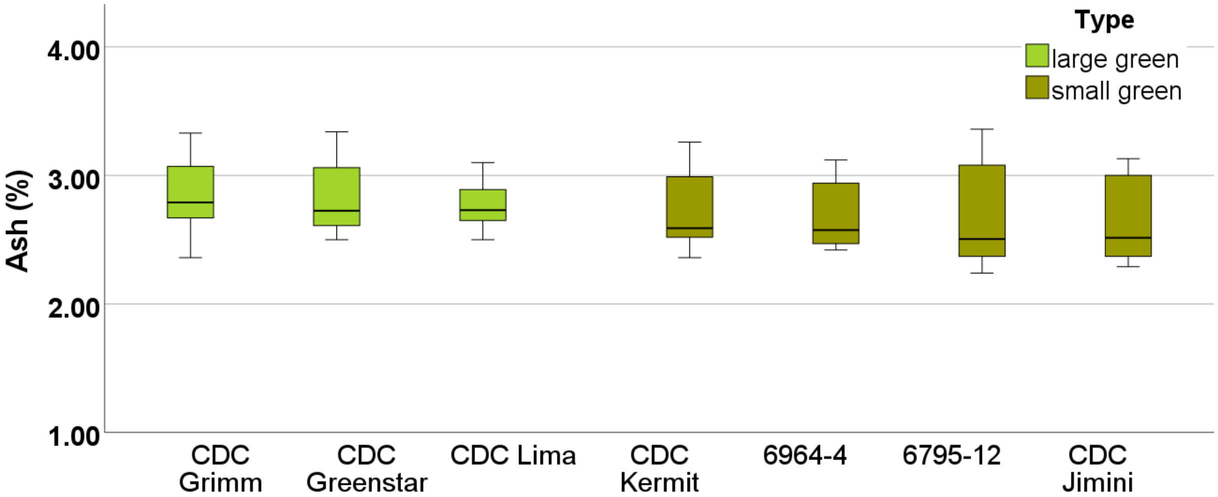
	Large green	Small green
Variety	***	***
Location	***	***
Variety x Location	***	***

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

6. Ash Content

Method: Ash content (%) was determined using AACC 08-01.01[2] with modification. Samples were heated at 560°C till they turned white. Duplicated measurements were performed for each sample, and the average was reported on a dry basis (d.b.).

Results: Figure 1.6.1. Box and Whisker plot of green lentils for ash content (%) resulting from 6 locations. Results by type (large and small lentils) were reported from highest to lowest.



Large green:

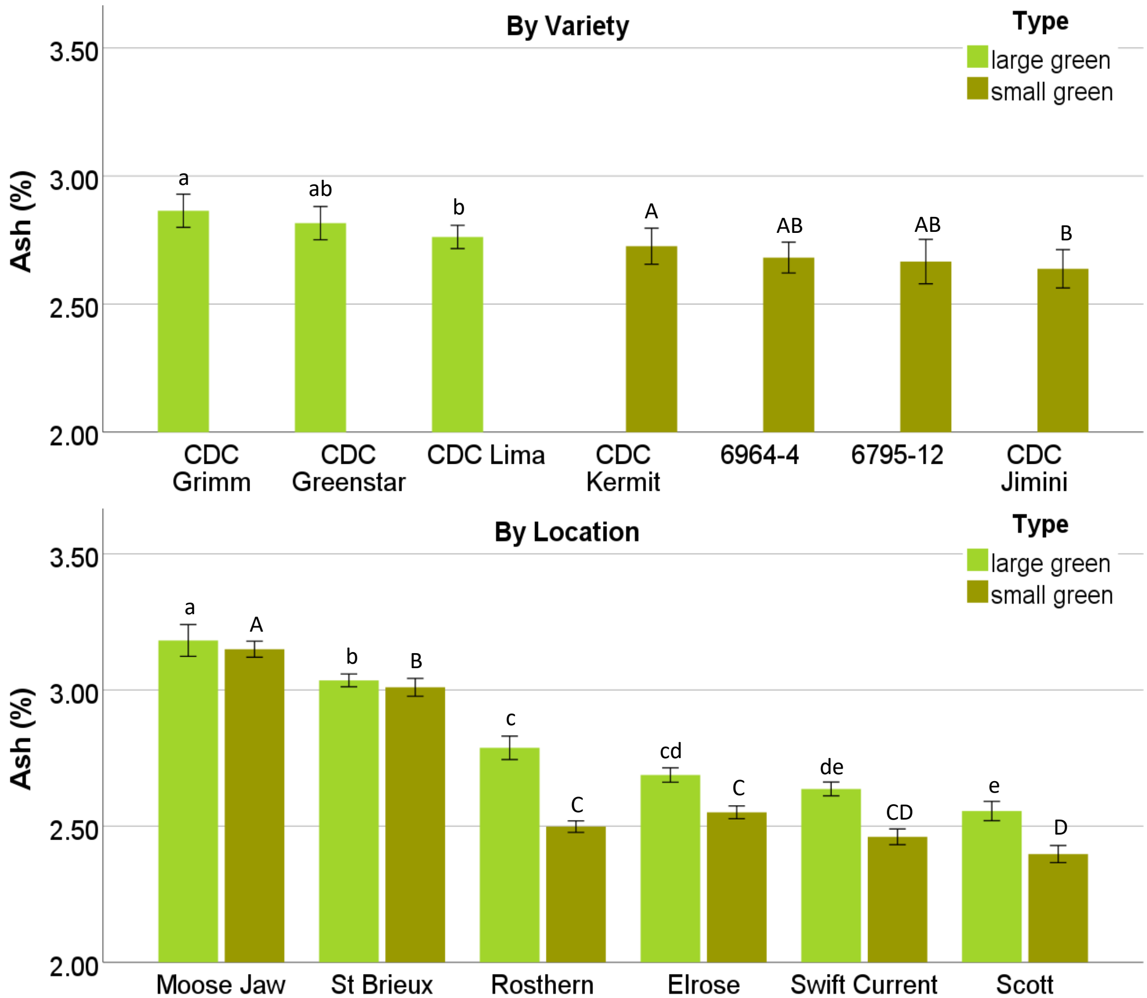
- CDC Lima was the lowest in ash with the least variability.

Small green:

- Line 6795-12 had a large variability.

[2] AACC (1999). American Association of Cereal Chemists International. Approved methods of analysis (11th ed.). The Saint Pauls Association: Saint Paul, MN.

Figure 1.6.2. Mean ash of green lentils by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by large green variety. Capital letters indicated significant differences (p<0.05) by small green variety.

By Variety:

- **Large green:** Only a 0.1% difference was found from highest to lowest.
- **Small green:** Less than 0.1% difference was found from highest to lowest.

By Location: Location effect played a role. Moose Jaw had the highest ash content for both seed types, while seeds from Scott had the lowest ash level.

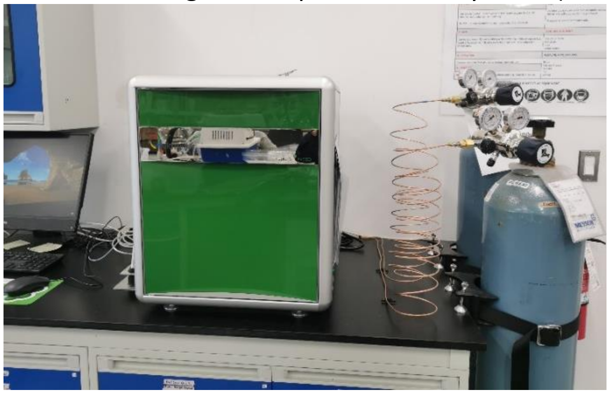
Table 1.6. Effects of variety and location.

	Large green	Small green
Variety	**	*
Location	***	***
Variety x Location	*	**

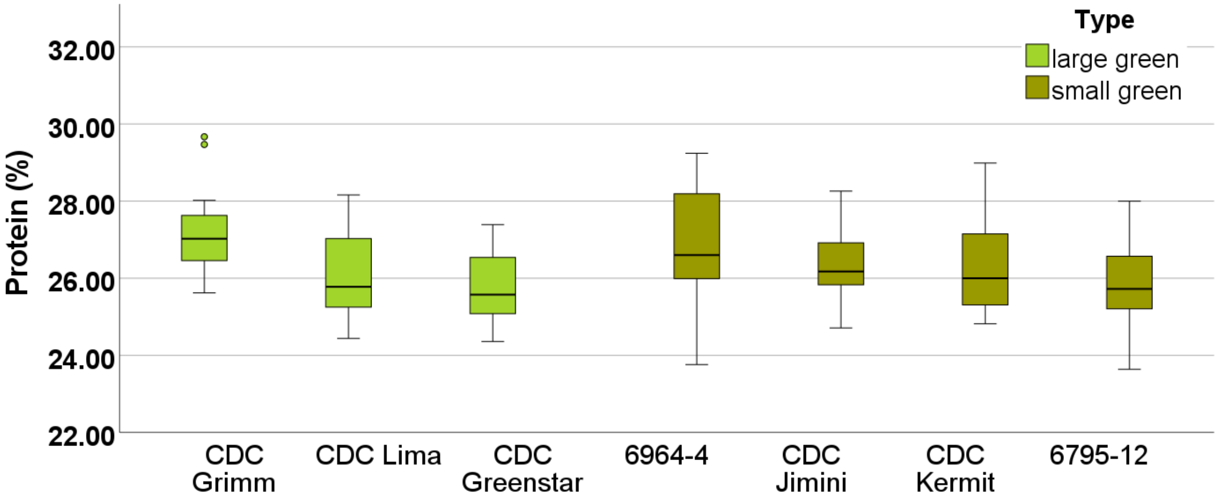
Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

7. Protein Content

Method: The protein content (%) of each flour was determined through AACC 46-30[2] using the combustion method through a Rapid N Exceed (Elementar, USA). Duplicated measurements were performed for each sample, and the average was reported on a dry basis (d.b.).



Results: Figure 1.7.1. Box and Whisker plot of green lentils for protein content (%) resulting from 6 locations. Results by type (large and small lentils) were reported from highest to lowest.



Large green:

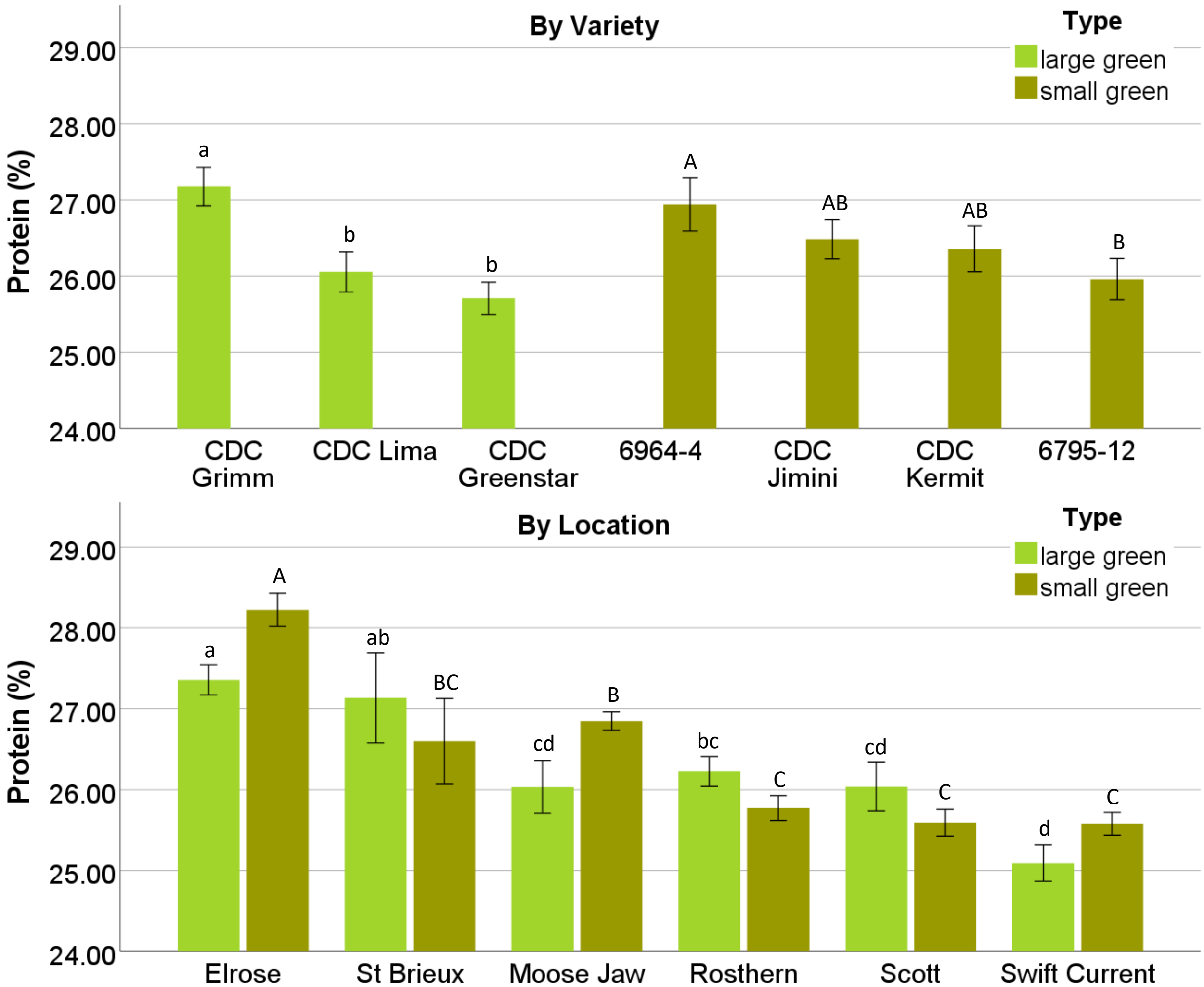
- CDC Grimm had the highest protein level with small variability.

Small green:

- Line 6964-4 had the highest protein but also a large variability.

[2] AACC (1999). American Association of Cereal Chemists International. Approved methods of analysis (11th ed.). The Saint Pauls Association: Saint Paul, MN.

Figure 1.7.2. Mean protein of green lentils by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by large green variety. Capital letters indicated significant differences (p<0.05) by small green variety.

By Variety:

- **Large green:** Protein of CDC Grimm was 1.5% higher than CDC Greenstar.
- **Small green:** Line 6964-4 was 1% higher than line 6795-12.

By Location: Elrose had the highest protein for both types, while Swift Current had the lowest protein for both types.

Table 1.7. Effects of variety and location.

	Large green	Small green
Variety	***	*
Location	***	***
Variety x Location	*NS*	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

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8. Colour

Method: The absolute colour of each flour was determined using the Konica Minolta CR-400 Chroma meter, where *L*, a*,* and *b** values were reported. Three measurements were made for each sample, and the mean value was reported.

- ***L* (lightness):*** white (100) to black (0)
- ***a*:*** red (+) to green (-)
- ***b*:*** yellow (+) to blue (-)

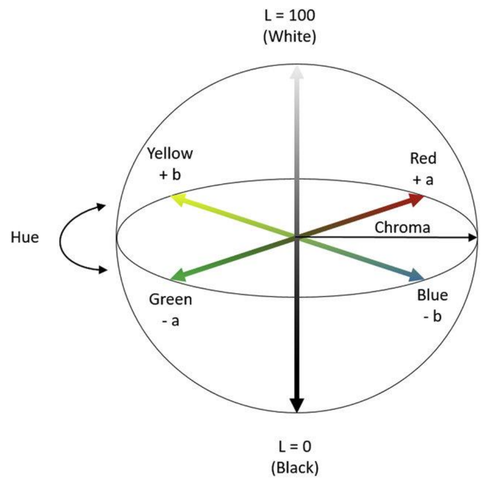
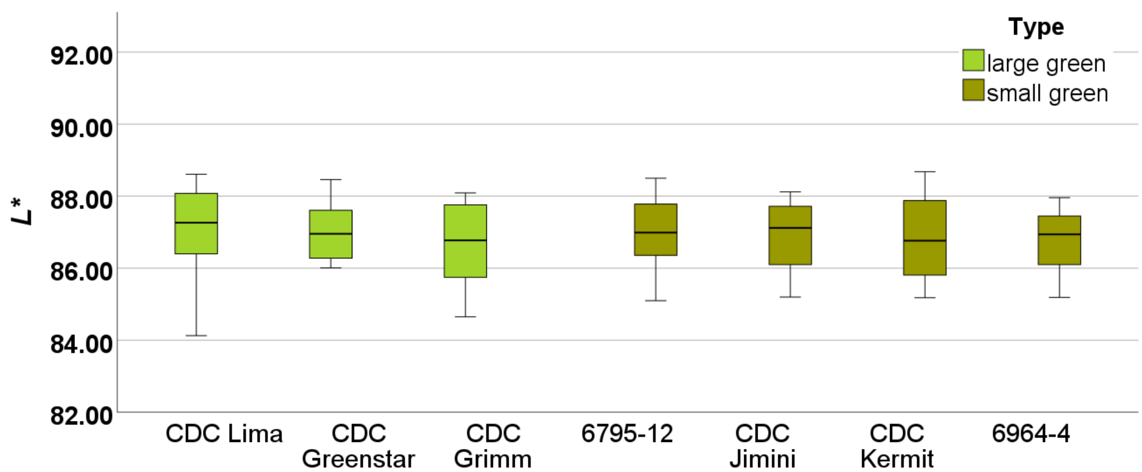


Figure 1.8.1. The CIELAB color spacediagram[3].

a) ***L* (lightness):*** white (100) to black (0)

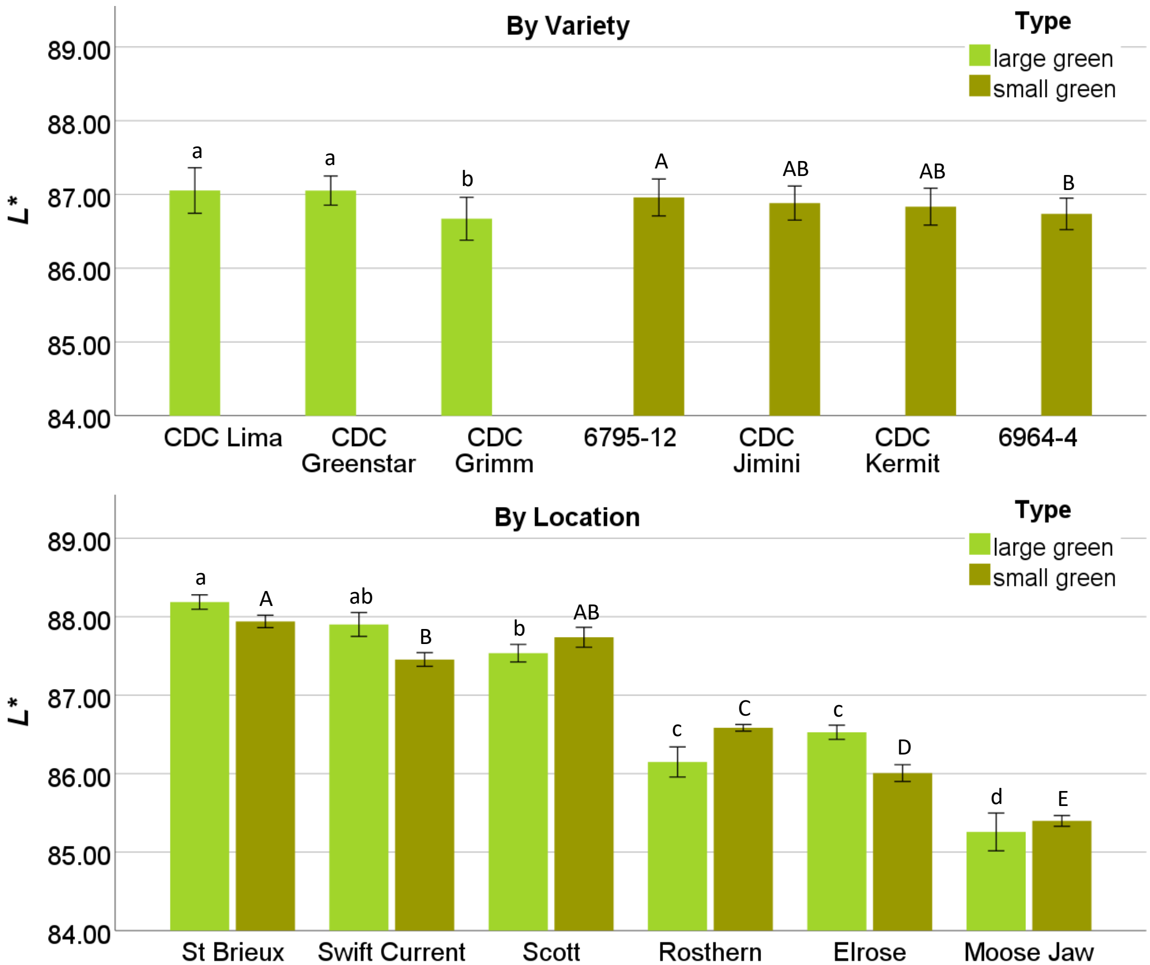
Results: Figure 1.8.2. Box and Whisker plot of green lentils for lightness resulting from 6 locations. Results by type (large and small lentils) were reported from highest to lowest.



- Lightness for green lentils was similar.

[3] Ly, B. C. K., Dyer, E. B., Feig, J. L., Chien, A. L., & Del Bino, S. (2020). Research techniques made simple: cutaneous colorimetry: a reliable technique for objective skin color measurement. *Journal of Investigative Dermatology*, *140*(1), 3-12.

Figure 1.8.3. Mean lightness of green lentils by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by large green variety. Capital letters indicated significant differences (p<0.05) by small green variety.

By Variety:

- **Large green:** Only a 0.4 unit difference was found between 3 varieties.
- **Small green:** Only a 0.2 unit difference was found between 4 varieties.

By Location: Location played a significant role. The mean differences of *L** values from highest to lowest were over 2.5 units for both types.

Table 1.8.1. Effects of variety and location.

	Large green	Small green
Variety	**	*NS*
Location	***	***
Variety x Location	**	**

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

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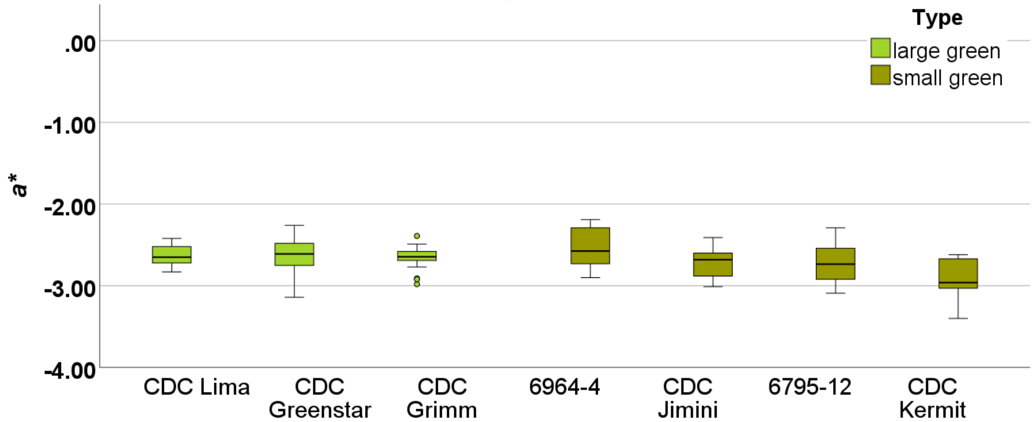
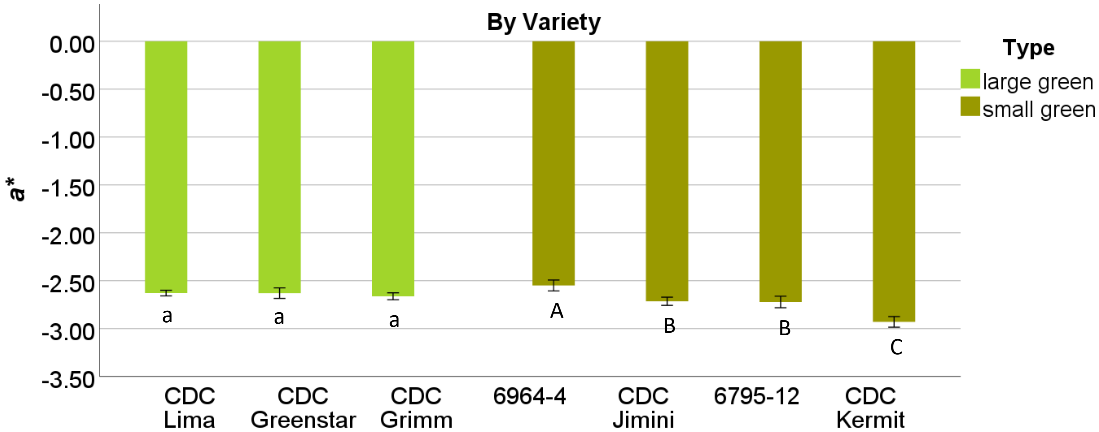
b) ***a*:*** red (+) to green (-)

Results: Figure 1.8.4. Box and Whisker plot of green lentils for *a** resulting from 6 locations. Results by type (large and small lentils) were reported from highest to lowest.



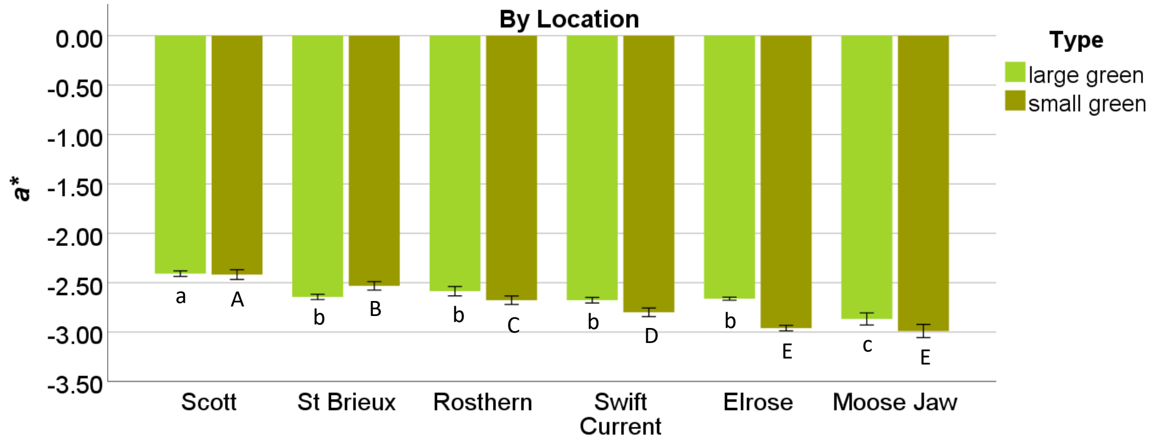
Large green: All had similar greenness.
Small green: CDC Kermit had the greatest greenness.

