2022 Pulse Quality Evaluation

Chickpea

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, lentils, chickpeas, faba beans, 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 Chickpea Quality

This report evaluated **360** chickpea samples harvested from **six locations**, including Avonlea, Elrose, Goodale, Lucky Lake, Moose Jaw, and Swift Current, in **2022**. There were **twenty varieties**, which included seventeen varieties of kabuli, one black desi variety, and two varieties of desi. 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 chickpea samples harvested in 2022 for the Pulse Quality Program.

Crop	Type	Variety		Site	Number of samples
Chickpea	**Kabuli**	2307-15	Amit	Avonlea Elrose Goodale Lucky Lake Moose Jaw Swift Current	360
		2335-23	CDC Lancer		
		2336-18	CDC Leader		
		2444-6	CDC Orion		
		3315-6	CDC Orkney		
		3385-4	CDC Pasqua		
		3540-11	CDC Pearl		
		3549-2	Kasin		
		3550-12			
	Black desi	CDC Kala			
	Desi	2435-2	CDC Sunset		

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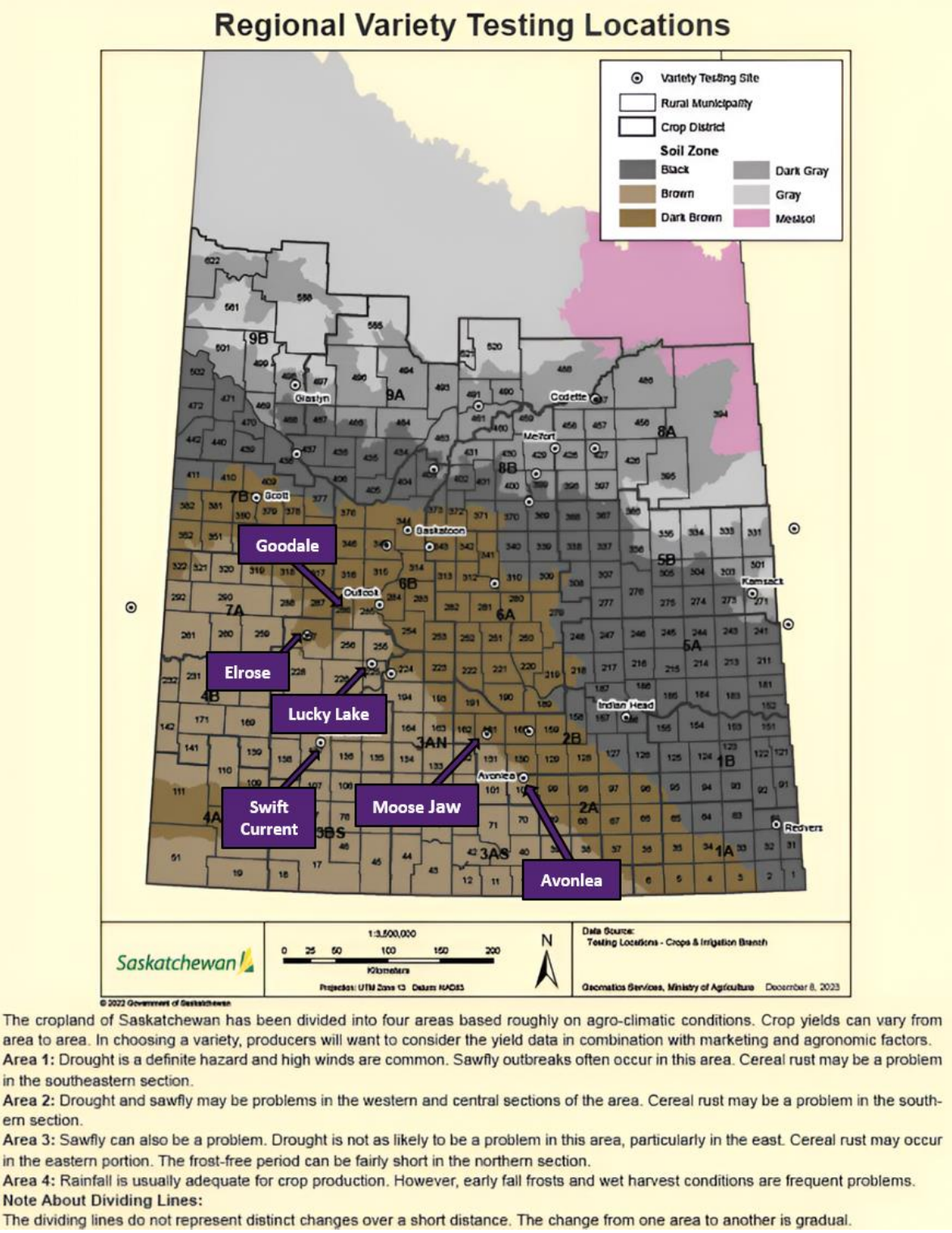

The cropland of Saskatchewan has been divided into four areas based roughly on agro-climatic conditions. Crop yields can vary from area to area. In choosing a variety, producers will want to consider the yield data in combination with marketing and agronomic factors.