Figure 1.8.5.1. Mean *a** of green lentils by variety. Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences ($p<0.05$) by large green variety. Capital letters indicated significant differences ($p<0.05$) by small green variety.

Figure 1.8.5.2. Mean *a** of green lentils by location. Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by large green variety. Capital letters indicated significant differences (p<0.05) by small green variety.

By Variety:

- **Large green:** no differences (p>0.05).
- **Small green:** A 0.4 unit difference was found from highest to lowest.

By Location: About 0.5 unit of difference was observed from highest to lowest for both types.

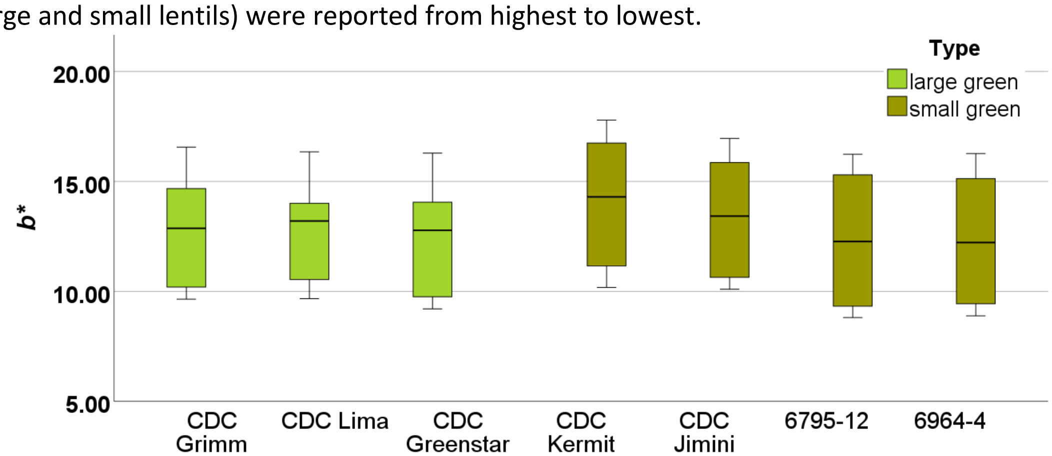
Table 1.8.2. Effects of variety and location.

	Large green	Small green
Variety	*NS*	***
Location	***	***
Variety x Location	**	***

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

c) ***b*:*** yellow (+) to blue (-)

Results: Figure 1.8.6. Box and Whisker plot of green lentils for *b** resulting from 6 locations. Results by type (large and small lentils) were reported from highest to lowest.



- Overall, *b** values for small green were higher than large green.

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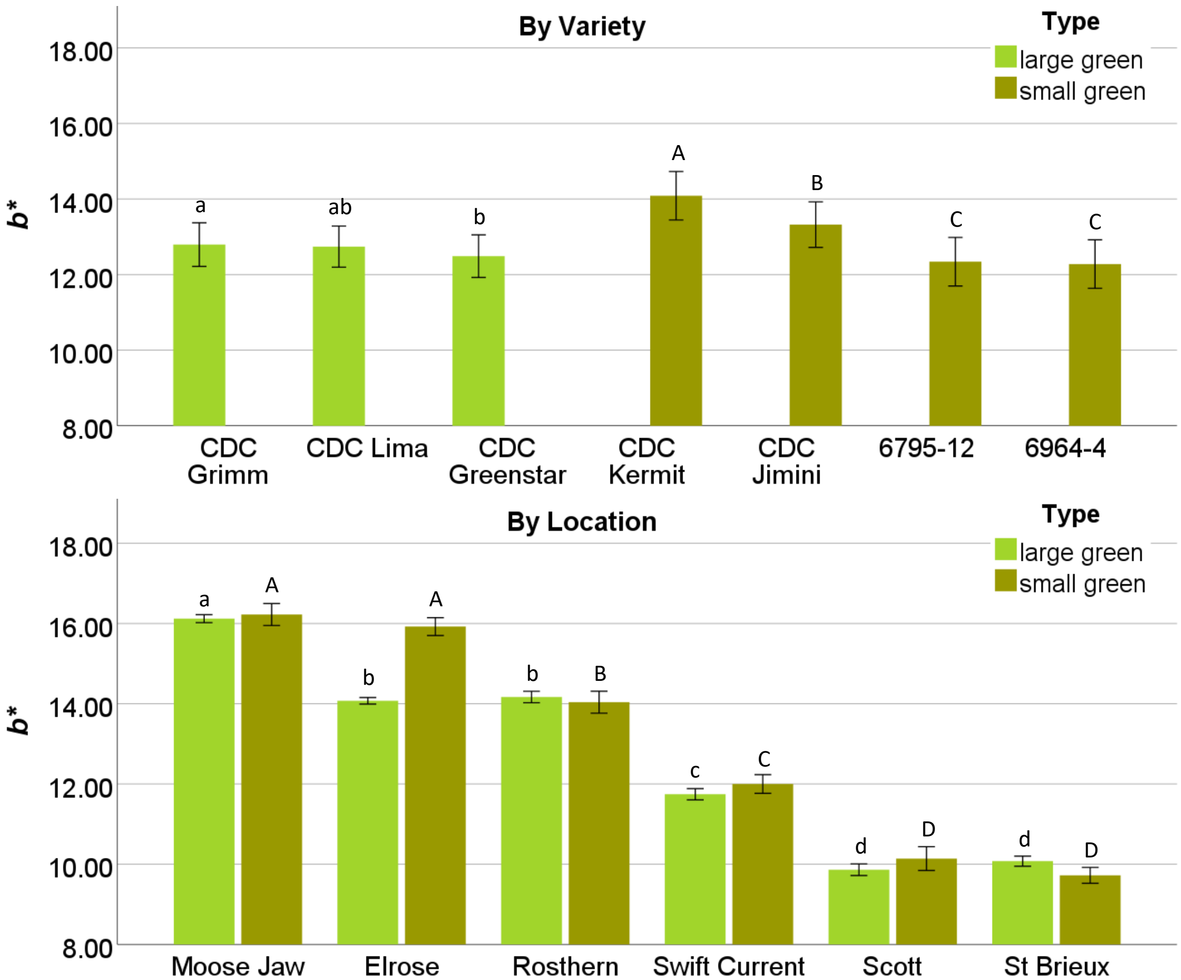
Figure 1.8.7. Mean *b** of green lentils by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by large green variety. Capital letters indicated significant differences (p<0.05) by small green variety.

By Variety:

- **Tannin:** only 0.4 unit of difference was observed.
- **Zero Tannin:** CDC Kermit had greater yellowness.

By Location: played a role on both types. Yellowness of both seed types from Moose Jaw was about 6 units stronger than St Brieux.

Table 1.8.3. Effects of variety and location.

	Large green	Small green
Variety	*	***
Location	***	***
Variety x Location	*NS*	*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

9. Hausner Ratio

Hausner ratio measures the ratio of tapped density to loose bulk density, indicating the flow-ability and the compressibility of the flour after milling. Hausner ratio is an important parameter in food products handling, packaging, storage, processing, and distribution. It is useful in the specification of products derived from size reduction or drying processes. Usually, the lower the flow-ability a flour, the more compressible it becomes[4].

Method: The bulk and tapped volumes of 10 g of flour were determined using a 25 mL graduated cylinder. Duplicated measurements were made for each flour, and the Hausner ratio is calculated as:

Hausner ratio = $\frac{Tapped\ density}{Loose\ bulk\ density} = \frac{Bulk\ volume\ (mL)}{Tapped\ volume\ (mL)}$

Table 9. Relationship between powder flow-ability and Hausner ratio.

Type of flow	Hausner ratio
Excellent	1.00-1.11
Good	1.12-1.18
Fair	1.19-1.25
Passable	1.26-1.34
Poor	1.35-1.45
Very poor	1.46-1.59
Very, very poor	>1.59

[4] Buanz, A. (2021). Powder characterization. In *Remington* (pp. 295-305). Academic Press. https://doi.org/10.1016/B978-0-12-820007-0.00016-7

Amankwah, N. Y. A., Agbenorhevi, J. K., & Rockson, M. A. (2022). Physicochemical and functional properties of wheat-rain tree (Samanea saman) pod composite flours. *International Journal of Food Properties*, *25*(1), 1317-1327. https://doi.org/10.1080/10942912.2022.2077367

Aulton, M. E., & Taylor, K. M. G. (2013). *Powder flow* (pp. 189-200). Edinburgh, Scotland: Churchill Livingstone (Elsevier).

Maninder, K., Sandhu, K. S., & Singh, N. (2007). Comparative study of the functional, thermal and pasting properties of flours from different field pea (Pisum sativum L.) and pigeon pea (Cajanus cajan L.) cultivars. *Food chemistry*, *104*(1), 259-267. https://doi.org/10.1016/j.foodchem.2006.11.037

Ogunsina, B. S., Radha, C., & Govardhan Singh, R. S. (2010). *Physicochemical and functional properties of full-fat and defatted Moringa oleifera kernel flour. International Journal of Food Science & Technology, 45(11), 2433–2439.* https://doi.org/10.1111/j.1365-2621.2010.02423.x

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Results: Figure 1.9.1. Box and Whisker plot of green lentils for Hausner ratio resulting from 6 locations. Results by type (large and small lentils) were reported from highest to lowest.

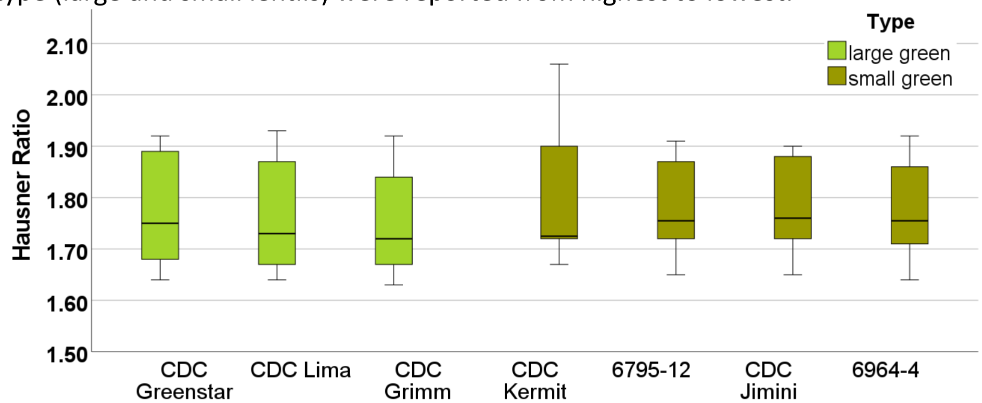
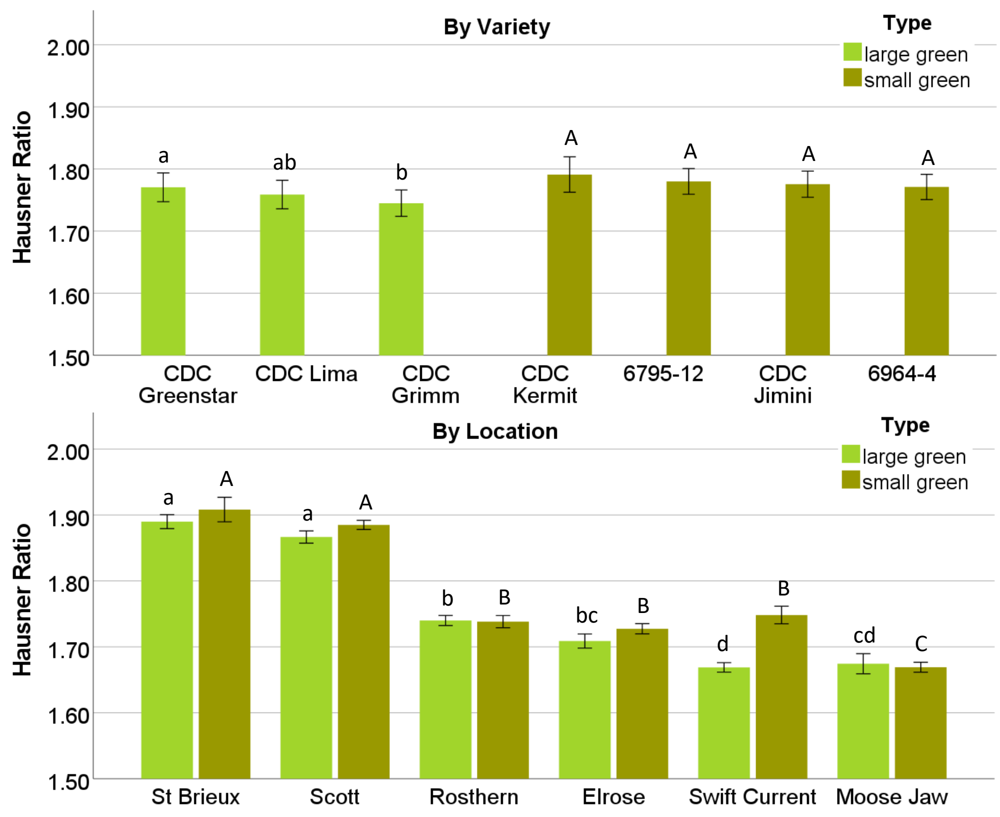


Figure 1.9.2. Mean Hausner ratio of green lentils by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by large green variety. Capital letters indicated significant differences (p<0.05) by small green variety.

- The results of Hausner ratio for 7 varieties across 6 locations were all greater than 1.6, suggesting all green lentil flours are classified as very, very poor flow.

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SASKATCHEWAN pulse Growers

10. Particle Size

Method: The particle size of each flour was measured using the Mastersizer 3000 with a dry sample cell (Malvern Instruments Ltd., Worcestershire, UK). Five measurements were made for each flour, and the averages of D_{90} (µm) and $D_{4,3}$ (µm) were reported.

- **D_{90} (µm):** describes the diameter where 90% of the flour distribution has a smaller particle size and indicates whether the milling process reached the expected fineness.
- **$D_{4,3}$ (µm):** describes the mean diameter over volume.

Results: Figure 1.10.1. Box and Whisker plot of green lentils for D_{90} and $D_{4,3}$ values resulting from 6 locations. Results by type (large and small lentils) were reported from highest to lowest.

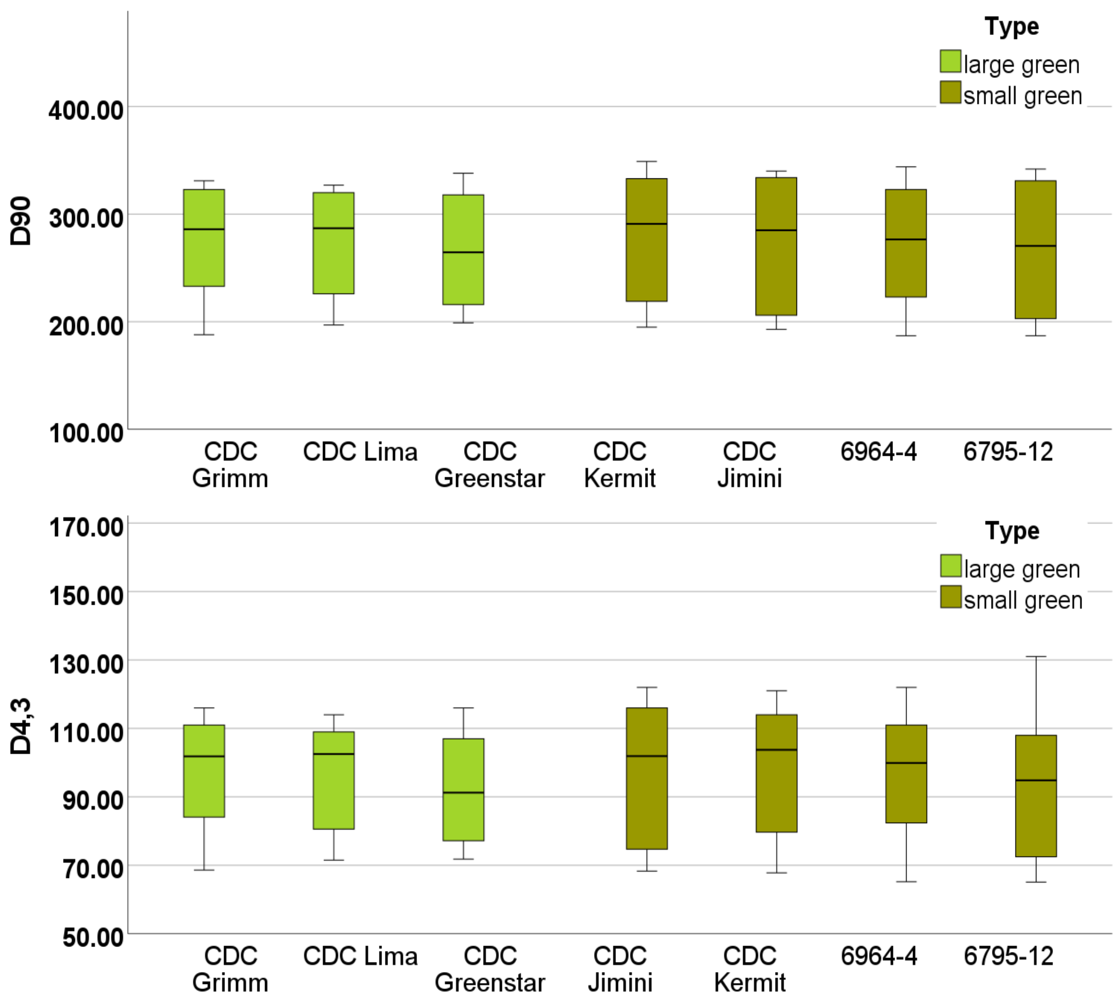
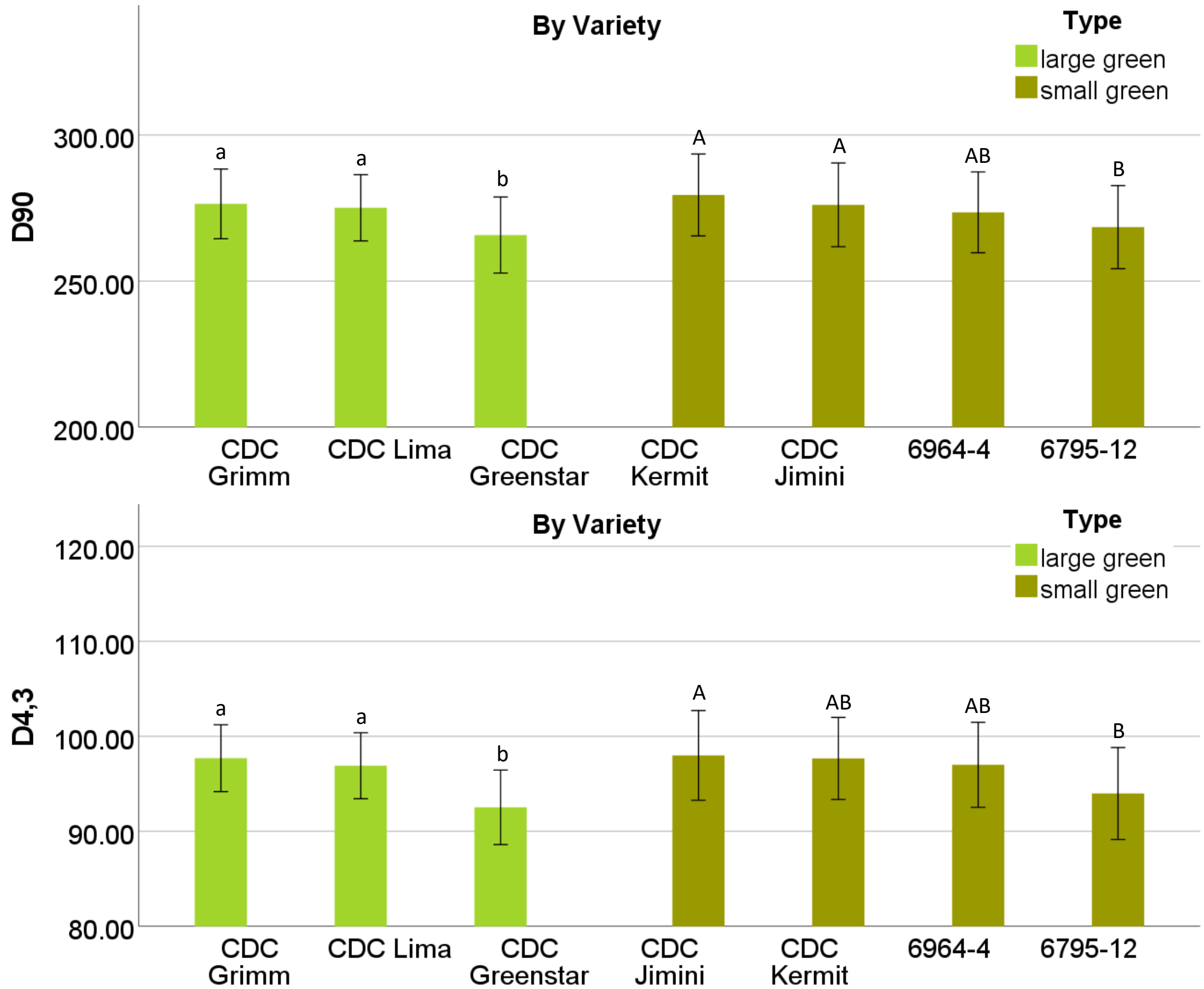


Figure 1.10.2. D_{90} (µm, top) and $D_{4,3}$ (µm, bottom) of green lentil flours by variety. Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by large green variety. Capital letters indicated significant differences (p<0.05) by small green variety.

- **D_{90}:** all below 280 µm.
- **$D_{4,3}$:** The mean diameters of all flours were below 100 µm.

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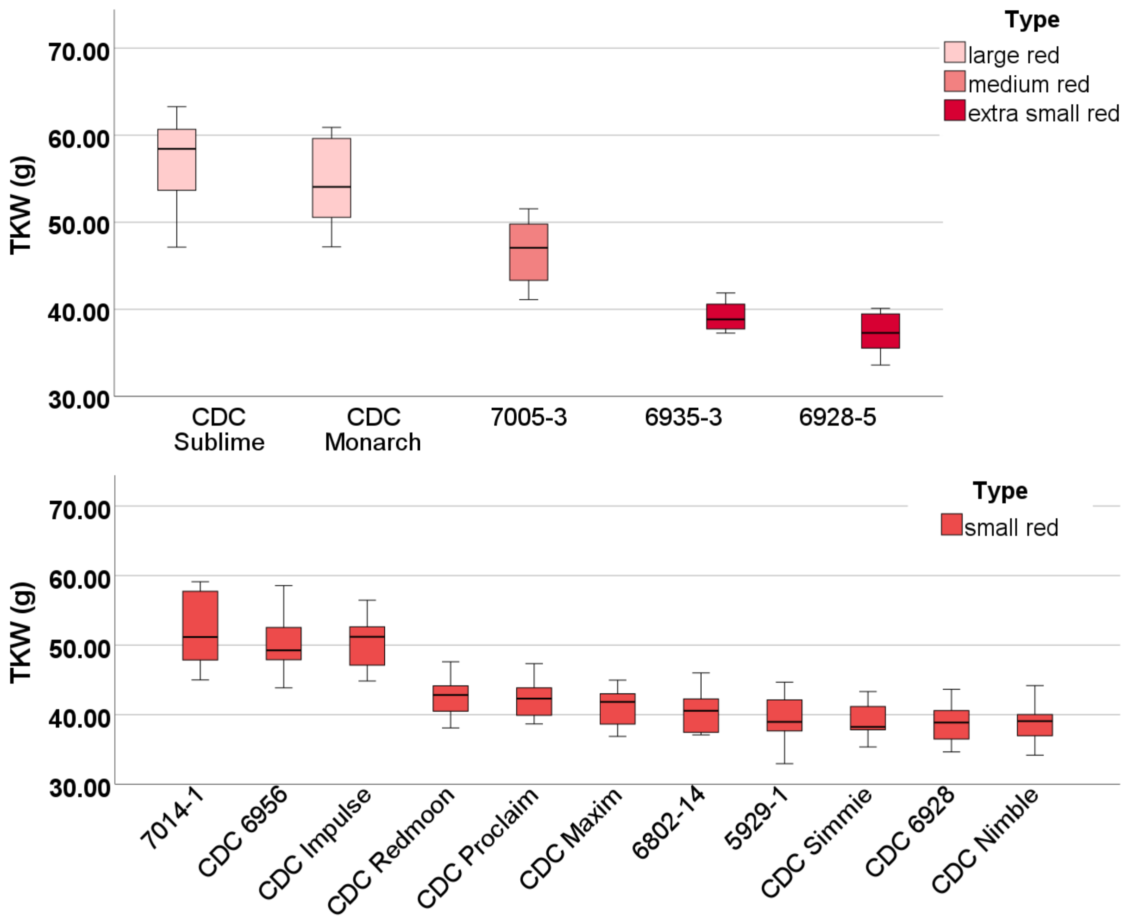
2) 2022 Red Lentil Quality

1. 1000 Seed Weight

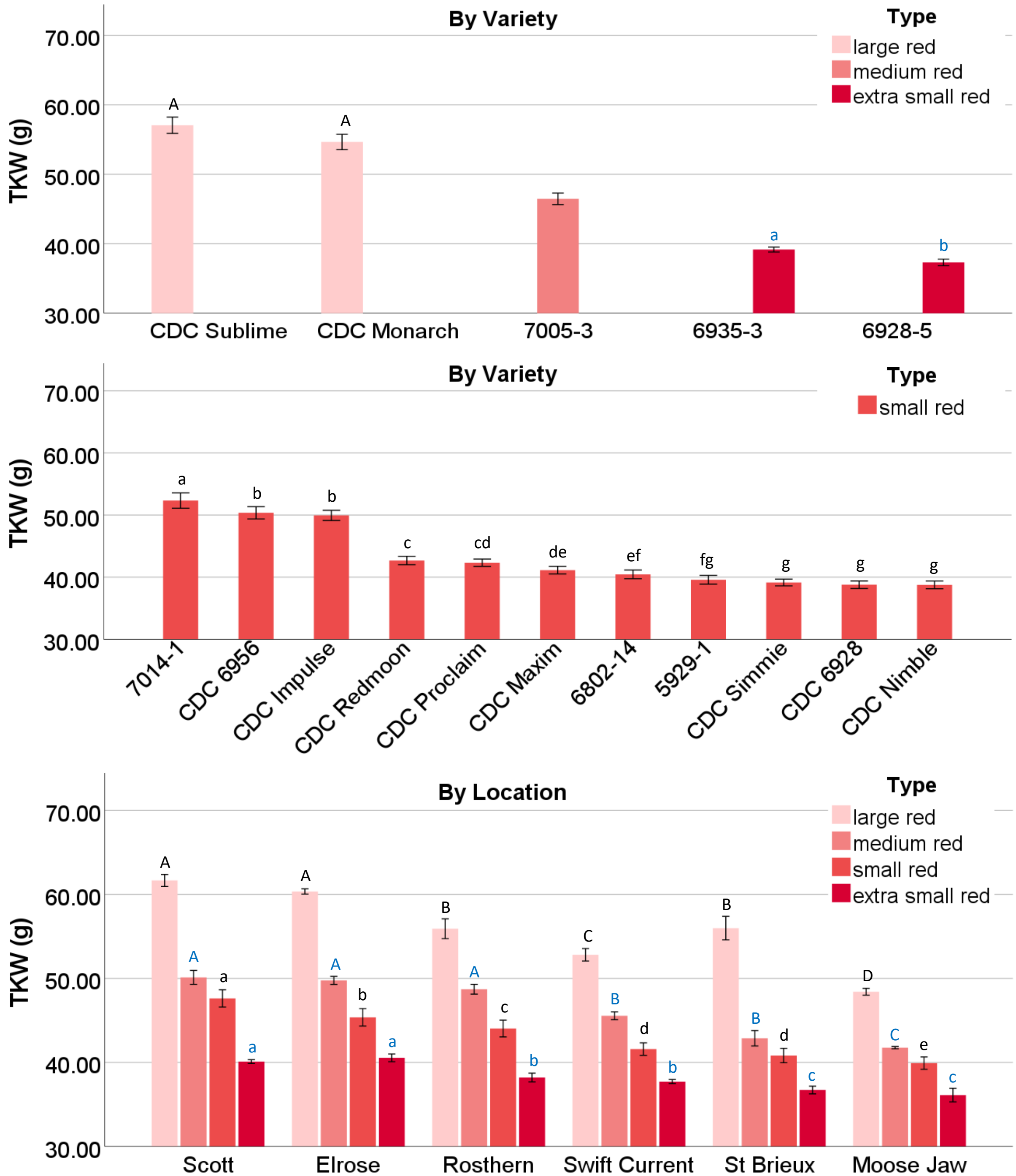
Method: Seed weight is an important parameter to indicate seed size and yield production. This test was conducted by weighing 300 seeds with duplicated measurements per sample, and the 1000 seed weight (TKW) was reported.

Results: Figure 2.1.1 Box and Whisker plot of red lentils for TKW resulting from 6 locations. Results by type were reported from highest to lowest.



- **Large red:** CDC Sublime had a larger variability
- **Medium red:** results ranged from 40 g to 53 g.
- **Small red:** Line 7014-1 was the largest but also had a large variability. CDC 6956 and CDC Impulse were similar and larger than the other 8 varieties. CDC Simmie, CDC 6928, and CDC Nimble were similar and the smalles.
- **Extra small red:** Line 6935-3 was larger than line 6928-5.

Figure 2.1.2. Mean TKW of red lentils by variety and by location. Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by large red lentil. Capital letters in blue indicated significant differences (p<0.05) by medium red. Small letters in black indicated significant differences (p<0.05) by small red. Small letters in blue indicated significant differences (p<0.05) by extra small red.

By Variety:

- **Large red:** No statistical difference.
- **Medium red:** Mean was 46.5 g.
- **Small red:** Line 7014-1 (largest) was over 13 g larger than CDC Simmie, CDC 6928, and CDC Nimble (smallest).
- **Extra small red:** TKW of line 6935-3 was 1.9 g higher than line 6928-5.

By Location: TKW was highest in Scott, followed by Elrose for all types. Moose Jaw was lowest for all types.

- **Large red:** Scott was 13.3 g higher than Moose Jaw.
- **Medium red:** Scott was 8.5 g higher than Moose Jaw.
- **Small red:** Scott was 7.7 g higher than Moose Jaw.
- **Extra small red:** Scott was 4.5 g higher than Moose Jaw.

Table 2.1. Effects of variety and location.

	Large red	Medium red	Small red	Extra small red
Variety	*NS*	n.a.	***	***
Location	***	***	***	***
Variety x Location	*NS*	n.a.	***	**

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

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2. Seed Size Distribution

Method: 250 g of seeds were placed on a series of round-hole opening sieves. The weight of seeds retained on each sieve was determined and reported as % of seeds retained. Duplicated measurements were performed.

Sieves used for lentils:

a. #16R: 6.35 mm
b. #14R: 5.56 mm
c. #12R: 4.76 mm
d. #10R: 3.97 mm

Results: Table 2.2. Seed size distribution (%) of each red lentil variety. Data represent mean ± one standard deviation.

Variety	> # 16R (%)	> # 14R (%)	> # 12R (%)	> # 10R (%)	Below # 10R (%)
CDC Sublime	3.4 ± 2.1^{a}	68.7 ± 7.2^{a}	25.2 ± 7.5^{b}	1.7 ± 1.0^{a}	1.0 ± 0.7^{a}
CDC Monarch	0.3 ± 0.5^{b}	57.8 ± 13.9^{b}	38.3 ± 13.7^{a}	2.3 ± 1.0^{a}	1.2 ± 1.3^{a}
7005-3	0.0 ± 0.0	8.9 ± 4.4	73.1 ± 3.3	16.7 ± 6.1	1.3 ± 0.8
5929-1	0.0 ± 0.0^{c}	0.9 ± 0.4^{e}	47.6 ± 13.2^{e}	49.5 ± 12.5^{a}	2.0 ± 0.9^{a}
6802-14	0.0 ± 0.0^{c}	1.4 ± 1.3^{de}	70.2 ± 11.9^{b}	27.5 ± 13.0^{d}	0.9 ± 0.3^{b}
CDC 6928	0.0 ± 0.0^{c}	1.3 ± 0.9^{de}	60.5 ± 12.2^{cd}	36.0 ± 11.9^{c}	2.2 ± 1.2^{a}
CDC 6956	0.0 ± 0.0^{c}	13.3 ± 6.7^{c}	75.2 ± 4.5^{a}	10.4 ± 3.0^{f}	1.1 ± 0.7^{b}
7014-1	0.1 ± 0.1^{b}	50.2 ± 17.1^{a}	46.6 ± 16.0^{e}	2.6 ± 1.4^{g}	0.5 ± 0.4^{c}
CDC Impulse	0.1 ± 0.1^{a}	46.7 ± 12.0^{b}	48.5 ± 10.7^{e}	4.2 ± 1.9^{g}	0.5 ± 0.4^{c}
CDC Maxim	0.0 ± 0.0^{c}	2.8 ± 2.5^{d}	68.7 ± 10.6^{b}	27.3 ± 12.5^{d}	1.3 ± 0.8^{b}
CDC Nimble	0.0 ± 0.0^{c}	0.4 ± 0.4^{e}	58.0 ± 13.3^{d}	39.6 ± 13.0^{b}	2.1 ± 1.0^{a}
CDC Proclaim	0.0 ± 0.0^{c}	1.1 ± 0.7^{e}	75.5 ± 11.9^{a}	22.3 ± 12.0^{e}	1.1 ± 0.7^{b}
CDC Redmoon	0.0 ± 0.0^{c}	0.8 ± 0.8^{e}	59.1 ± 13.6^{cd}	38.3 ± 13.6^{bc}	1.9 ± 1.0^{a}
CDC Simmie	0.0 ± 0.0^{c}	0.9 ± 1.1^{e}	62.0 ± 14.9^{c}	35.3 ± 14.6^{c}	1.9 ± 1.4^{a}
6928-5	0.0 ± 0.0	0.8 ± 0.7^{a}	55.4 ± 13.1^{a}	41.3 ± 12.3^{a}	2.4 ± 1.1^{a}
6935-3	0.0 ± 0.0	0.2 ± 0.2^{b}	51.9 ± 9.6^{a}	45.7 ± 9.2^{a}	2.2 ± 0.9^{a}

Note: Different small letters within each type indicated significant differences (p<0.05).

- **Large red:** Most seeds retained onto sieves #14 and #12.
- **Medium red:** Seeds tended to retain onto sieves #14, #12, and #10.
- **Small red:** Line 7014-1 and CDC Impulse tended to retain onto sieves #14 and #12. CDC 6956 retained onto sieves #14, #12, and #10. Other small red varieties tended to retain onto sieves #12 and #10.
- **Extra small red:** Both extra small red varieties tended to retain onto sieves #12 and #10.

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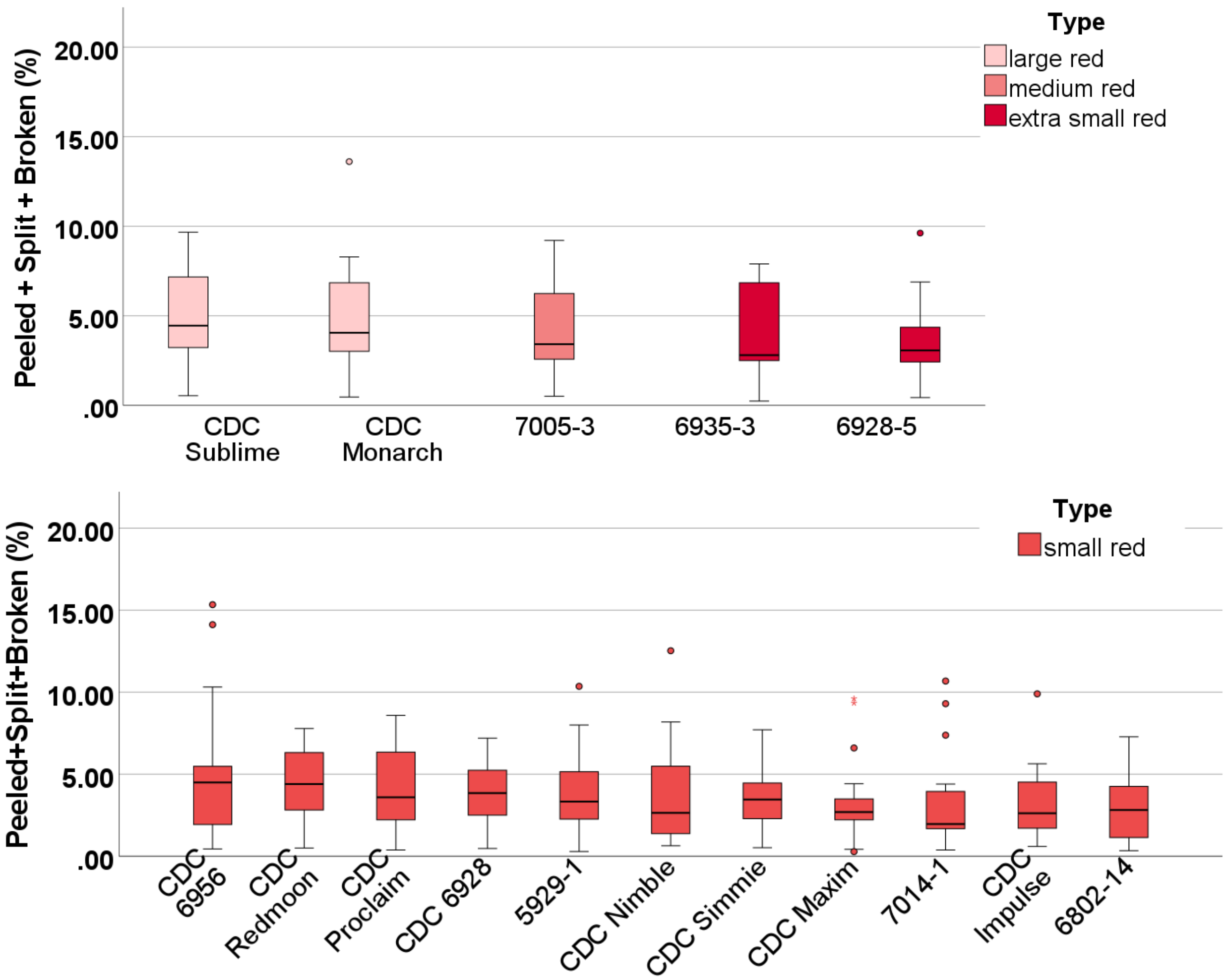
3. Peeled + Split + Broken

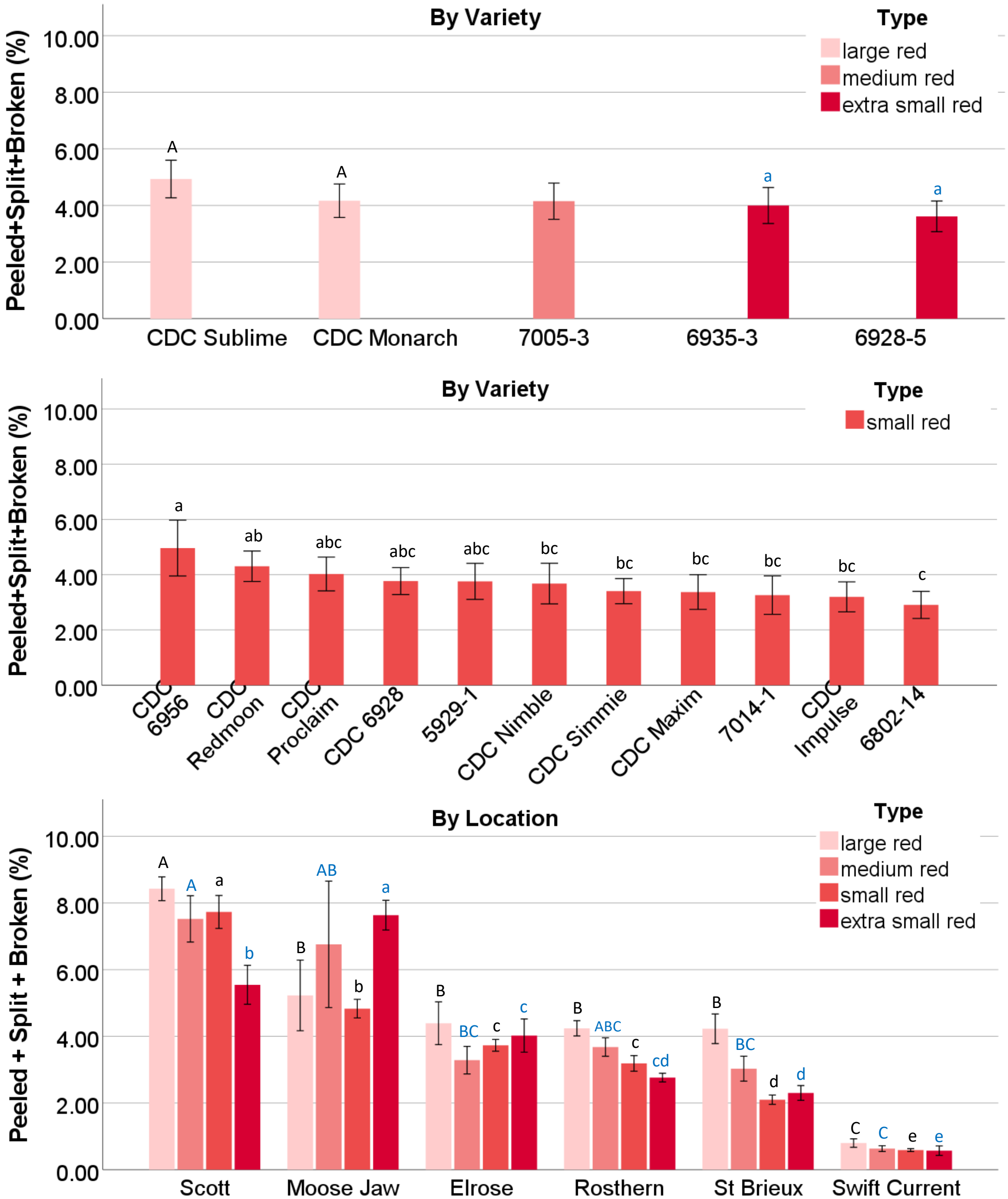
Method: 50 grams of each sample was used for evaluation, and damaged seeds were selected by hand. Results included splits, cracks, seed coat damage, partially missing hull, and partially missing cotyledon.

Results: Figure 2.3.1. The Box and Whisker plot of the peeled + split + broken red lentils resulting from 6 locations. Results by type were reported from highest to lowest.



- **Large red:** CDC Sublime and CDC Monarch were similar.
- **Medium red:** similar to large red.
- **Small red:** Some outliers were observed.
- **Extra small red:** Line 6935-3 had a larger variability.

Figure 2.3.2. Mean peeled + split + broken (%) of red lentils by variety and by location. Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by large red lentil. Capital letters in blue indicated significant differences (p<0.05) by medium red. Small letters in black indicated significant differences (p<0.05) by small red. Small letters in blue indicated significant differences (p<0.05) by extra small red.

By Variety:

- **Large red:** bith were similar (p>0.05)
- **Medium red:** Mean was 4.2%.
- **Small red:** CDC 6956 (highest) was 2% higher than line 6802-14 (lowest).
- **Extra small red:** No statistical difference.

By Location: The amount of peeled + split + broken lentils was extremely high in Scott and Moose Jaw for all types. In contrast, very low damage was observed in the seeds harvested in Swift Current, where post-harvest processing may play a role.

Table 2.3. Effects of variety and location.

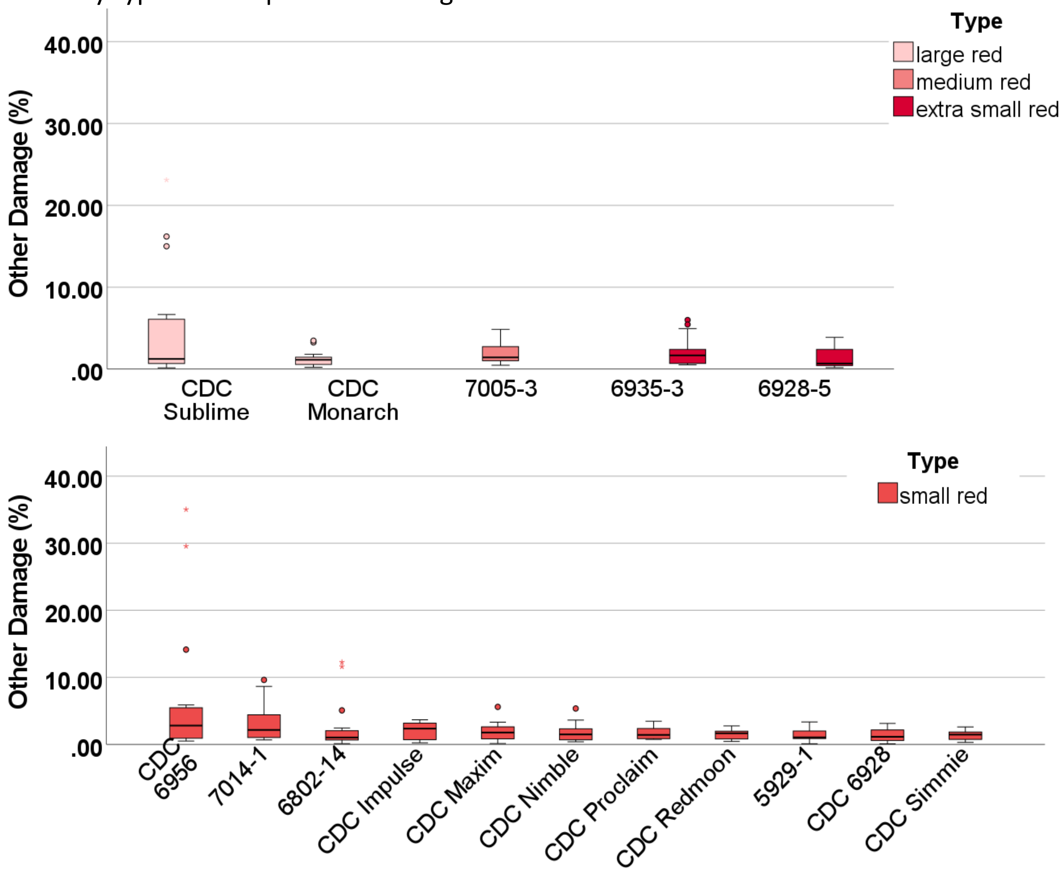
	Large red	Medium red	Small red	Extra small red
Variety	*NS*	n.a.	***	*NS*
Location	***	**	***	***
Variety x Location	*NS*	n.a.	***	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

4. Other Damage

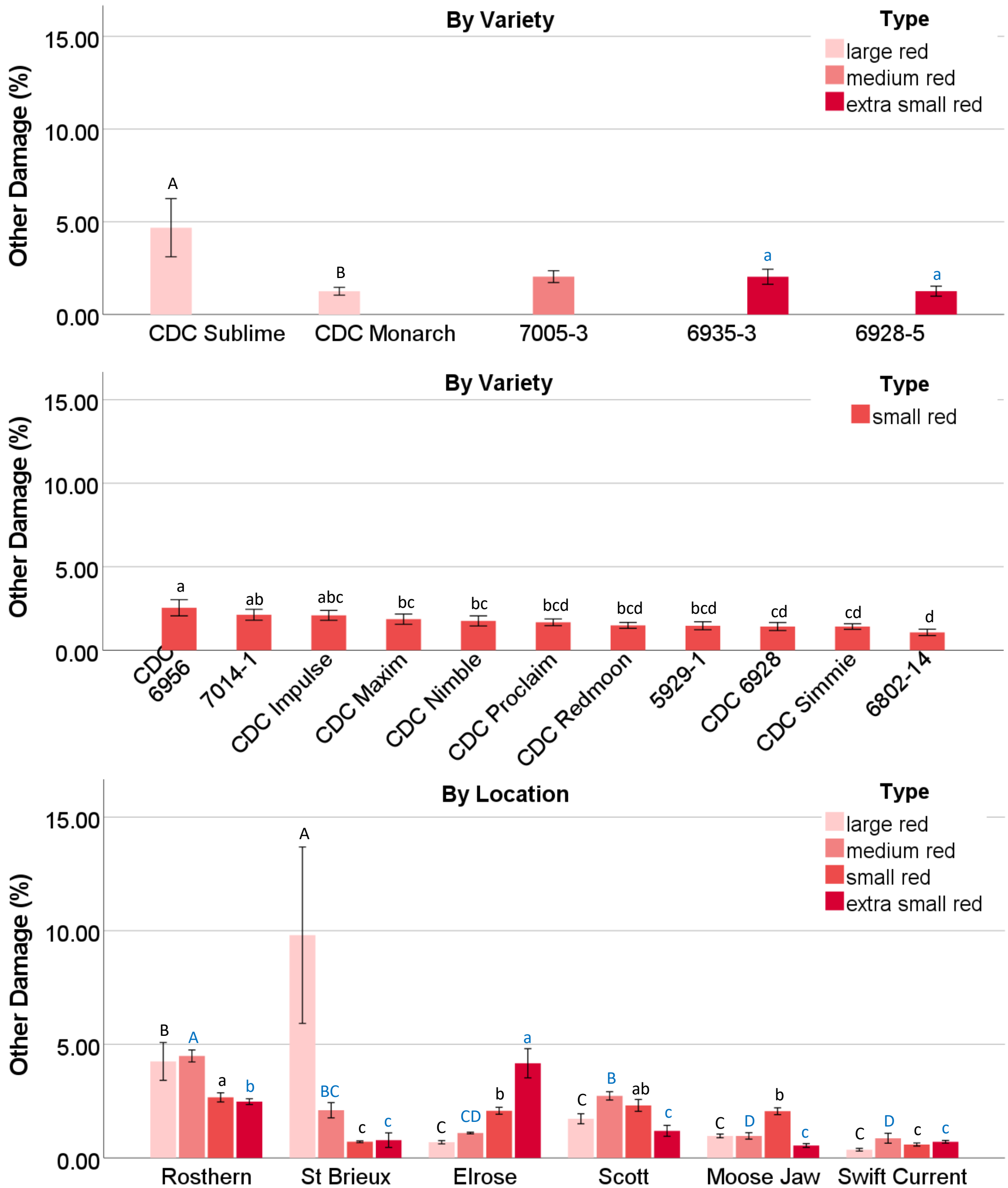
Method: 50 grams of each sample was used for evaluation, and damaged seeds were selected by hand. Other damage included wrinkles, sprouting, distinct immaturity, distinct deterioration or discolouration by weather or disease, insect damage, heat damage, and any other damage that affects appearance.

Results: Figure 2.4.1. Box and Whisker plot of red lentils for other damage resulting from 6 locations. Results by type were reported from highest to lowest.



- **Large red:** CDC Monarch was smaller with a small variability.
- **Medium red:** Other damage was relatively low.
- **Small red:** CDC 6956 had the highest damage, followed by line 7014-1. Other varieties remained low levels.
- **Extra small red:** both were similar.

Figure 2.4.2. Mean other damage of red lentils by variety and by location. Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by large red lentil. Capital letters in blue indicated significant differences (p<0.05) by medium red. Small letters in black indicated significant differences (p<0.05) by small red. Small letters in blue indicated significant differences (p<0.05) by extra small red.

By Variety:

- **Large red:** CDC Monarch was 3% smaller than CDC Sublime.
- **Medium red:** Mean was 2%.
- **Small red:** A 1.5% difference was observed from highest to lowest.
- **Extra small red:** No statistical difference.