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 chickpea 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 two sections: **1)** 2022 kabuli chickpea varieties and **2)** 2022 black desi + desi varieties. Each section includes ten subsections for the results of the following quality parameters:

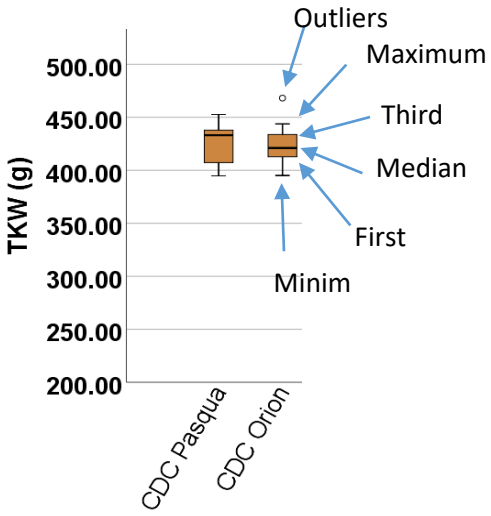
1. 1000 seed weight
2. Seed size distribution
3. Split amount
4. Other damage
5. Hardness of whole seed
6. Ash content
7. Protein content
8. Colour (*L*, a*,* and *b**)
9. Hausner Ratio
10. Particle size

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 average value 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 location for kabuli, desi, and black desi chickpeas and by variety for kabuli chickpeas.

An independent T-test was conducted to identify the differences in the quality parameters for desi chickpeas by variety.

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

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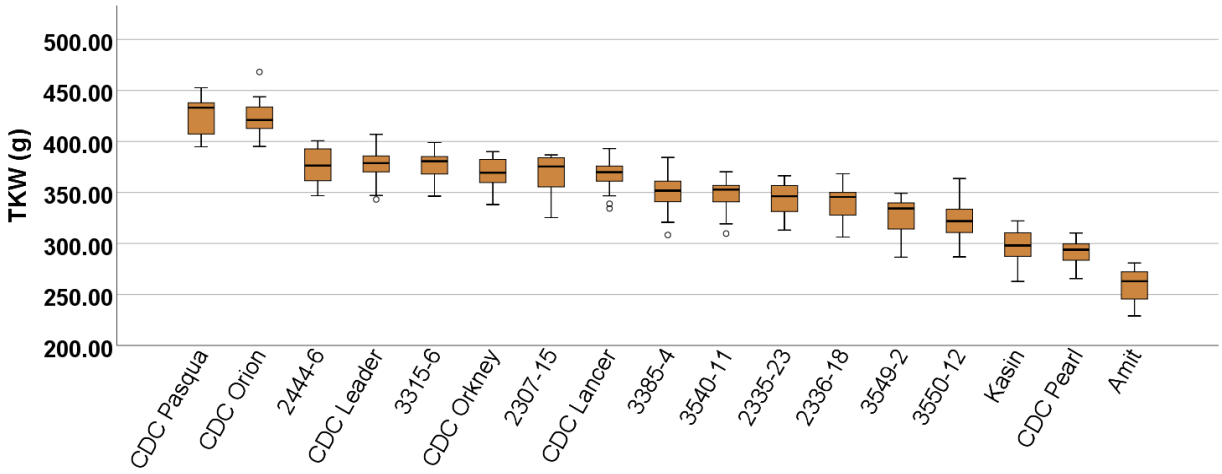
1) 2022 Kabuli Chickpea Quality

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 kabuli chickpeas for TKW resulting from 6 locations. Results were reported from highest to lowest.



- CDC Pasqua and CDC Orion had the largest TKW.
- Amit was the smallest in TKW.
- Kasin and CDC Pearl were the second smallest in TKW.