By Location: Swift Current had the lowest other damage for both seed types.

- **Large red:** Other damage was extremely high in St Brieux (9.8%), followed by Rosthern (4.3%).
- **Medium red:** Rosthern was highest.
- **Small red:** Swift Current and St Brieux were below 1%. Other locations ranged from 2% to 3%.
- **Extra small red:** Elrose was highest.

Table 2.4. Effects of variety and location.

	Large red	Medium red	Small red	Extra small red
Variety	***	n.a.	***	*NS*
Location	***	***	***	***
Variety x Location	***	n.a.	***	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

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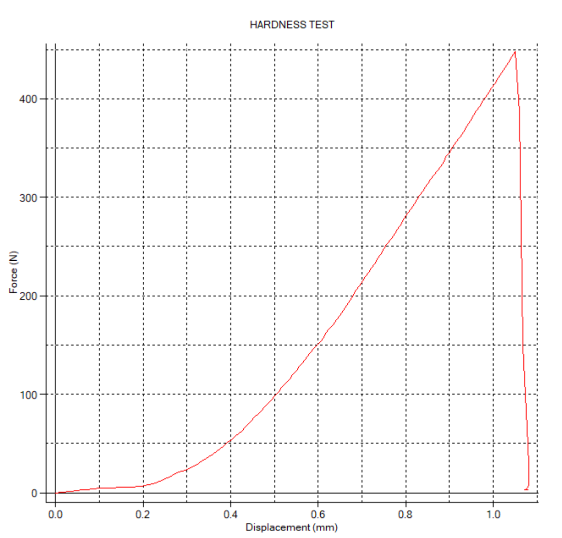
5. Hardness of Whole Seed

Seed hardness is an important parameter to indicate milling yield and cooking quality. Seed hardness is affected by seed size, shape, density, composition, etc.

Method:
Seed hardness was determined by measuring the force of breaking a seed using a texture analyzer (TMS-Pro, Food Technology Corporation, USA) equipped with a 2500 N load cell with a modified method from Karami et al. (2017) and Lovas-Kiss (2020)[5].

In brief, a seed was placed under the 10 mm cylinder probe that was lowered with a speed of 50 mm/min. The forces to lower the probe till a seed was broken were monitored. The mean peak force (N) of 10 seeds was reported.



[5] Karami, S., Sabzalian, M. R., Rahimmalek, M., Saeidi, G., & Ghasemi, S. (2017). Interaction of seed coat color and seed hardness: An effective relationship which can be exploited to enhance resistance to the safflower fly (Acanthiophilus helianthi) in Carthamus spp. Crop Protection, 98, 267-275.

Lovas‐Kiss, Á., Vincze, O., Kleyheeg, E., Sramkó, G., Laczkó, L., Fekete, R., ... & Green, A. J. (2020). Seed mass, hardness, and phylogeny explain the potential for endozoochory by granivorous waterbirds. Ecology and Evolution, 10(3), 1413-1424.

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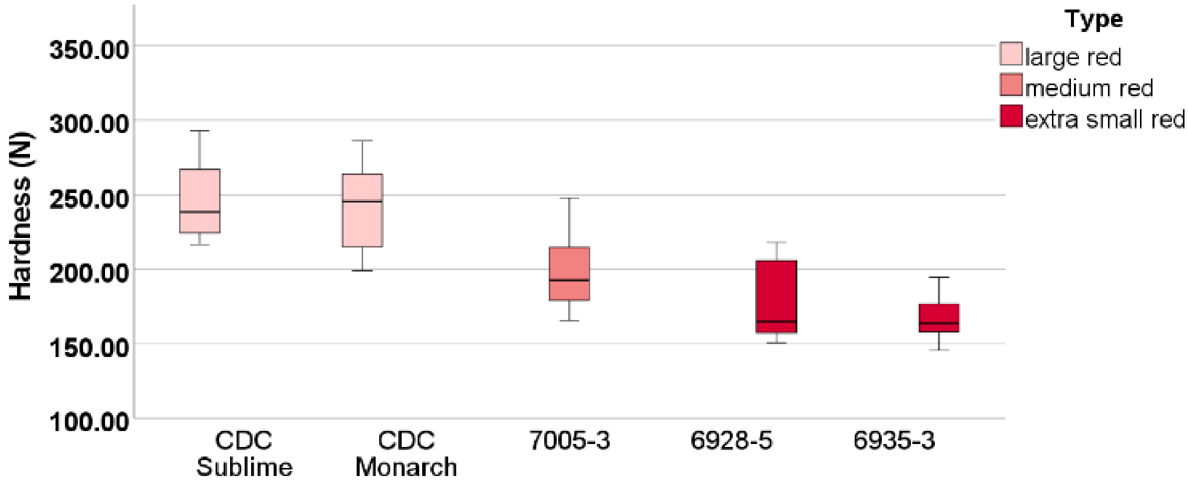
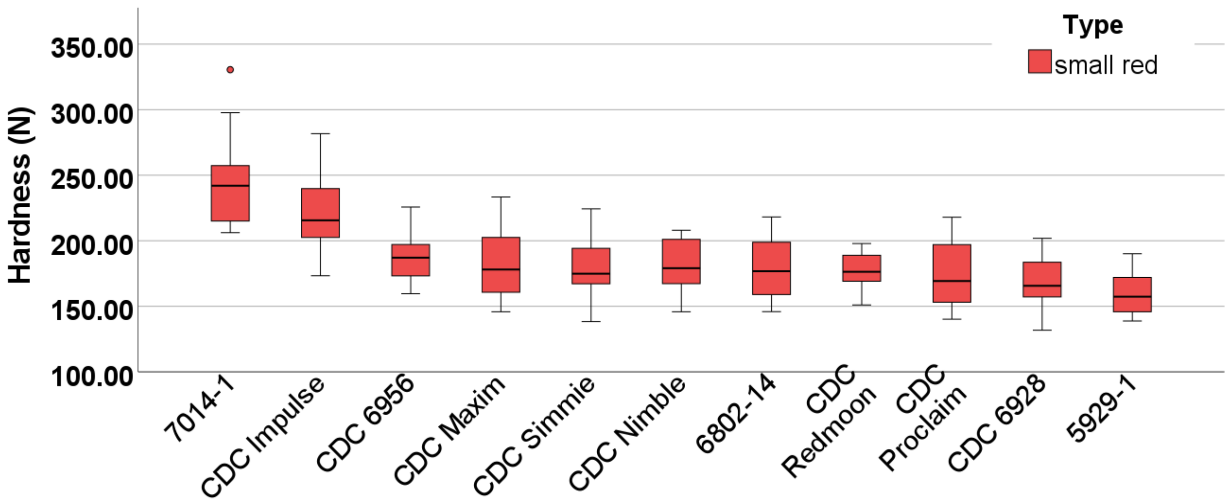
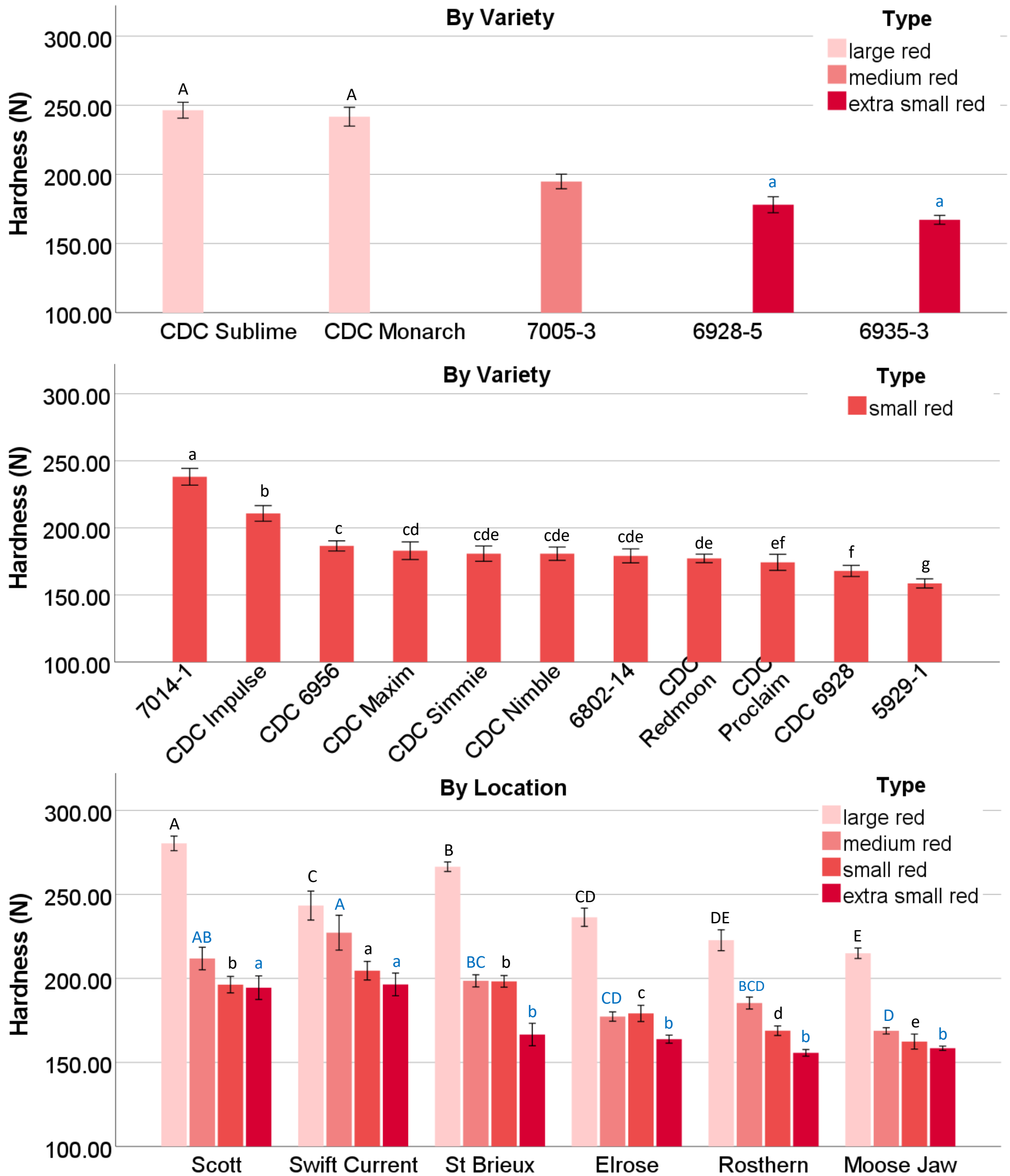
Results: Figure 2.5.1. Box and Whisker plot of red lentils for seed hardness (N) resulting from 6 locations. Results by type were reported from highest to lowest.





- **Large red:** CDC Monarch was smaller with large variability.
- **Medium red:** Mean was in between of large type and extra small.
- **Small red:** Line 7014-1 was largest, followed by CDC Impulse. Other varieties had the medium values below 200 N.
- **Extra small red:** Line 6928-5 had a large variability.

Figure 2.5.2. Mean seed hardness of red lentils by variety and by location. Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by large red lentil. Capital letters in blue indicated significant differences (p<0.05) by medium red. Small letters in black indicated significant differences (p<0.05) by small red. Small letters in blue indicated significant differences (p<0.05) by extra small red.

By Variety:

- **Large red:** No statistical difference.
- **Medium red:** Mean was 195 N.
- **Small red:** Hardness of line 7014-1 was 79 N higher than line 5929-1.
- **Extra small red:** No statistical difference.

By Location: Location also impacted the hardness of red lentils. Seed hardness in Scott was generally higher than those from Moose Jaw.

- **Large red:** A 65 N difference was found from highest to lowest.
- **Medium red:** A 59 N difference was found from highest to lowest.
- **Small red:** A 42 N difference was found from highest to lowest.
- **Extra small red:** A 41 N difference was found from highest to lowest.

Table 2.5. Effects of variety and location.

	Large red	Medium red	Small red	Extra small red
Variety	*NS*	n.a.	***	*NS*
Location	***	***	***	***
Variety x Location	*NS*	n.a.	***	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

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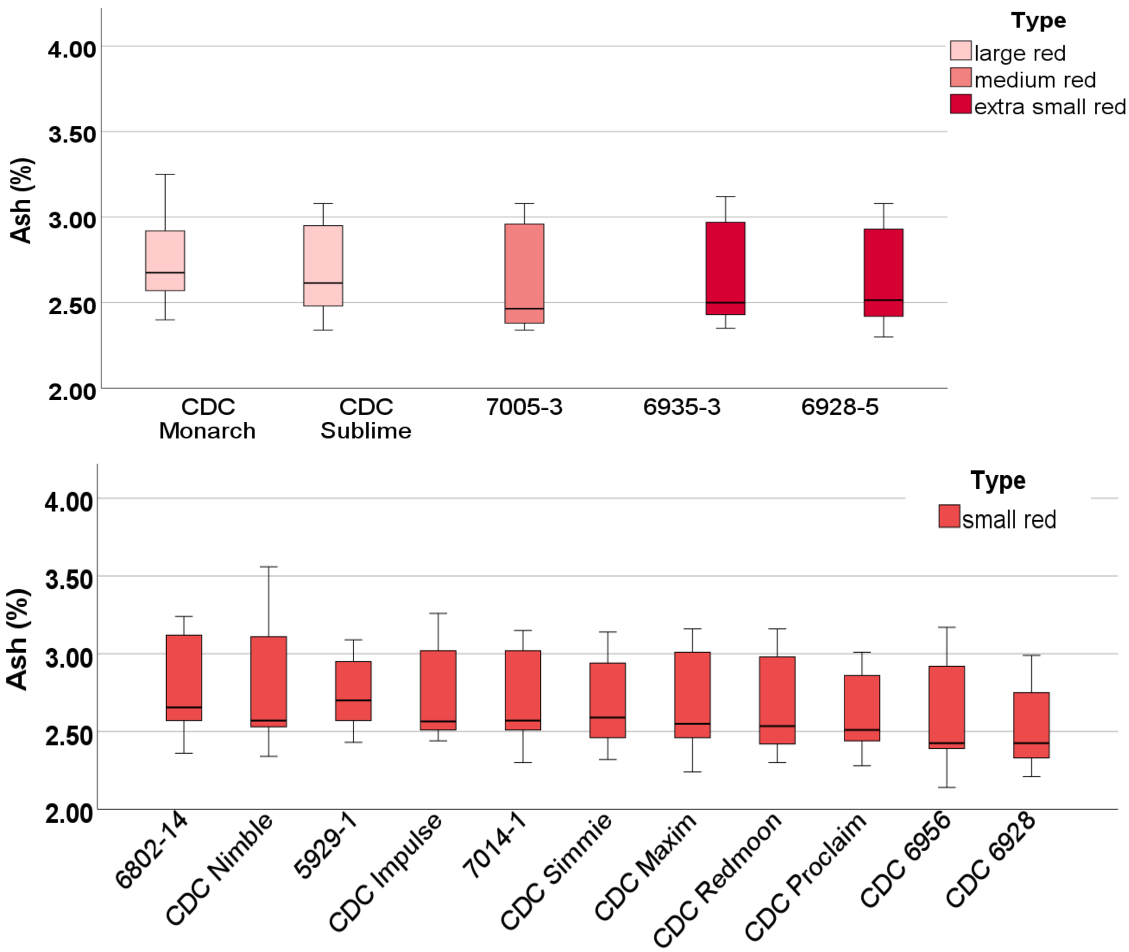
6. Ash Content

Method: Ash content (%) was determined using AACC 08-01.01[6] with modification. Samples were heated at 560°C till they turned white. Duplicated measurements were performed for each sample, and the average was reported on a dry basis (d.b.).

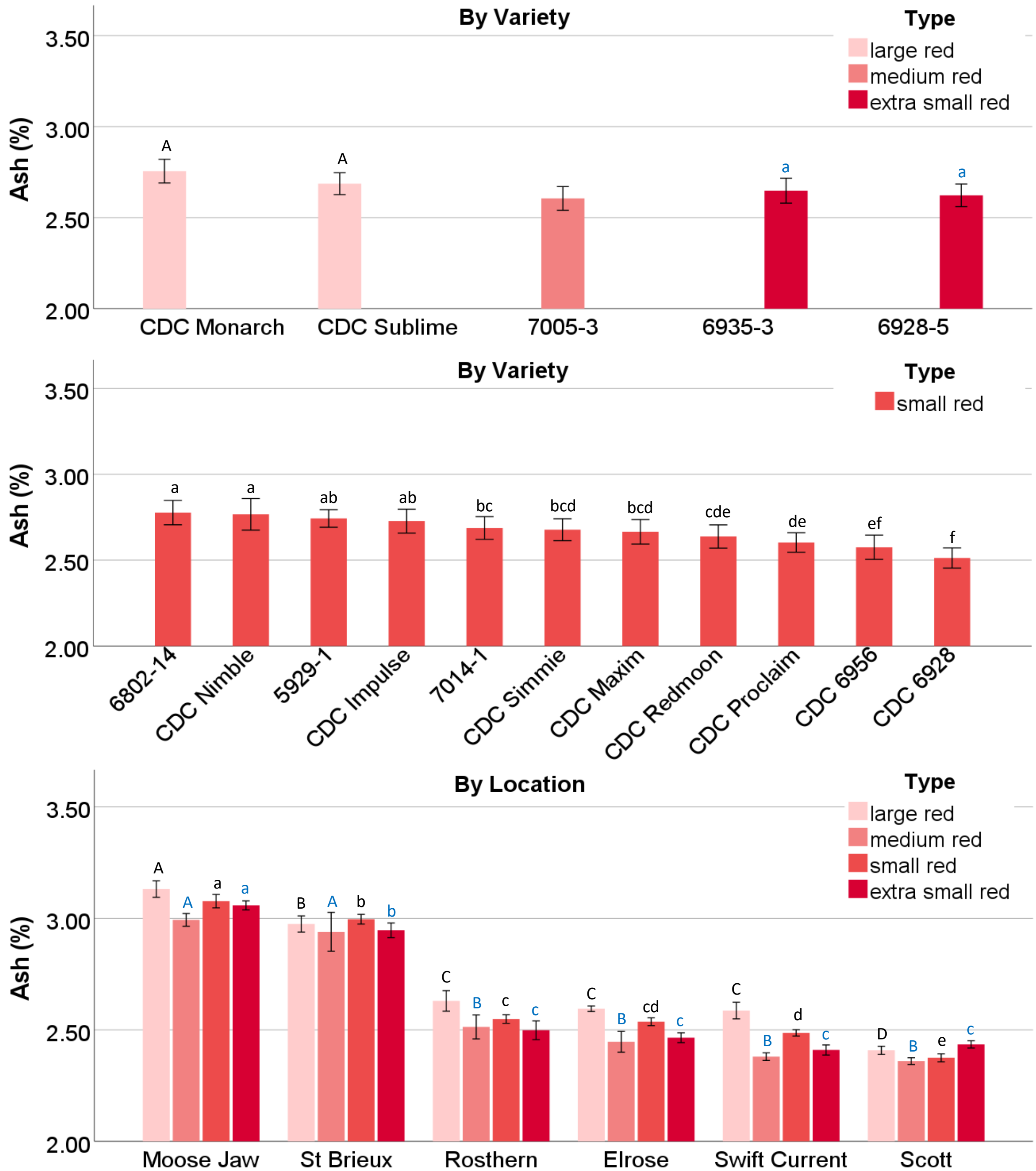
Results: Figure 2.6.1. Box and Whisker plot of red lentils for ash content (%) resulting from 6 locations. Results by type were reported from highest to lowest.



Ash levels were similar.

[6] AACC (1999). American Association of Cereal Chemists International. Approved methods of analysis (11th ed.). The Saint Pauls Association: Saint Paul, MN.

Figure 2.6.2. Mean ash of red lentils by variety and by location. Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences ($p<0.05$) by large red lentil. Capital letters in blue indicated significant differences ($p<0.05$) by medium red. Small letters in black indicated significant differences ($p<0.05$) by small red. Small letters in blue indicated significant differences ($p<0.05$) by extra small red.

By Variety:

- **Large red:** No statistical difference.
- **Medium red:** Mean was 2.6%.
- **Small red:** A 0.7% difference was found from highest to lowest.
- **Extra small red:** No statistical difference.

By Location: Ash contents of red lentils from Moose Jaw and St Brieux were higher for all types, while seeds from the other four locations were similar.

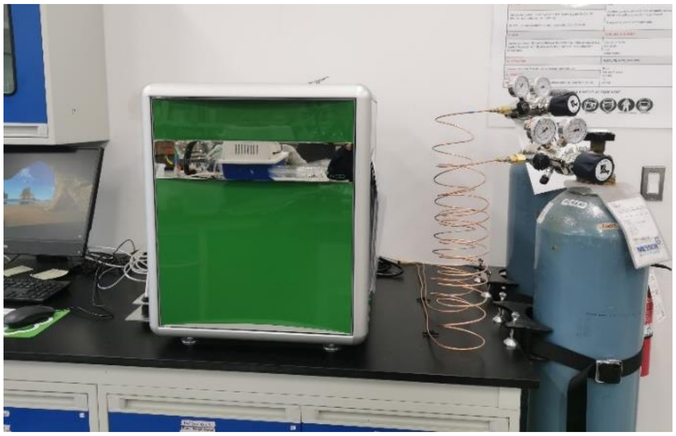
Table 2.6. Effects of variety and location.

	Large red	Medium red	Small red	Extra small red
Variety	*NS*	n.a.	***	*NS*
Location	***	***	***	***
Variety x Location	*NS*	n.a.	***	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

7. Protein Content

Method: The protein content (%) of each flour was determined through AACC 46-30[2] using the combustion method through a Rapid N Exceed (Elementar, USA). Duplicated measurements were performed for each sample, and the average was reported on a dry basis (d.b.).



[2] AACC (1999). American Association of Cereal Chemists International. Approved methods of analysis (11th ed.). The Saint Pauls Association: Saint Paul, MN.

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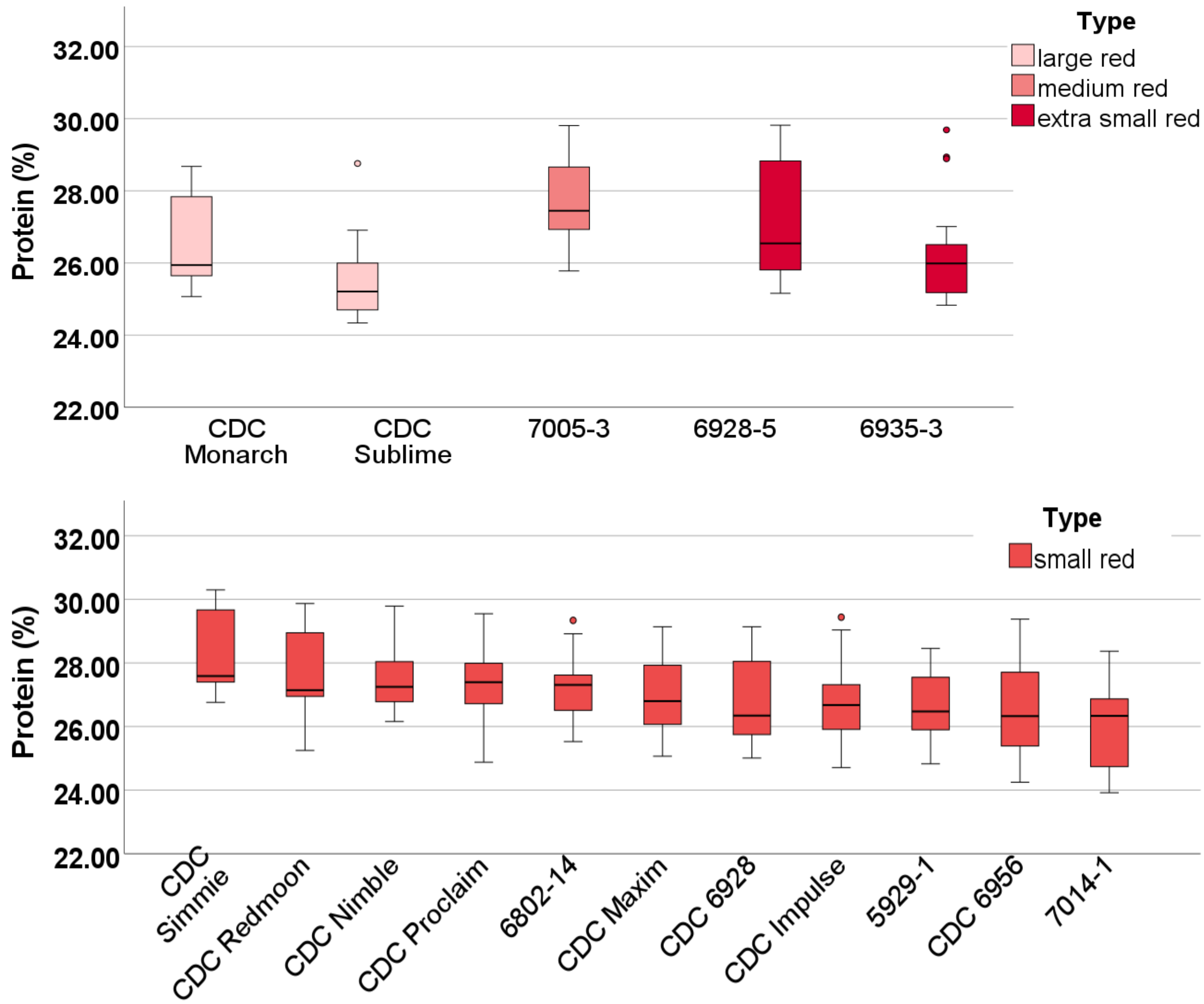
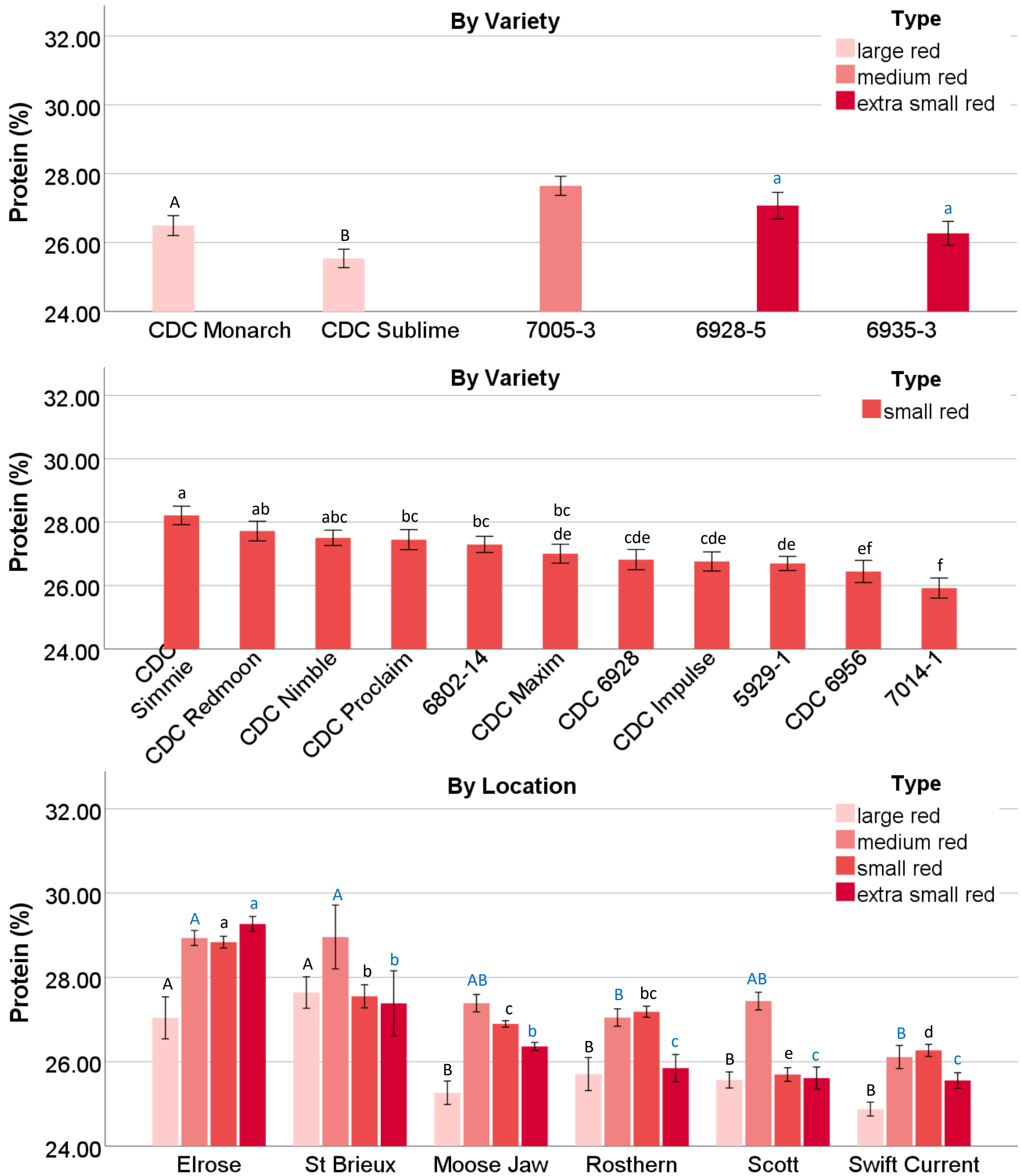
Results: Figure 2.7.1. Box and Whisker plot of red lentils for protein content (%) resulting from 6 locations. Results by type were reported from highest to lowest



- **Large red:** CDC Monarch was higher.
- **Medium red:** ranged from 26% to 28%.
- **Small red:** CDC Simmie had the highest protein, while line 7014-1 had the lowest.
- **Extra small red:** Line 6928-5 was higher but varied more.

Figure 2.7.2. Mean protein of red lentils by variety and by location. Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by large red lentil. Capital letters in blue indicated significant differences (p<0.05) by medium red. Small letters in black indicated significant differences (p<0.05) by small red. Small letters in blue indicated significant differences (p<0.05) by extra small red.

By Variety:

- **Large red:** CDC Monarch was 1% higher than CDC Sublime.
- **Medium red:** Mean was 27.6%.
- **Small red:** A 2.3% difference was found from highest to lowest.
- **Extra small red:** No statistical difference.

By Location:

- **Large red:** A 2.7% difference was observed from the highest (St Brieux) to the lowest (Swift Current).
- **Medium red:** A 2.9% difference was observed from the highest (St Brieux) to the lowest (Swift Current).
- **Small red:** A 3.1% difference was observed from the highest (Elrose) to the lowest (Scott).
- **Extra small red:** A 3.7% difference was observed from the highest (Elrose) to the lowest (Swift Current).

Table 2.7. Effects of variety and location.

	Large red	Medium red	Small red	Extra small red
Variety	***	n.a.	***	*NS*
Location	***	***	***	***
Variety x Location	*	n.a.	*	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

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8. Colour

Method: The absolute colour of each flour was determined using the Konica Minolta CR-400 Chroma meter, where *L*, a*,* and *b** values were reported. Three measurements were made for each sample, and the mean value was reported.

- ***L* (lightness):*** white (100) to black (0)
- ***a*:*** red (+) to green (-)
- ***b*:*** yellow (+) to blue (-)

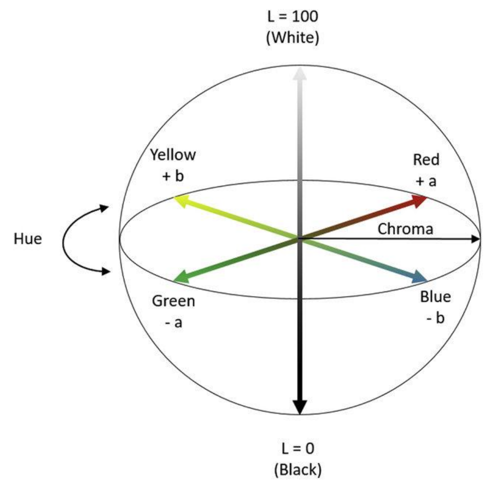
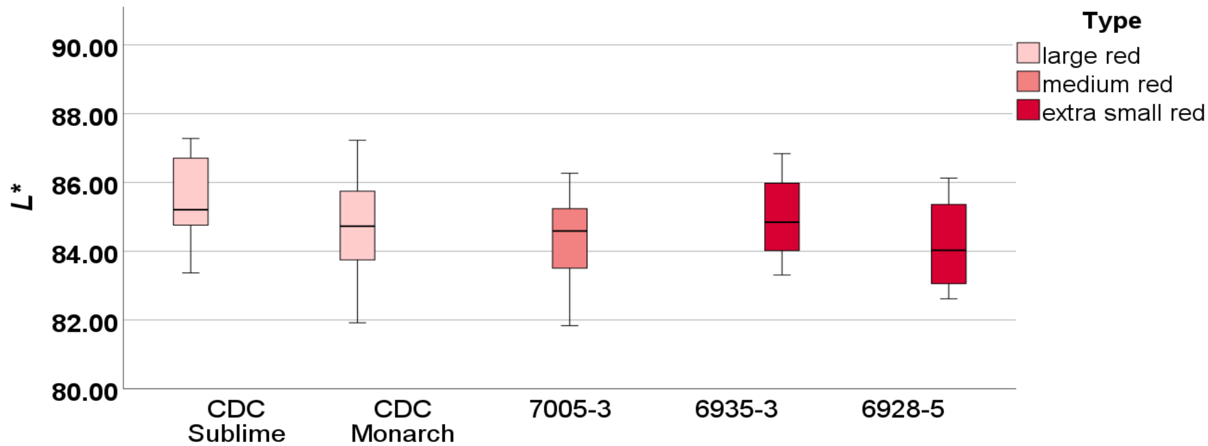


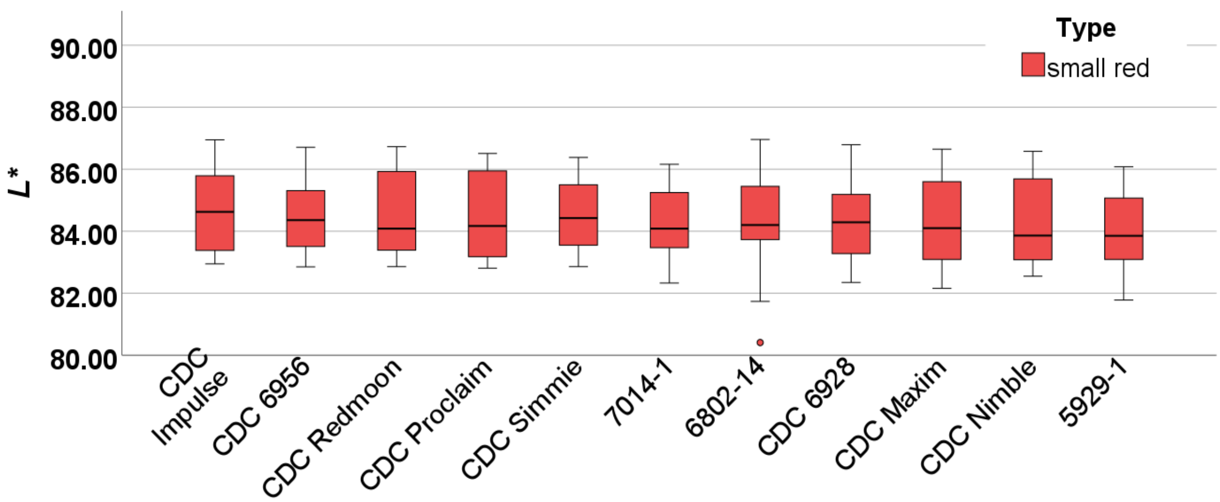
Figure 2.8.1. The CIELAB color spacediagram[7].

[7] Ly, B. C. K., Dyer, E. B., Feig, J. L., Chien, A. L., & Del Bino, S. (2020). Research techniques made simple: cutaneous colorimetry: a reliable technique for objective skin color measurement. *Journal of Investigative Dermatology*, *140*(1), 3-12.

a) ***L* (lightness):*** white (100) to black (0)

Results: Figure 2.8.2. Box and Whisker plot of red lentils for lightness resulting from 6 locations. Results by type were reported from highest to lowest.





- **Large red:** CDC Monarch were smaller and varied more.
- **Medium red:** Lightness was lower than both large red lentils.
- **Small red:** Lightness were similar for small red lentils.
- **Extra small red:** Line 6935-3 was higher.

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Figure 2.8.3. Mean lightness of red lentils by variety and by location. Each bar represents mean ± one standard error.

Note: Capital letters in black indicated significant differences (p<0.05) by large red lentil. Capital letters in blue indicated significant differences (p<0.05) by medium red. Small letters in black indicated significant differences (p<0.05) by small red. Small letters in blue indicated significant differences (p<0.05) by extra small red.

By Variety:

- **Large red:** No difference (p>0.05).
- **Medium red:** Lightness was 84.3.
- **Small red:** Only a 0.7 unit difference was observed from the highest to the lowest.
- **Extra small red:** No difference (p>0.05).

By Location: *L** values varied between locations. St Brieux generally had the greatest lightness, while Mosse Jaw had the lowest lightness for all types. The difference from highest to lowest within each type was around 4 units.

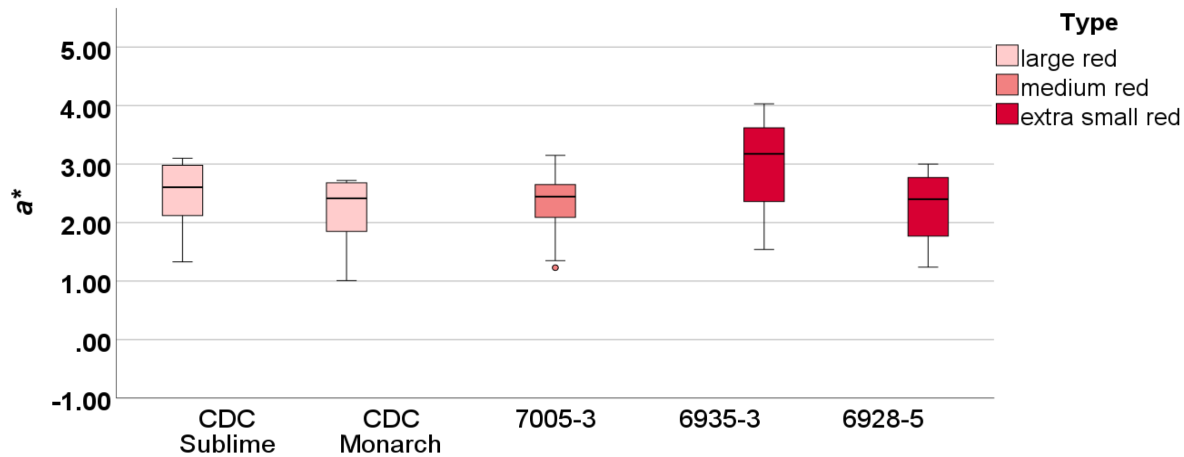
Table 2.8.1. Effects of variety and location.

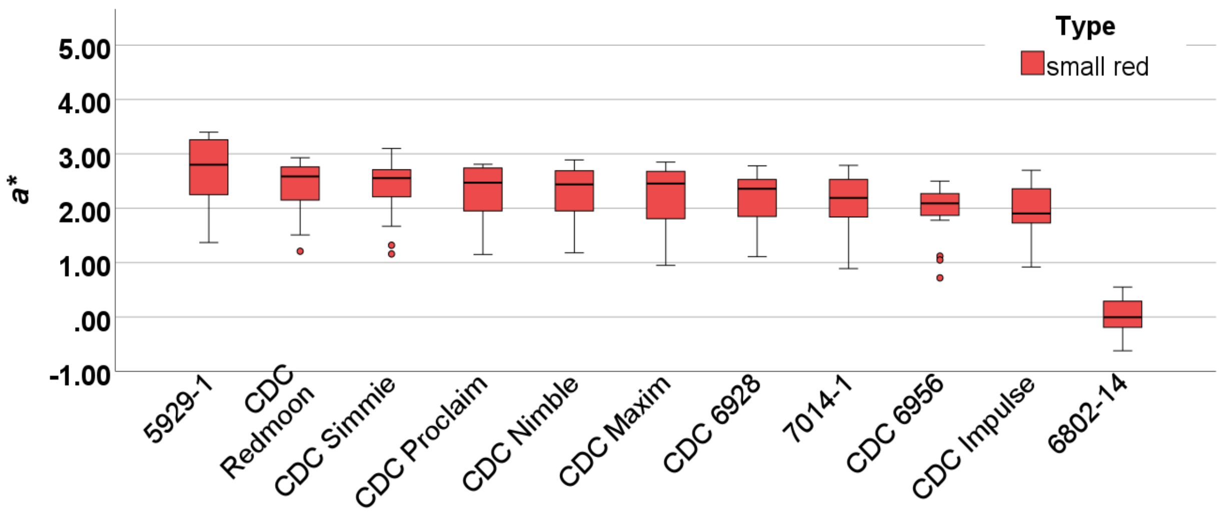
	Large red	Medium red	Small red	Extra small red
Variety	*NS*	n.a.	***	*NS*
Location	***	***	***	***
Variety x Location	*NS*	n.a.	**	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

b) ***a*:*** red (+) to green (-)

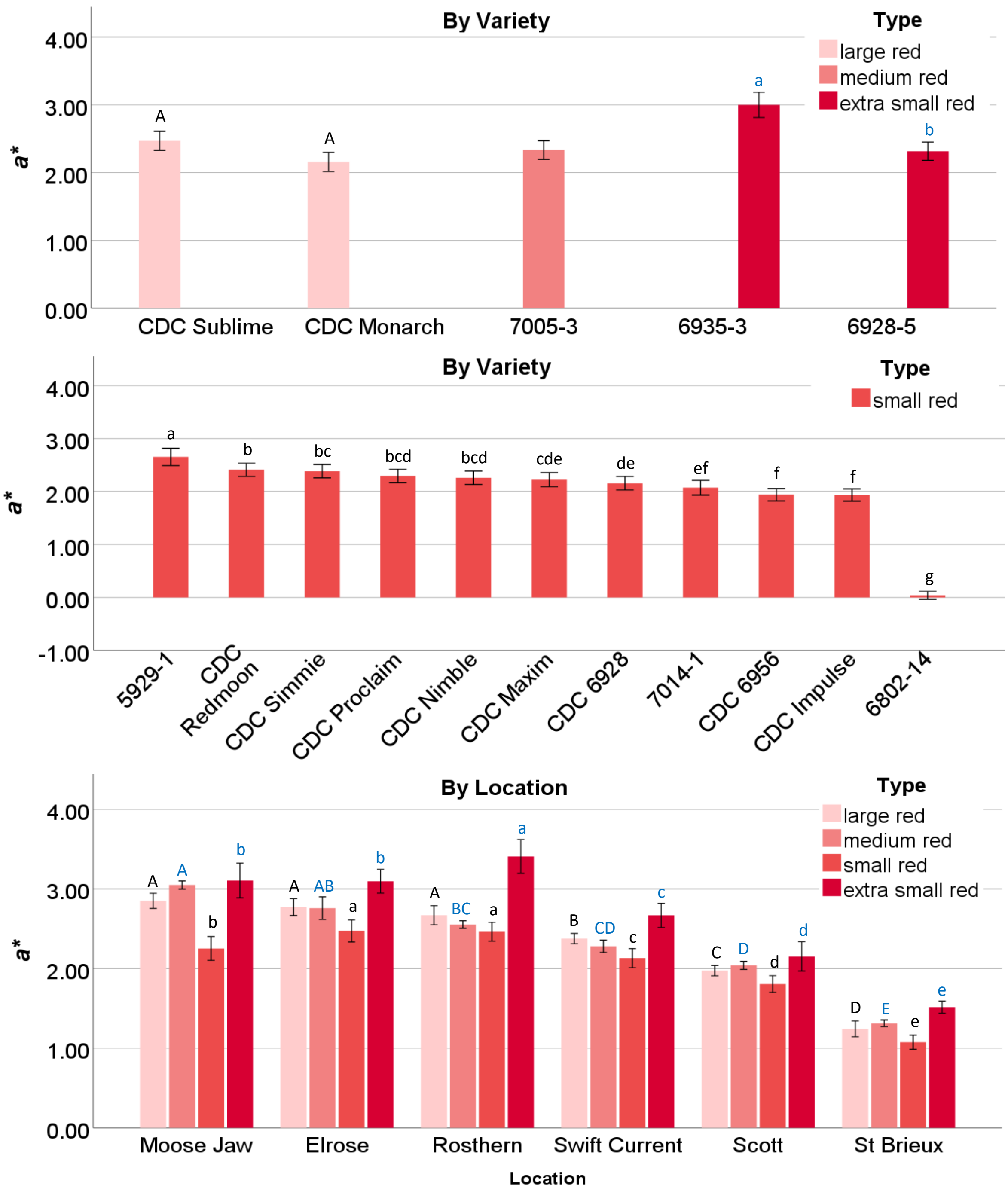
Results: Figure 2.8.4. Box and Whisker plot of red lentils for *a** resulting from 6 locations. Results by type were reported from highest to lowest.





- **Large red:** CDC Sublime was sighlty higher.
- **Medium red:** similar to CDC Simmie.
- **Small red:**
    - Line 6935-3 had the highest redness.
    - Line 6802-14: About half of the cotyledons were in yellow instead of red. Therefore, the *a** values ranged from -1 to 1.
- **Extra small red:** Line 6935-3 had the highest redness.

Figure 2.8.5. Mean *a** of red lentils by variety and by location. Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences ($p<0.05$) by large red lentil. Capital letters in blue indicated significant differences ($p<0.05$) by medium red. Small letters in black indicated significant differences ($p<0.05$) by small red. Small letters in blue indicated significant differences ($p<0.05$) by extra small red.

By Variety:

- **Large red:** No difference (p>0.05).
- **Medium red:** Mean was 2.3.
- **Small red:**
  - **Line 6802-14:** Mean was 0.0, indicating zero redness due to the presence of 50% of yellow cotyledons.
  - **Except line 6802-14:** A 0.8-unit difference was observed from the highest to the lowest.
- **Extra small red:** Line 6935-3 was 0.7-unit higher than line 6928-5.

By Location: All four types of samples from St Brieux had the lowest redness.

- **Large red:** A 1.6-unit difference was observed from the highest (Moose Jaw, Elrose, and Rosthern) to the lowest.
- **Medium red:** A 1.8-unit difference was observed from the highest (Moose Jaw) to the lowest.
- **Small red:** A 1.4-unit difference was observed from the highest (Elrose) to the lowest.
- **Extra small red:** A 1.9-unit difference was observed from the highest (Rosthern) to the lowest.

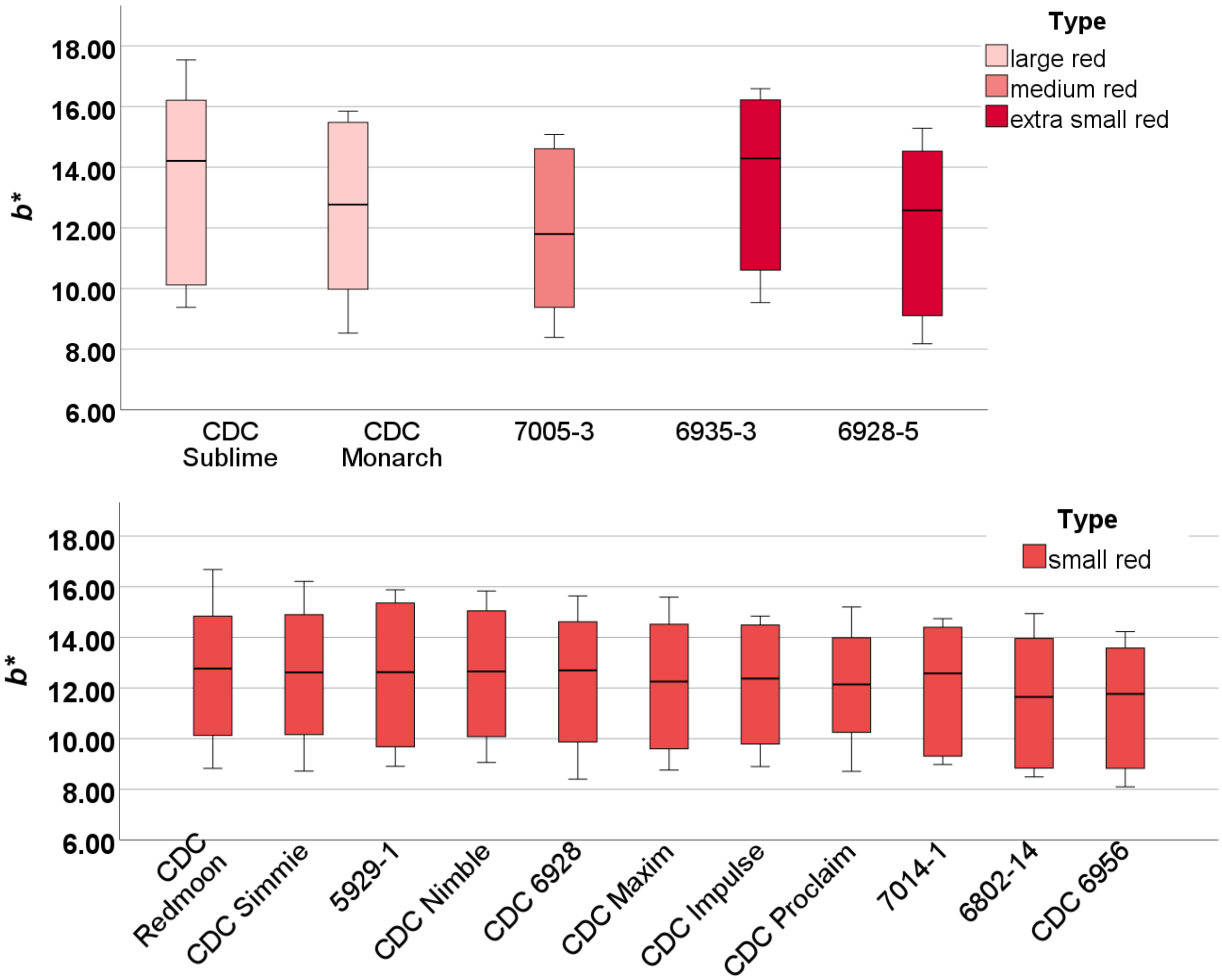
Table 2.8.2. Effects of variety and location.

	Large red	**Medium red**	**Small red**	**Extra small red**
Variety	*NS*	n.a.	***	***
Location	***	***	***	***
Variety x Location	*NS*	n.a.	***	**

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

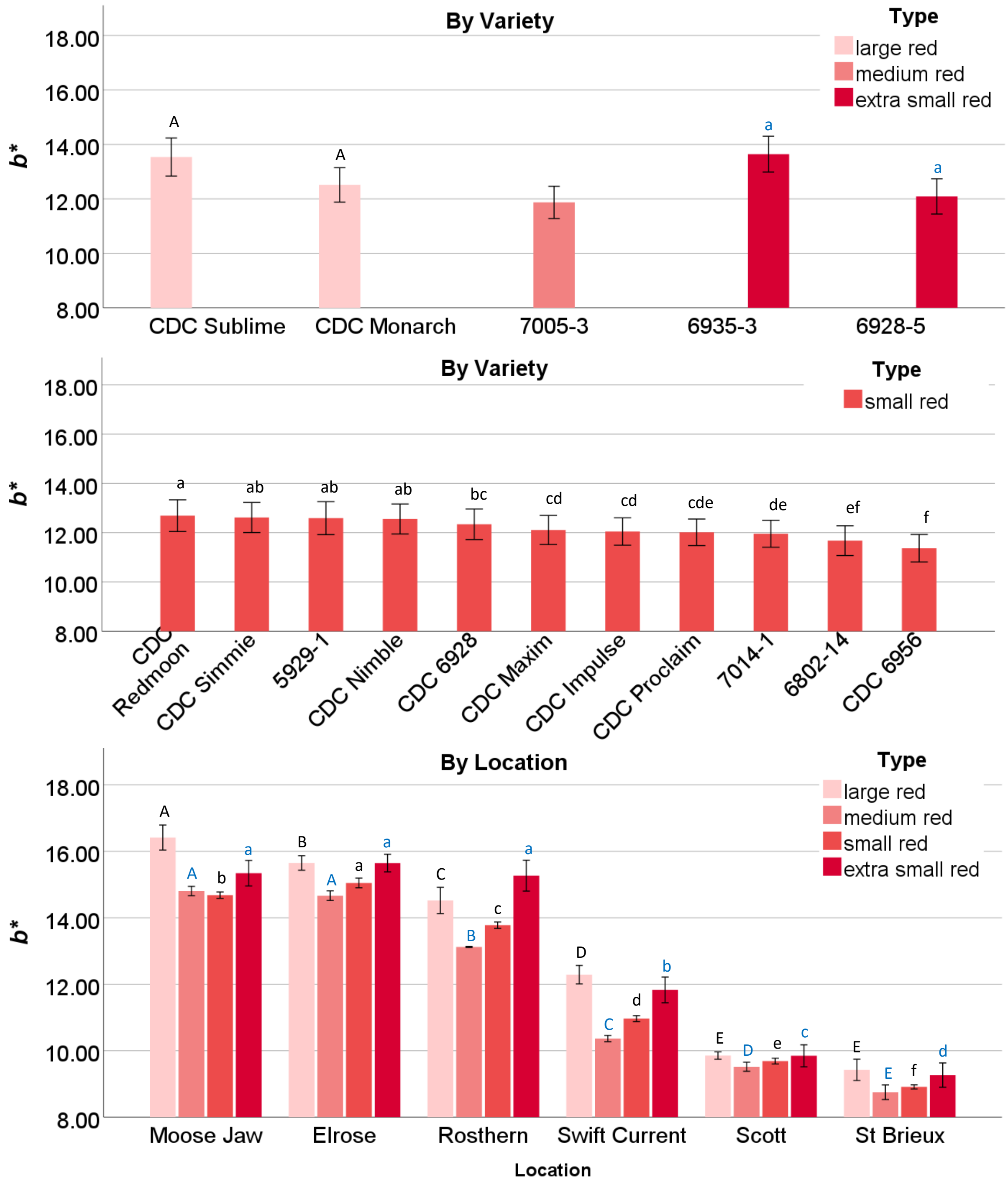
c) ***b*:*** yellow (+) to blue (-)

Results: Figure 2.8.6. Box and Whisker plot of red lentils for *b** resulting from 6 locations. Results by type were reported from highest to lowest.



- **Large red:** CDC Sublime had higher yellowness.
- **Medium red:** similar to line 6928-5.
- **Small red:** All varied a lot.
- **Extra small red:** Line 6935-3 had higher yellowness.

Figure 2.8.7. Mean *b** of red lentils by variety and by location. Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by large red lentil. Capital letters in blue indicated significant differences (p<0.05) by medium red. Small letters in black indicated significant differences (p<0.05) by small red. Small letters in blue indicated significant differences (p<0.05) by extra small red.

By Variety:

- **Large red:** No difference (p>0.05).
- **Medium red:** Mean was 11.9.
- **Small red:** A 1.3-unit difference was observed from the highest to the lowest.
- **Extra small red:** No difference (p>0.05).

By Location: Yellowness varied significantly between locations. In general, samples from St Brieux had the lowest yellowness, followed by those from Scott.

- **Large red:** A 6.1 unit difference was observed from the highest (Moose Jaw) to the lowest.
- **Medium red:** A 6 unit difference was observed from the highest (Moose Jaw) to the lowest.
- **Small red:** A 6 unit difference was observed from the highest (Elrose) to the lowest.
- **Extra small red:** A 6.3 unit difference was observed from the highest (Elrose) to the lowest.

Table 2.8.3. Effects of variety and location.

	Large red	**Medium red**	**Small red**	**Extra small red**
Variety	*NS*	n.a.	***	*NS*
Location	***	***	***	***
Variety x Location	*NS*	n.a.	***	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

9. Hausner Ratio

Hausner ratio measures the ratio of tapped density to loose bulk density, indicating the flow-ability and the compressibility of the flour after milling. Hausner ratio is an important parameter in food products handling, packaging, storage, processing, and distribution. It is useful in the specification of products derived from size reduction or drying processes. Usually, the lower the flow-ability a flour, the more compressible it becomes[8].

Method: The bulk and tapped volumes of 10 g of flour were determined using a 25 mL graduated cylinder. Duplicated measurements were made for each flour, and the Hausner ratio is calculated as:

Hausner ratio = $\frac{Tapped\ density}{Loose\ bulk\ density} = \frac{Bulk\ volume\ (mL)}{Tapped\ volume\ (mL)}$

Table 9. Relationship between powder flow-ability and Hausner ratio.

Type of flow	Hausner ratio
Excellent	1.00-1.11
Good	1.12-1.18
Fair	1.19-1.25
Passable	1.26-1.34
Poor	1.35-1.45
Very poor	1.46-1.59
Very, very poor	>1.59

[8] Buanz, A. (2021). Powder characterization. In *Remington* (pp. 295-305). Academic Press. https://doi.org/10.1016/B978-0-12-820007-0.00016-7

Amankwah, N. Y. A., Agbenorhevi, J. K., & Rockson, M. A. (2022). Physicochemical and functional properties of wheat-rain tree (Samanea saman) pod composite flours. *International Journal of Food Properties*, *25*(1), 1317-1327. https://doi.org/10.1080/10942912.2022.2077367

Aulton, M. E., & Taylor, K. M. G. (2013). *Powder flow* (pp. 189-200). Edinburgh, Scotland: Churchill Livingstone (Elsevier).

Maninder, K., Sandhu, K. S., & Singh, N. (2007). Comparative study of the functional, thermal and pasting properties of flours from different field pea (Pisum sativum L.) and pigeon pea (Cajanus cajan L.) cultivars. *Food chemistry*, *104*(1), 259-267. https://doi.org/10.1016/j.foodchem.2006.11.037

Ogunsina, B. S., Radha, C., & Govardhan Singh, R. S. (2010). *Physicochemical and functional properties of full-fat and defatted Moringa oleifera kernel flour. International Journal of Food Science & Technology, 45(11), 2433–2439.* https://doi.org/10.1111/j.1365-2621.2010.02423.x

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Results: Figure 2.9.1. Box and Whisker plot of red lentils for Hausner ratio resulting from 6 locations. Results by type were reported from highest to lowest.

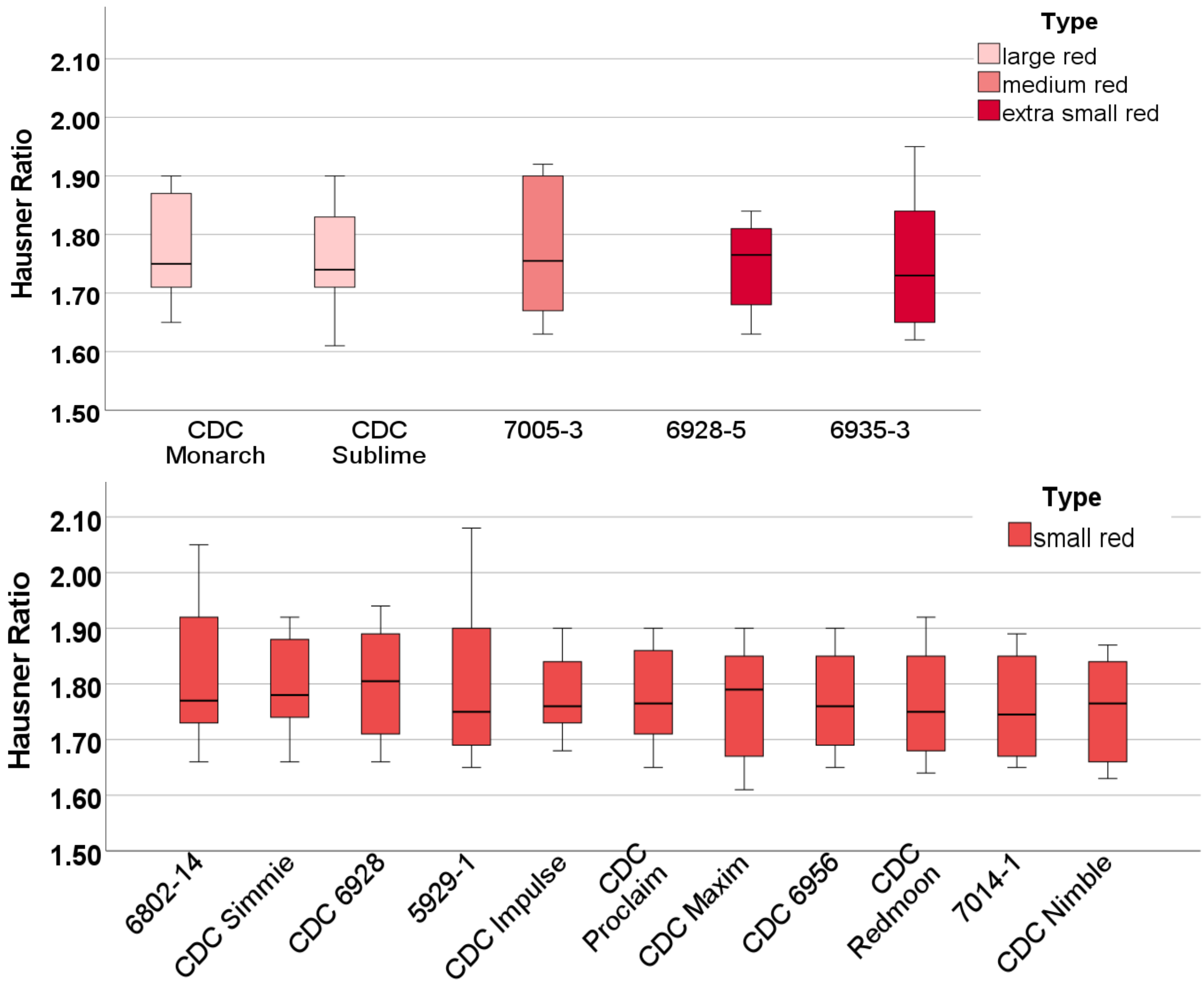
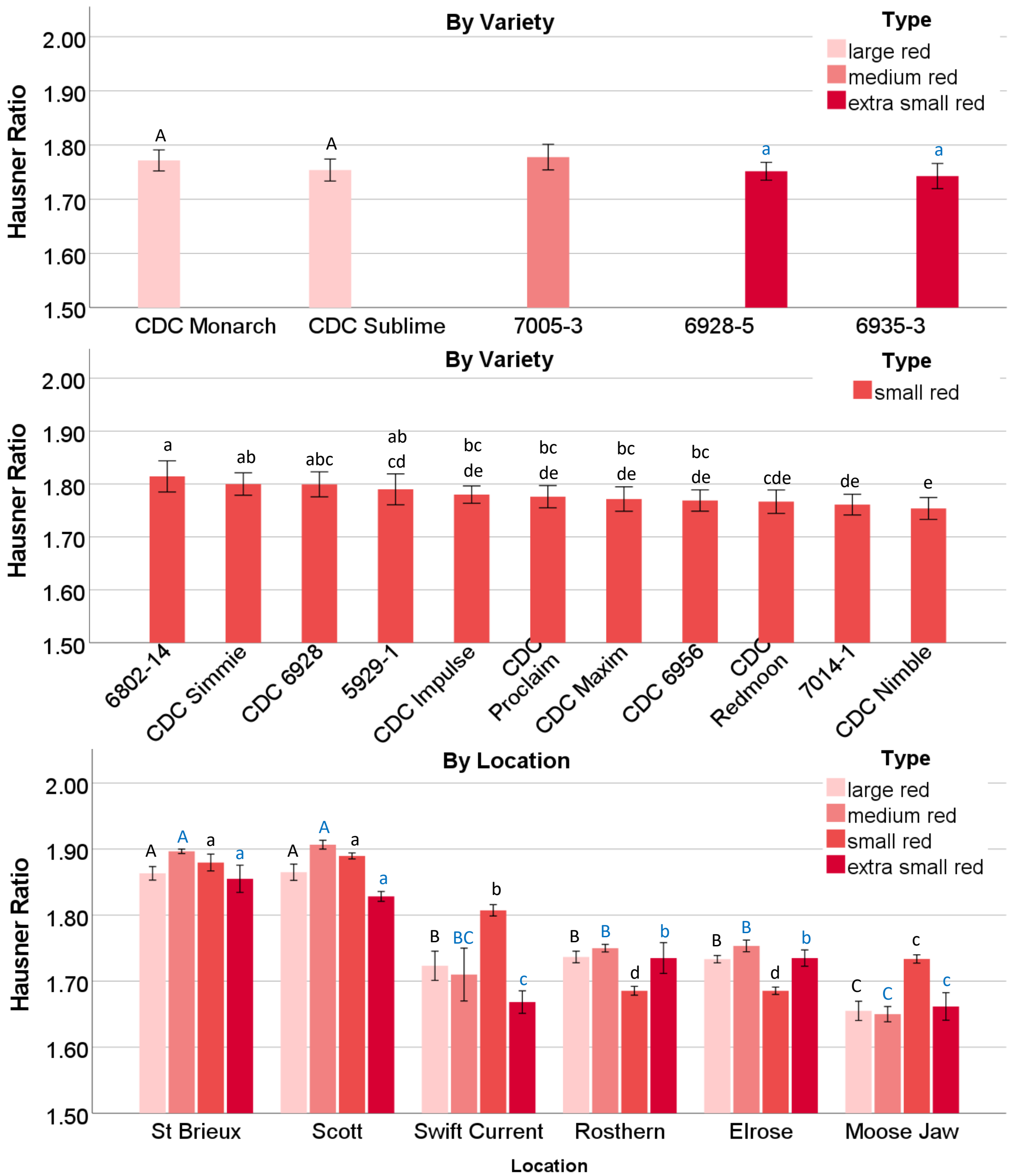


Figure 2.9.2. Mean Hausner ratio of red lentils by variety and by location. Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by large red lentil. Capital letters in blue indicated significant differences (p<0.05) by medium red. Small letters in black indicated significant differences (p<0.05) by small red. Small letters in blue indicated significant differences (p<0.05) by extra small red.

- The results of Hausner ratio for all varieties across 6 locations were all greater than 1.6, suggesting all faba bean flours are classified as very, very poor flow.

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SASKATCHEWAN pulse Growers

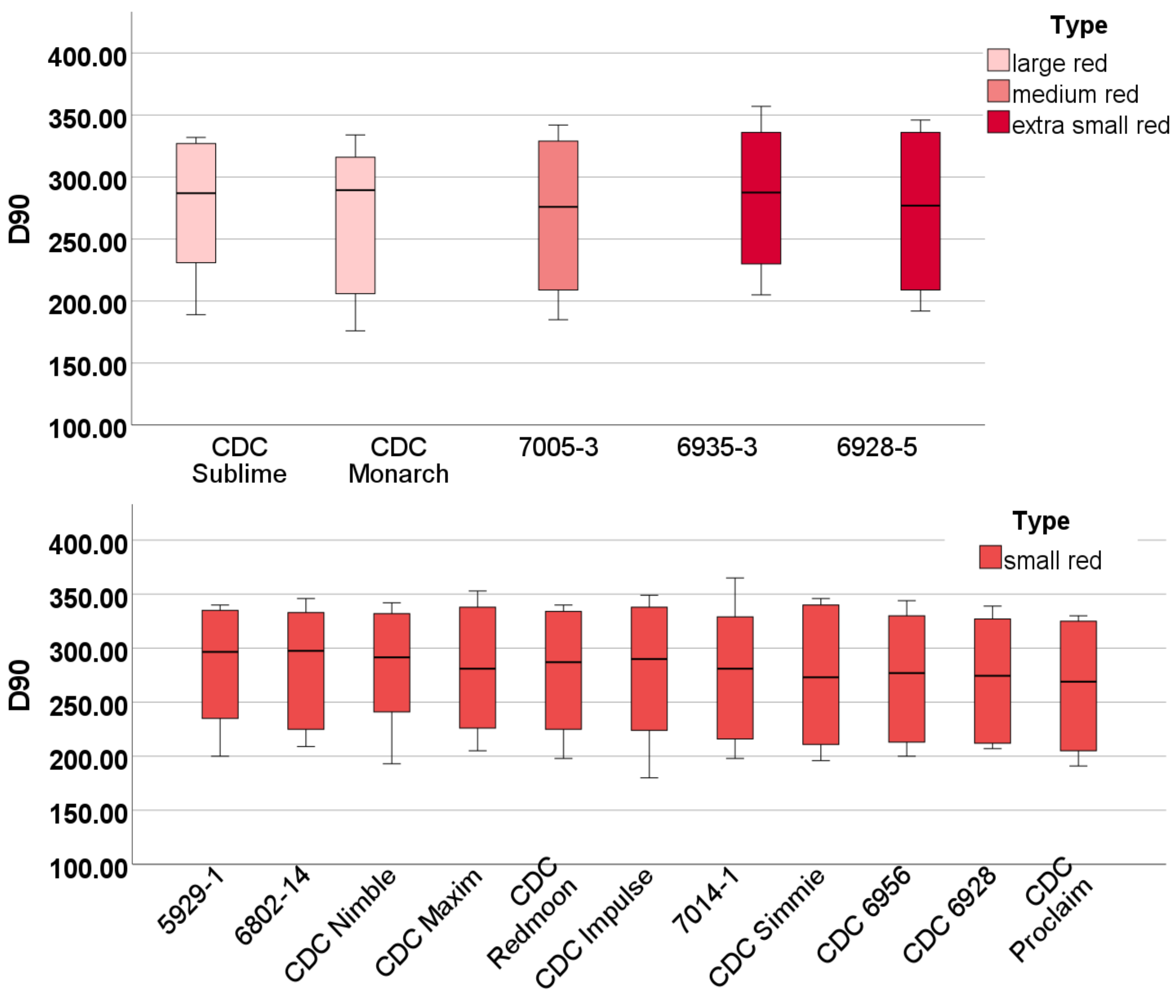
10. Particle Size

Method: The particle size of each flour was measured using the Mastersizer 3000 with a dry sample cell (Malvern Instruments Ltd., Worcestershire, UK). Five measurements were made for each flour, and the averages of D_{90} (µm) and $D_{4,3}$ (µm) were reported.

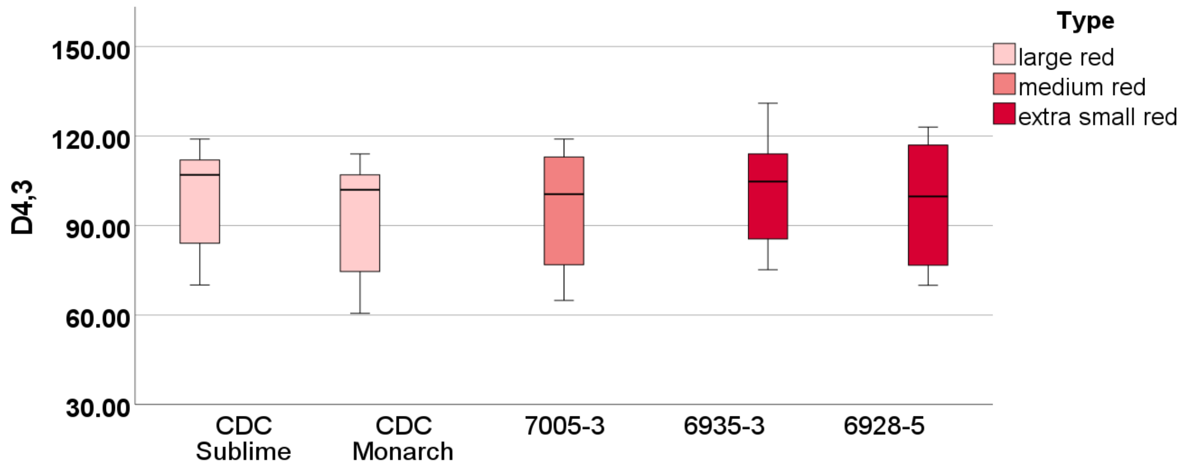
- **D_{90} (µm):** describes the diameter where 90% of the flour distribution has a smaller particle size and indicates whether the milling process reached the expected fineness.

- **$D_{4,3}$ (µm):** describes the mean diameter over volume.

Results: Figure 2.10.1. Box and Whisker plot of red lentils for D_{90} and $D_{4,3}$ values resulting from 6 locations. Results by type were reported from highest to lowest.



Results: Figure 2.10.2. Box and Whisker plot of red lentils for D_{90} and $D_{4,3}$ values resulting from 6 locations. Results by type were reported from highest to lowest.



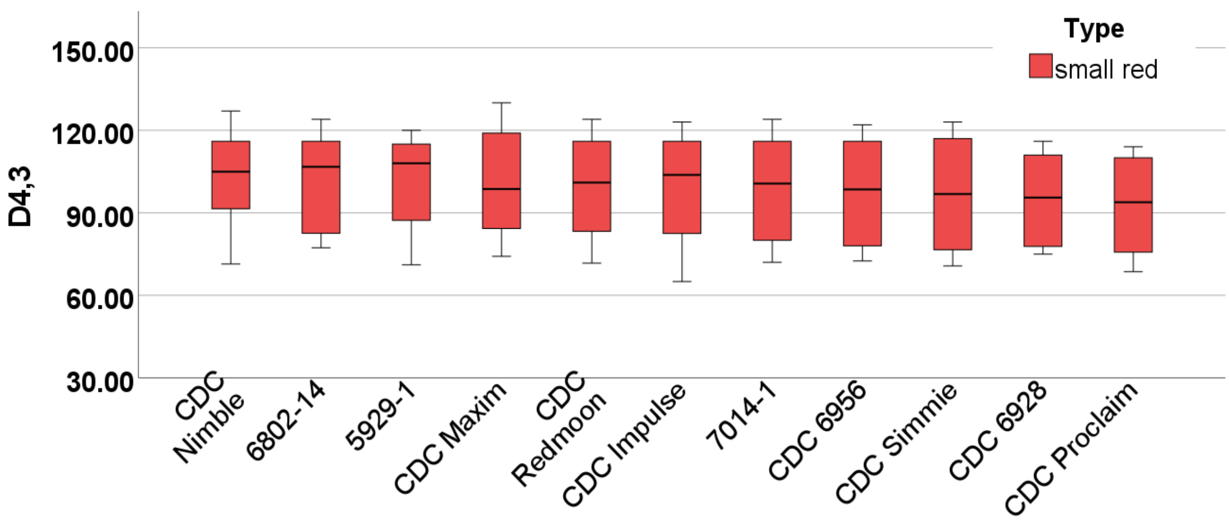
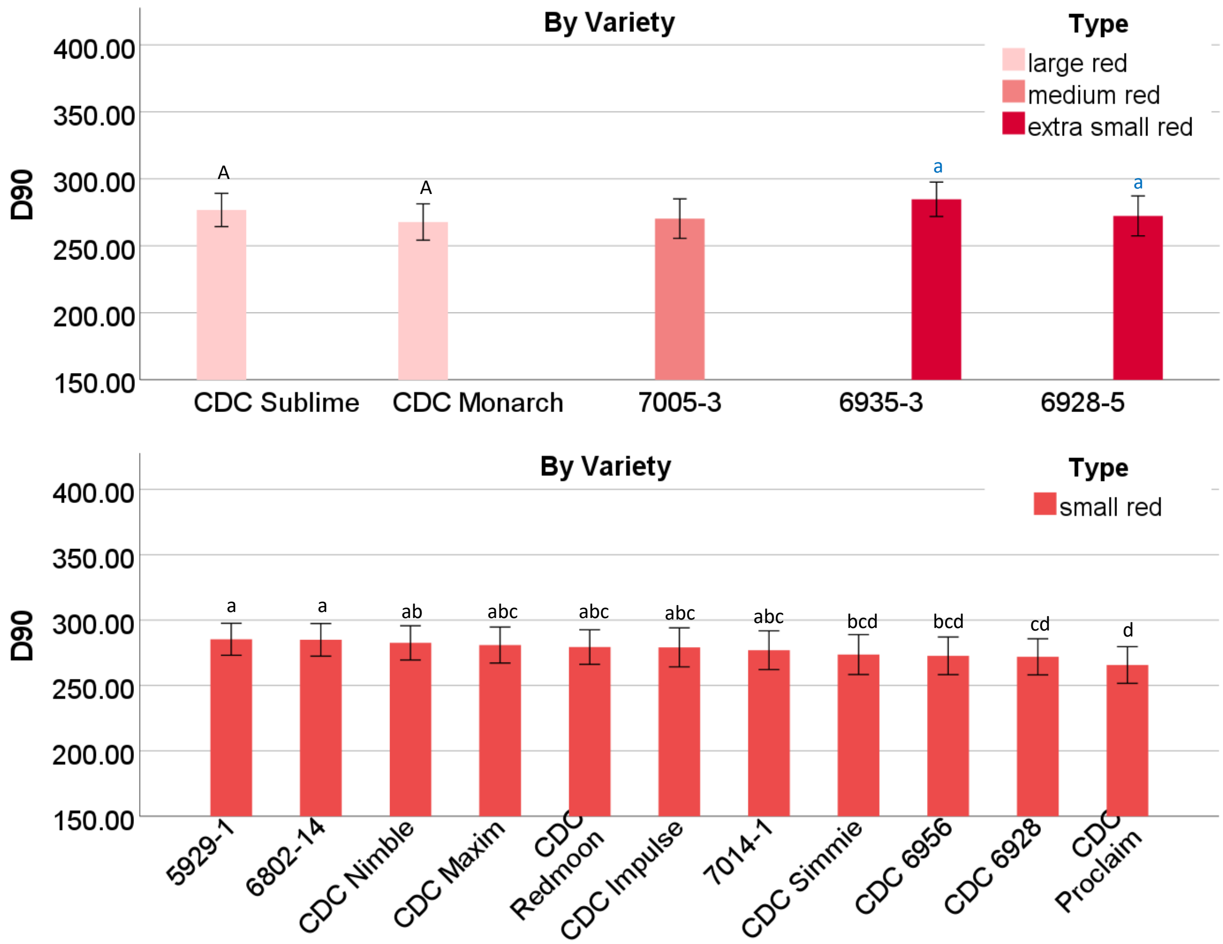


Figure 2.10.3. D_{90} (µm) of red lentil flours by variety. Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by large red lentil. Small letters in black indicated significant differences (p<0.05) by small red. Small letters in blue indicated significant differences (p<0.05) by extra small red.

- **D_{90}:** Means were all below 290 µm.

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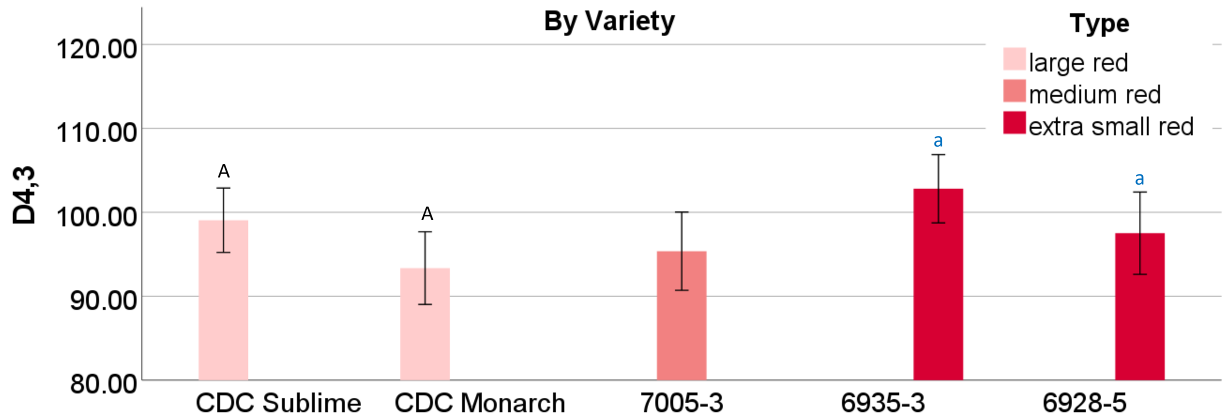
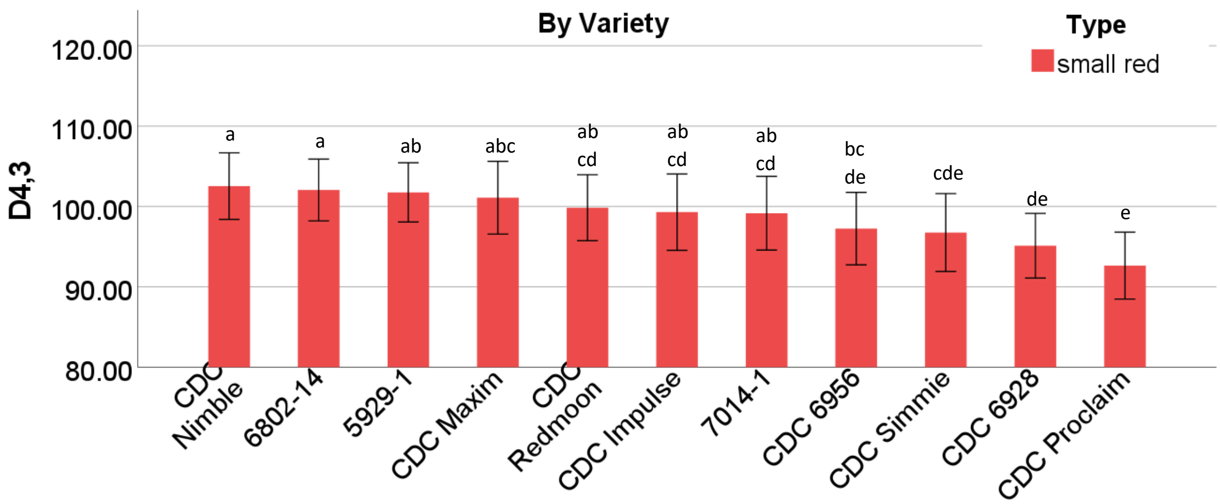
Figure 2.10.4. $D_{4,3}$ (µm) of red lentil flours by variety. Each bar represents mean ± one standard error.





Note: Capital letters in black indicated significant differences (p<0.05) by large red lentil. Small letters in black indicated significant differences (p<0.05) by small red. Small letters in blue indicated significant differences (p<0.05) by extra small red.

- **$D_{4,3}$:** The mean diameters of all flours were below 105 µm.

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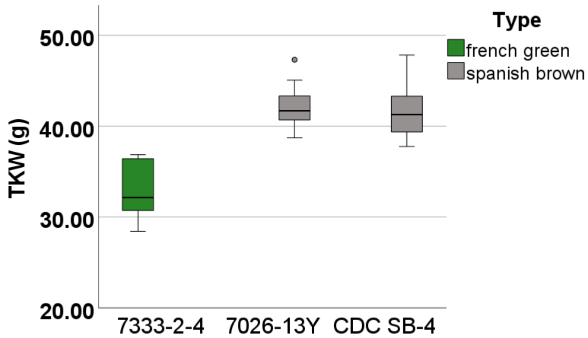
3) 2022 Specialty Lentil

1. 1000 Seed Weight

Method: Seed weight is important to indicate seed size and yield production. This test was conducted by weighing 300 seeds with duplicated measurements per sample. The 1000 seed weight (TKW) was reported.

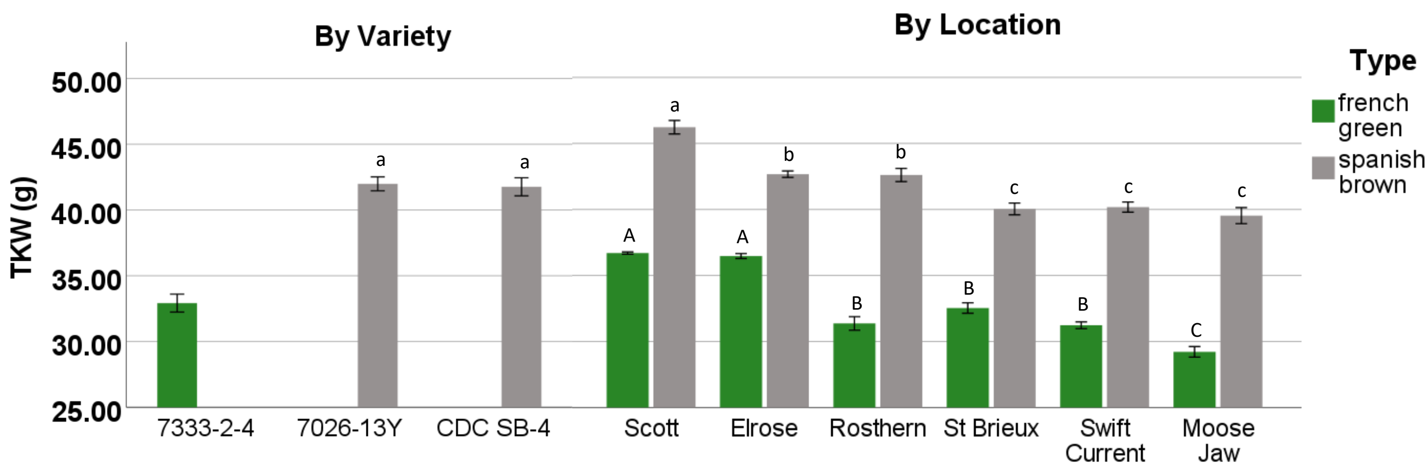
Results: Figure 3.1.1. Box and Whisker plot of specialty lentils for TKW from 6 locations.



French green: had a large variability.

Spanish brown: Line 7026-13 Y was larger with small variability.

Figure 3.1.2. Mean TKW by variety (left) and location (right). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by variety and by location for Spanish brown. Capital letters indicated significant differences (p<0.05) by location for French green.

By Variety: TKW was the same.for both Spanish brown. French green was smaller.

By Location:

- **French green:** Elrose and Elrose (highest) was 7 g higher than Moose Jaw (lowest).
- **Spanish brown:** A difference of 6 g was observed from highest to lowest.

Table 3.1. Effects of variety and location.

	Spanish brown
Variety	*NS*
Location	***
Variety x Location	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

2. Seed Size Distribution

Method: 250 g of seeds were placed on a series of round-hole opening sieves. The weight of seeds retained on each sieve was determined and reported as % of seeds retained. Duplicated measurements were performed.

Sieves used for evaluation:

a. #14R: 5.56 mm
b. #12R: 4.76 mm
c. #10R: 3.97 mm

Results:

Table 3.2. Seed size distribution (%) of each specialty lentil variety. Data represent mean ± one standard deviation.

Variety	> # 14R (%)	> # 12R (%)	> # 10R (%)	Below # 10R (%)
7333-2-4	0.0 ± 0.0	29.2 ± 12.2	66.8 ± 10.5	4.0 ± 2.1
7026-13Y	0.3 ± 0.4[a]	60.5 ± 13.4[a]	37.8 ± 13.2[a]	1.4 ± 0.8[a]
CDC SB-4	0.5 ± 0.5[a]	68.7 ± 11.1[a]	29.6 ± 11.0[a]	1.3 ± 0.6[a]

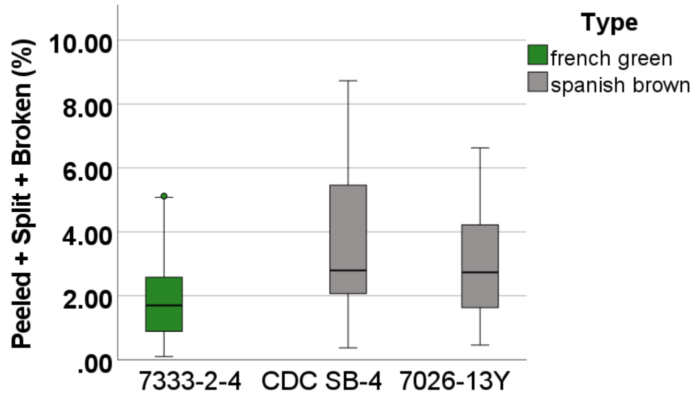
Note: Means of Spanish brown varieties within a column followed by different lowercase letters are significantly different (p<0.05).

- Over 90% of the seeds (all three varieties) retained on the #12 and #10 sieves.
- Line 7333-24 had more seeds retained onto #10 sieve., while the Spanish brown varieties had more seeds retained on #12 sieve.

3. Peeled + Split + Broken

Method: 50 grams of each sample was used for evaluation, and damaged seeds were selected by hand. Results included splits, cracks, seed coat damage, partially missing hull, and partially missing cotyledon.

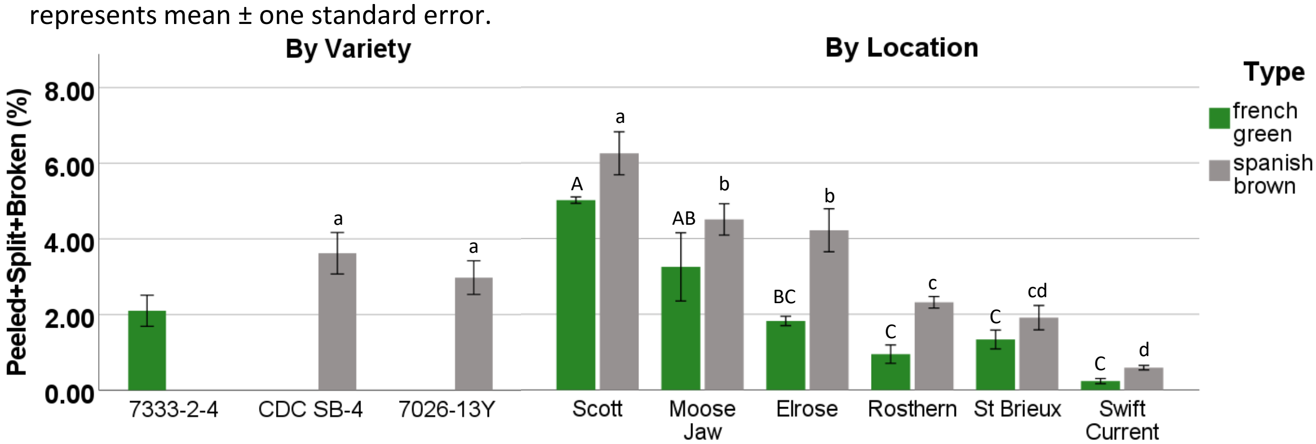
Results: Figure 3.3.1. Box and Whisker plot of peeled + split + broken specialty lentils from 6 locations.



French green: was lower than both Spanish brown seeds.

Spanish brown: Line 7026-13 Y had less variability.

Figure 3.3.2. Mean peeled + split + broken seeds by variety (left) and by location (right). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by variety and by location for Spanish brown. Capital letters indicated significant differences (p<0.05) by location for French green.

By Variety: No statistical difference between both Spanish brown varieties. French green was smaller.

By Location: Damage level varied between locations, where a 5% difference were found from highest to lowest for both types.

Table 3.3. Effects of variety and location.

	Spanish brown
Variety	*NS*
Location	***
Variety x Location	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

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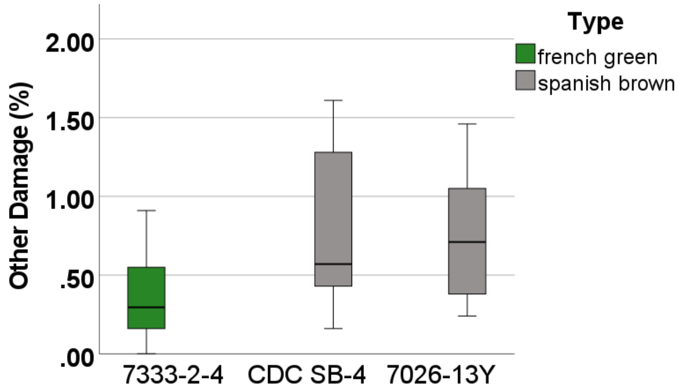
4. Other Damage

Method: 50 grams of each sample was used for evaluation, and damaged seeds were selected by hand. Other damage included sprouting, distinct immaturity, distinct deterioration or discolouration by weather or disease, insect damage, heat damage, and any other damage that affects appearance.

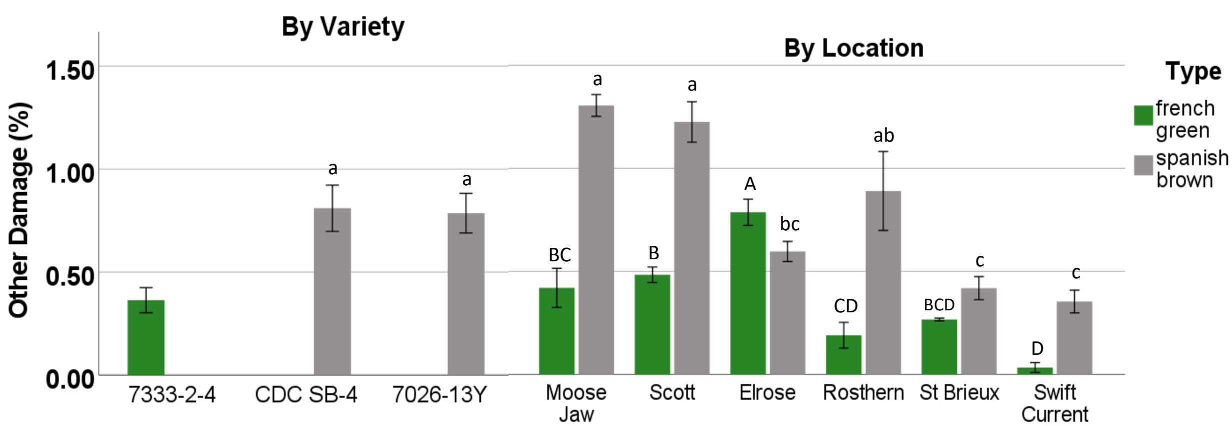
Results: Figure 3.4.1. Box and Whisker plot of other damage from 6 locations.



French green: was lower than both Spanish brown seeds with less variability.

Spanish brown: Line 7026-13 Y had less variability.

Figure 3.4.2. Mean other damage by variety (left) and by location (right). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by variety and by location for Spanish brown. Capital letters indicated significant differences (p<0.05) by location for French green.

By Variety No statistical difference between both Spanish brown varieties. French green was smaller.

By Location:

- **French green:** all below 1%.
- **Spanish brown:** A difference of 1% was found from highest to lowest.

Table 3.4. Effects of variety and location.

	Spanish brown
Variety	*NS*
Location	***
Variety x Location	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

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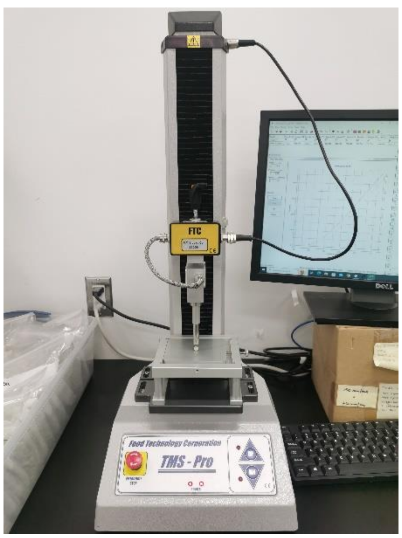
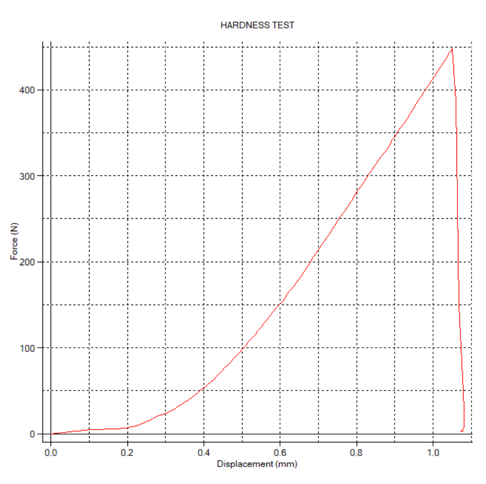
5. Hardness of Whole Seed

Seed hardness is an important parameter to indicate milling yield and cooking quality. Seed hardness is affected by seed size, shape, density, composition, etc.

Method:
Seed hardness was determined by measuring the force of breaking a seed using a texture analyzer (TMS-Pro, Food Technology Corporation, USA) equipped with a 2500 N load cell with a modified method from Karami et al. (2017) and Lovas-Kiss (2020)[9].

In brief, a seed was placed under the 10 mm cylinder probe that was lowered with a speed of 50 mm/min. The forces to lower the probe till a seed was broken were monitored. The mean peak force (N) of 10 seeds was reported.



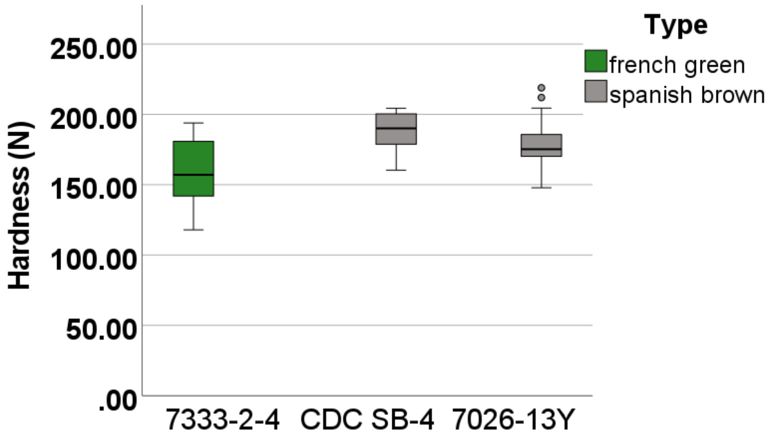


[9] Karami, S., Sabzalian, M. R., Rahimmalek, M., Saeidi, G., & Ghasemi, S. (2017). Interaction of seed coat color and seed hardness: An effective relationship which can be exploited to enhance resistance to the safflower fly (Acanthiophilus helianthi) in Carthamus spp. Crop Protection, 98, 267-275.

Lovas‐Kiss, Á., Vincze, O., Kleyheeg, E., Sramkó, G., Laczkó, L., Fekete, R., ... & Green, A. J. (2020). Seed mass, hardness, and phylogeny explain the potential for endozoochory by granivorous waterbirds. Ecology and Evolution, 10(3), 1413-1424.

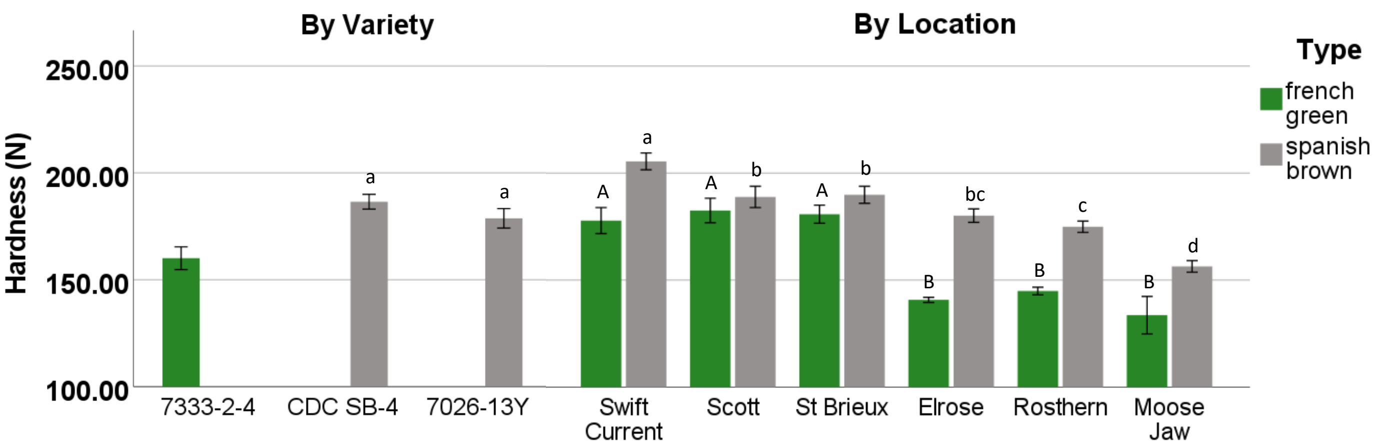
Results:

Figure 3.5.1. Box and Whisker plot of specialty lentils hardness resulting from 6 locations.



The Spanish brown varieties were slightly higher than the French green.

Figure 3.5.2. Mean hardness of specialty lentils by variety (left) and by location (right). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by variety and by location for Spanish brown. Capital letters indicated significant differences (p<0.05) by location for French green.

By Variety: No statistical difference between both Spanish brown varieties. French green was lower.

By Location:

- **French green:** A difference of 49 N was found from highest to lowest.
- **Spanish brown:** A difference of 49 N was determined from highest to lowest.

Table 3.5. Effects of variety and location.

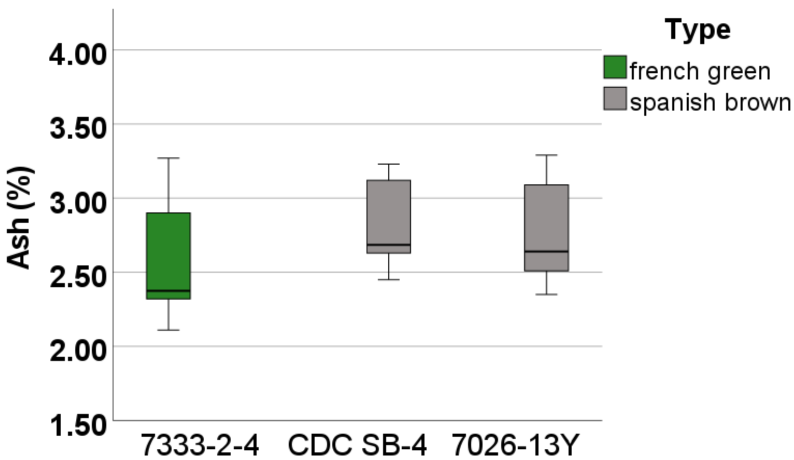
	Spanish brown
Variety	*NS*
Location	***
Variety x Location	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

6. Ash Content

Method: Ash content (%) was determined using AACC 08-01.01[10] with modification. Samples were heated at 560°C till they turned white. Duplicated measurements were performed for each sample, and the average was reported on a dry basis (d.b.).

Results: Figure 3.6.1. Box and Whisker plot of specialty lentils for ash content from 16 locations.



French green: had a large variability
Spanish brown: both were similar.

[10] AACC (1999). American Association of Cereal Chemists International. Approved methods of analysis (11th ed.). The Saint Pauls Association: Saint Paul, MN.

Figure 3.6.2. Mean ash content of specialty lentils by variety (left) and by location (right). Each bar represents mean ± one standard error.

Note: Small letters indicated significant differences (p<0.05) by variety and by location for Spanish brown. Capital letters indicated significant differences (p<0.05) by location for French green.

By Variety: No statistical difference between both Spanish brown varieties. French green was lower in ash.

By Location:

- **French green:** A difference of 1% was observed from highest to lowest.
- **Spanish brown:** A difference of 0.7% was observed from highest to lowest.

Table 3.6. Effects of variety and location.

	Spanish brown
Variety	*NS*
Location	***
Variety x Location	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

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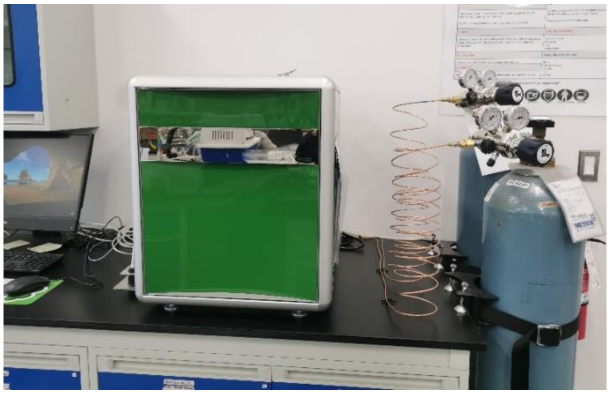
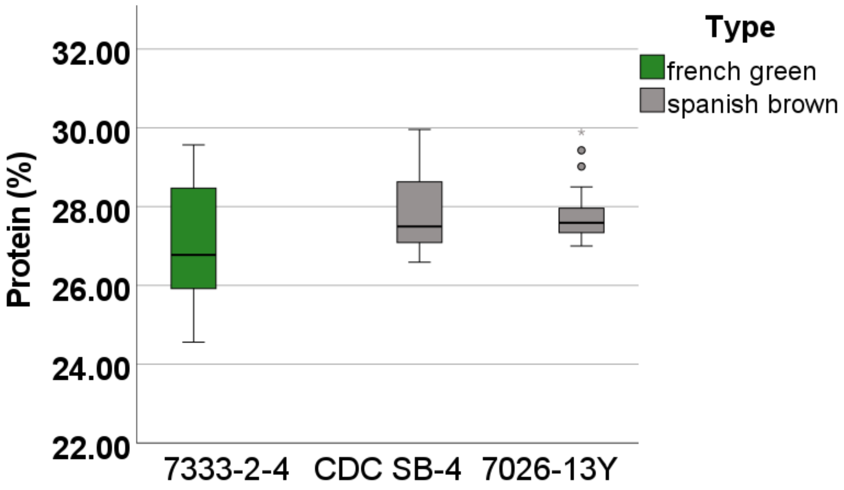
7. Protein Content

Method: The protein content (%) of each flour was determined through AACC 46-30[2] using the combustion method through a Rapid N Exceed (Elementar, USA). Duplicated measurements were performed for each sample, and the average was reported on a dry basis (d.b.).



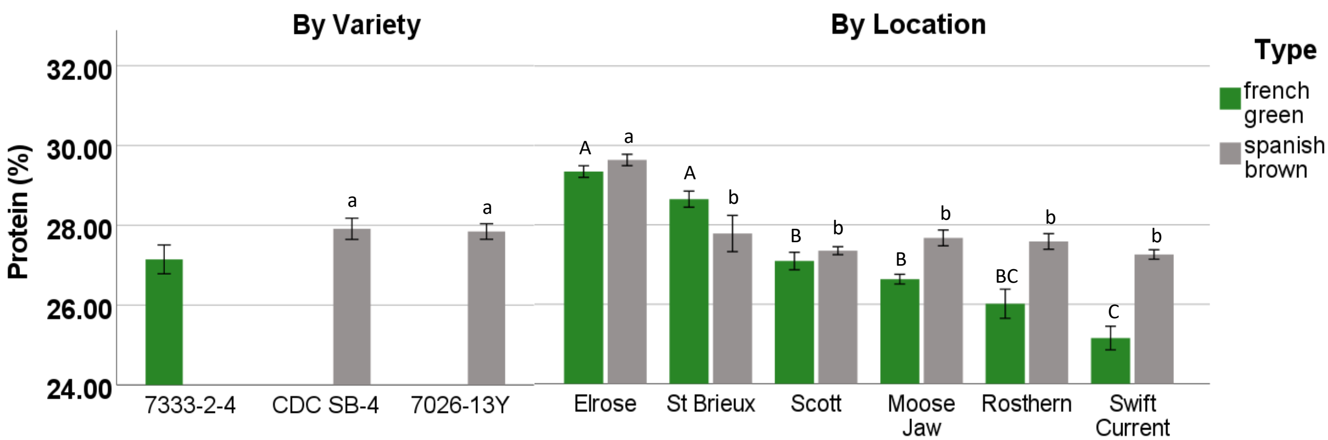
Results: Figure 3.7.1. Box and Whisker plot of specialty lentils for protein content resulting from 6 locations.



French green: had a large variability
Spanish brown: Line 7026-13 Y varied less.

[2] AACC (1999). American Association of Cereal Chemists International. Approved methods of analysis (11th ed.). The Saint Pauls Association: Saint Paul, MN.

Figure 3.7.2. Mean protein (%) of specialty lentils by variety (left) and by location (right). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by variety and by location for Spanish brown. Capital letters indicated significant differences (p<0.05) by location for French green.

By Variety: No statistical difference between both Spanish brown varieties. French green was lower in protein.

By Location:

- **French green:** Protein for Elrose and St Brieux were ~4% higher than the lowest .
- **Spanish brown:** Elrose was higher, and the other five locations were the same.

Table 3.7. Effects of variety and location.

	Spanish brown
Variety	*NS*
Location	***
Variety x Location	*NS*

Note: ***p<0.001; **p<0.01; *p<0.05; NS not significant.*

8. Colour

Method: The absolute colour of each flour was determined using the Konica Minolta CR-400 Chroma meter, where *L*, a*,* and *b** values were reported.

- ***L* (lightness):*** white (100) to black (0)
- ***a*:*** red (+) to green (-)
- ***b*:*** yellow (+) to blue (-)

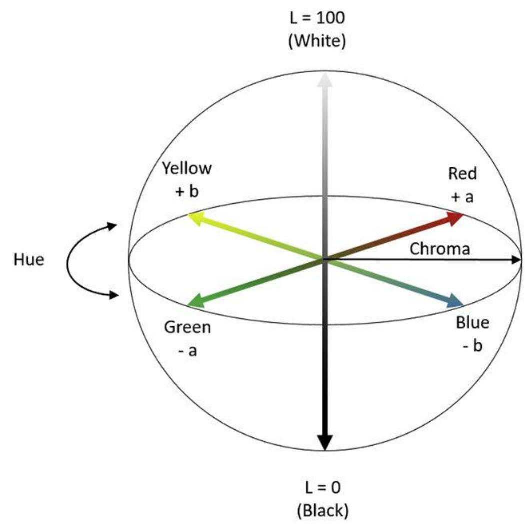
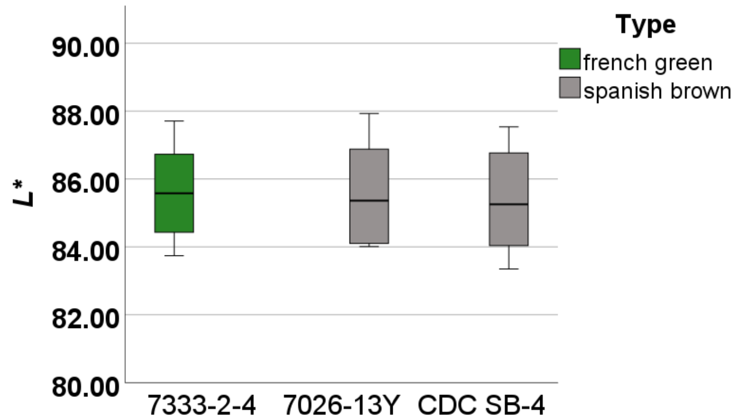


Figure 3.8.1. The CIELAB color spacediagram[11].

[11] Ly, B. C. K., Dyer, E. B., Feig, J. L., Chien, A. L., & Del Bino, S. (2020). Research techniques made simple: cutaneous colorimetry: a reliable technique for objective skin color measurement. *Journal of Investigative Dermatology*, *140*(1), 3-12.

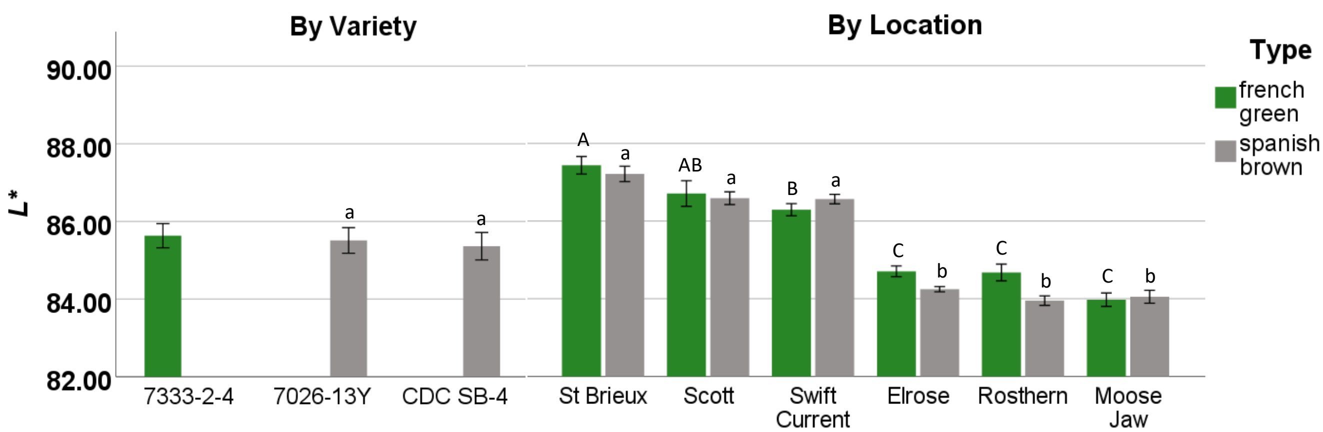
a) ***L* (lightness):*** white (100) to black (0)

Results: Figure 3.8.2. The Box and Whisker plot of specialty lentils for *L** values resulting from 6 locations.



Lightness were all similar.

Figure 3.8.3. Mean *L** value by variety (left) and by location (right). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by variety and by location for Spanish brown. Capital letters indicated significant differences (p<0.05) by location for French green.

By Variety: No statistical difference between both Spanish brown varieties. French green was similar as well.

By Location:
St Brieux (highest) was 3 units higher than Elrose, Rosthern, and Moose Jaw (lowest) for both seed types.

Table 3.8.1. Effects of variety and location.

	Spanish brown
Variety	*NS*
Location	***
Variety x Location	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

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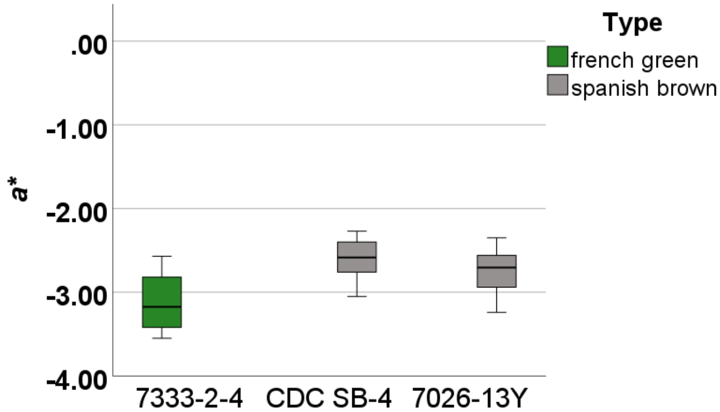
b) ***a*:*** red (+) to green (-)

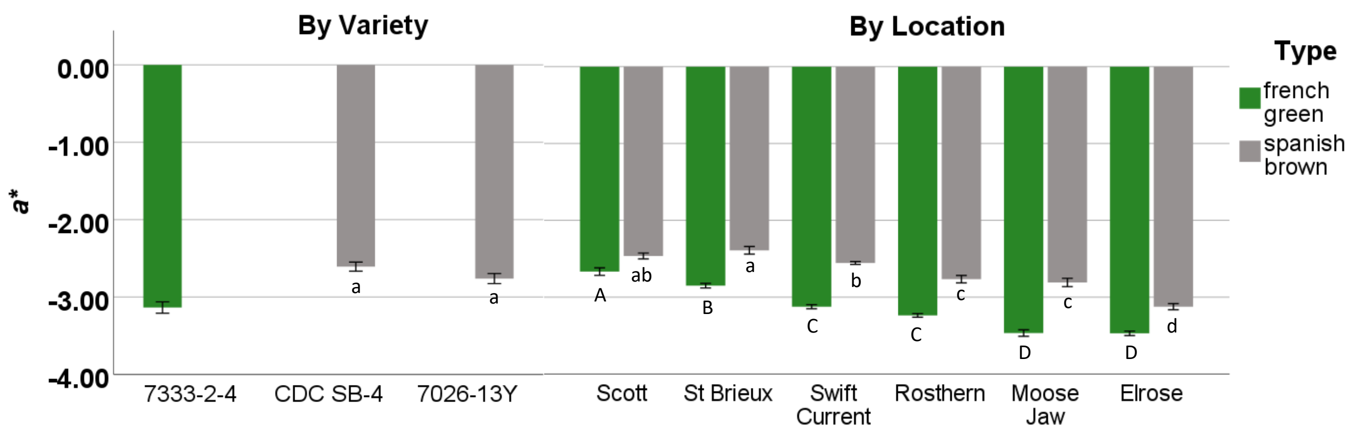
Results: Figure 3.8.4. The Box and Whisker plot of specialty lentils for *a** values resulting from 6 locations.



French green: had a slightly stronger greenness.

Spanish brown: both were similar.

Figure 3.8.5. Mean *a** value by variety (left) and by location (right). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by variety and by location for Spanish brown. Capital letters indicated significant differences (p<0.05) by location for French green.

By Variety: No statistical difference between both Spanish brown varieties.

By Location:

- **French green:** Only 0.8 unit difference was determined from the highest to the lowest.
- **Spanish brown:** Only 0.7 unit difference was determined from the highest to the lowest.

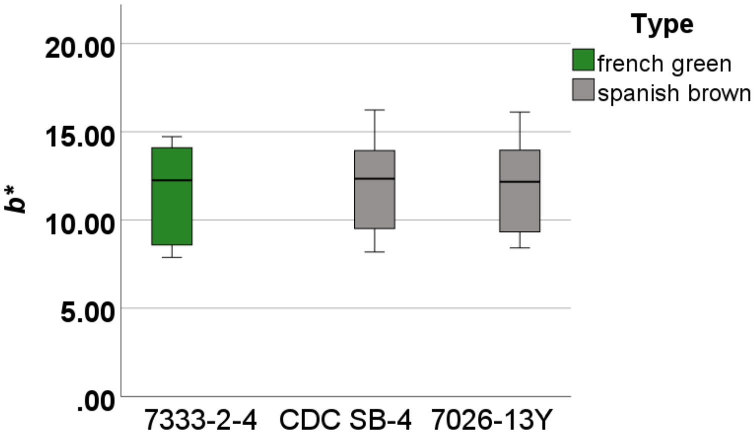
Table 3.8.2. Effects of variety and location.

	Spanish brown
Variety	*NS*
Location	***
Variety x Location	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

c) ***b*:*** yellow (+) to blue (-)

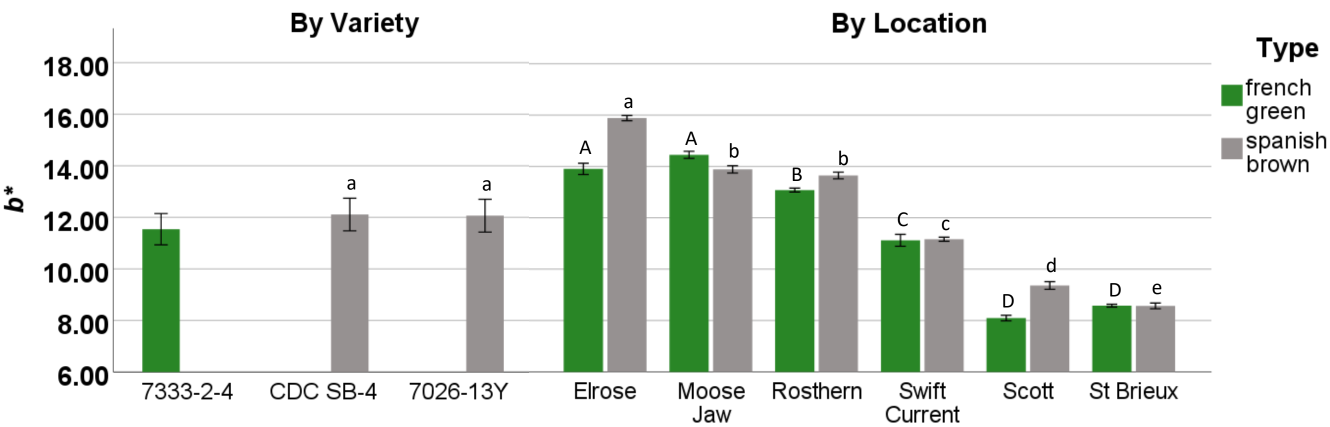
Results: Figure 3.8.6. Box and Whisker plot of specialty lentils for *b** values from 6 locations.



French green: TKW varied more than both Spanish browns.

Spanish brown: Line 7026-13 Y was larger with small variability.

Figure 3.8.7. Mean *b** value of specialty lentils by variety (left) and by location (right). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by variety and by location for Spanish brown. Capital letters indicated significant differences (p<0.05) by location for French green.

By Variety: No statistical difference between both Spanish brown varieties. French green was sightly lower.

By Location: *b** values varued sugnificantly between locations.

- **French green:** Moose Jaw and Elrose (highest) were ~6 units higher than St Brieux and Scott (lowest).
- **Spanish brown:** A difference of 7.3 units was determined from the highest (Elrose) to the lowest (St Brieux).

Table 3.8.3. Effects of variety and location.

	Spanish brown
Variety	*NS*
Location	***
Variety x Location	*NS*

Note: ***p<0.001; ***p<0.01; *p<0.05; NS not significant.*

9. Hausner Ratio

Hausner ratio measures the ratio of tapped density to loose bulk density, indicating the flow-ability and the compressibility of the flour after milling. Hausner ratio is an important parameter in food products handling, packaging, storage, processing, and distribution. It is useful in the specification of products derived from size reduction or drying processes. Usually, the lower the flow-ability a flour, the more compressible it becomes[12].

Method: The bulk and tapped volumes of 10 g of flour were determined using a 25 mL graduated cylinder. Duplicated measurements were made for each flour, and the Hausner ratio is calculated as:

Hausner ratio = $\frac{Tapped\ density}{Loose\ bulk\ density} = \frac{Bulk\ volume\ (mL)}{Tapped\ volume\ (mL)}$

Table 3.9. Relationship between powder flow-ability and Hausner ratio.

Type of flow	Hausner ratio
Excellent	1.00-1.11
Good	1.12-1.18
Fair	1.19-1.25
Passable	1.26-1.34
Poor	1.35-1.45
Very poor	1.46-1.59
Very, very poor	>1.59

[12] Buanz, A. (2021). Powder characterization. In *Remington* (pp. 295-305). Academic Press. https://doi.org/10.1016/B978-0-12-820007-0.00016-7

Amankwah, N. Y. A., Agbenorhevi, J. K., & Rockson, M. A. (2022). Physicochemical and functional properties of wheat-rain tree (Samanea saman) pod composite flours. *International Journal of Food Properties*, *25*(1), 1317-1327. https://doi.org/10.1080/10942912.2022.2077367

Aulton, M. E., & Taylor, K. M. G. (2013). *Powder flow* (pp. 189-200). Edinburgh, Scotland: Churchill Livingstone (Elsevier).

Maninder, K., Sandhu, K. S., & Singh, N. (2007). Comparative study of the functional, thermal and pasting properties of flours from different field pea (Pisum sativum L.) and pigeon pea (Cajanus cajan L.) cultivars. *Food chemistry*, *104*(1), 259-267. https://doi.org/10.1016/j.foodchem.2006.11.037

Ogunsina, B. S., Radha, C., & Govardhan Singh, R. S. (2010). *Physicochemical and functional properties of full-fat and defatted Moringa oleifera kernel flour. International Journal of Food Science & Technology, 45(11), 2433–2439.* https://doi.org/10.1111/j.1365-2621.2010.02423.x

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Results: Figure 3.9.1. Box and Whisker plot of specialty lentils for Hausner ratio from 6 locations.

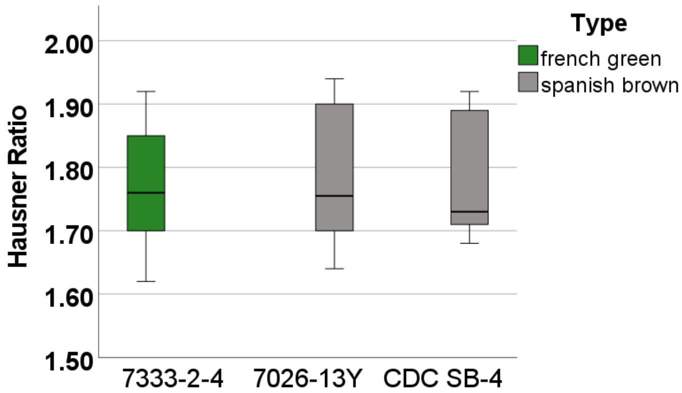
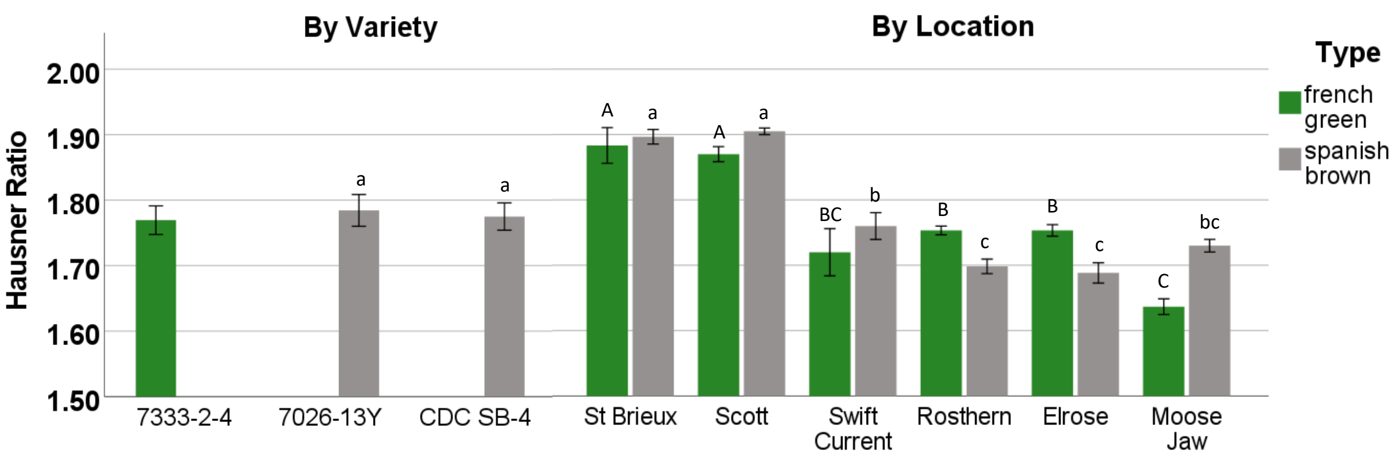


Figure 3.9.2. Mean Hausner ratio of specialty lentils by variety (left) and by location (right). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by variety and by location for Spanish brown. Capital letters indicated significant differences (p<0.05) by location for French green.

- Hausner ratios of three varieties across 6 locations were all greater than 1.6, suggesting all flours are classified as very, very poor flow.

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10. Particle Size

Method: The particle size of each flour was measured using the Mastersizer 3000 with a dry sample cell (Malvern Instruments Ltd., Worcestershire, UK). Five measurements were made for each flour, and the average values of D_{90} (µm) and $D_{4,3}$ (µm) were reported.

- **D_{90} (µm):** describes the diameter where 90% of the flour distribution has a smaller particle size and indicates whether the milling process reached the expected fineness.

- **$D_{4,3}$ (µm):** describes the mean diameter over volume.

Results: Figure 3.10.1. Box and Whisker plot of specialty lentils for D_{90} (µm, left) and $D_{4,3}$ (µm, right) resulting from 6 locations.

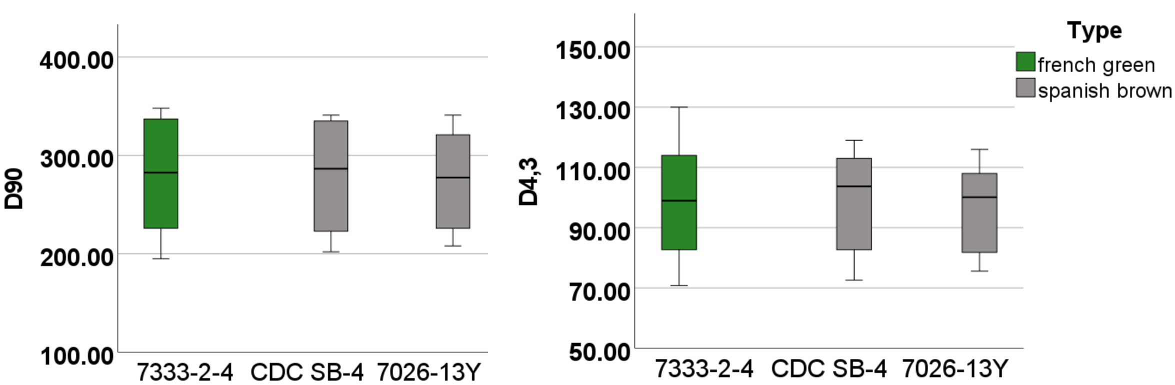
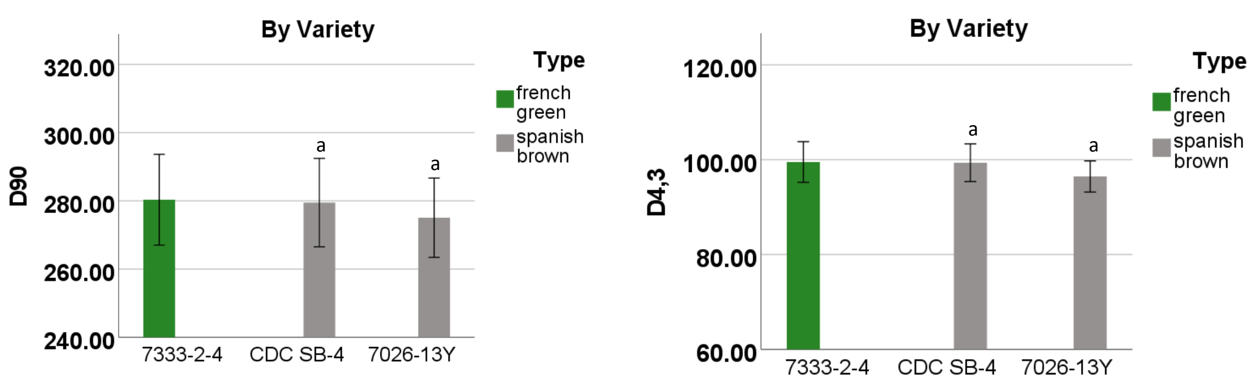


Figure 3.10.2. D_{90} (µm, left) and $D_{4,3}$ (µm, right) of specialty lentils flours by variety. Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences ($p<0.05$) by Spanish brown.

- **D_{90}:** All three varieties were below 300 µm.
- **$D_{4,3}$:** The mean diameter of three varieties was below 100 µm.