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

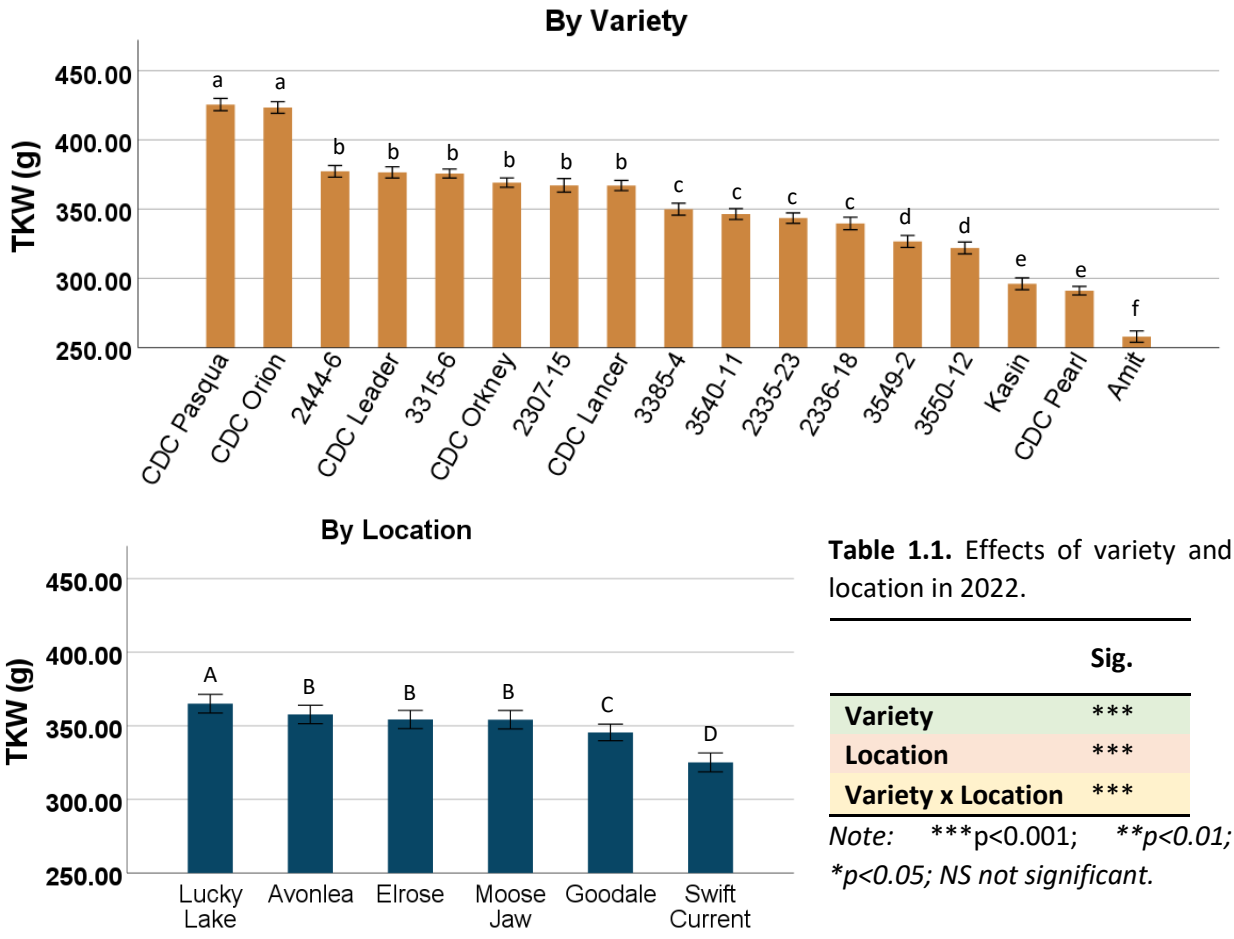

Table 1.1. Effects of variety and location in 2022.

	Sig.
Variety	***
Location	***
Variety x Location	***

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

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

By Variety:

- A difference of over 165 g was determined from the largest (CDC Pasqua & CDC Orion) to the smallest (Amit).

By Location:

- TKW of Lucky Lake (highest) was 40 g higher than Swift Current (smallest).
- TKW of the Avonlea, Elrose, and Moose Jaw were similar.

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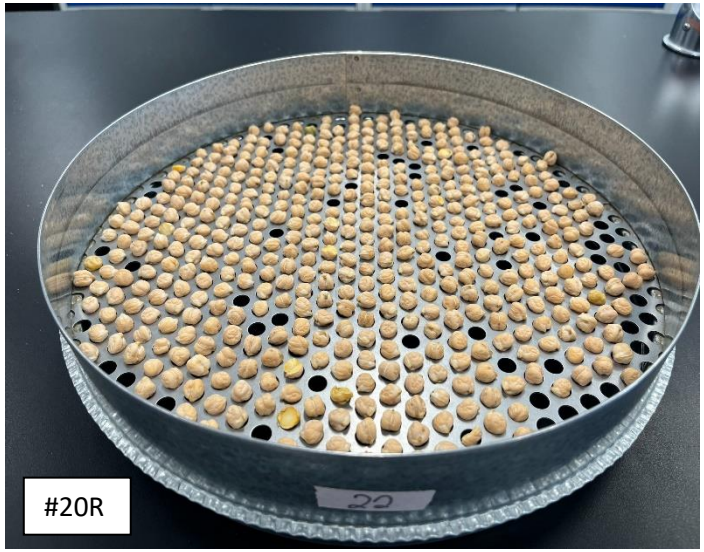
2. Seed Size Distribution

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 chickpeas:

a. #24R: 9.52 mm
b. #22R: 8.73 mm
c. #20R: 7.94 mm
d. #18R: 7.14 mm
e. #16R: 6.35 mm
f. #14R: 5.56 mm



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

Variety	> # 24R (%)	> # 22R (%)	> # 20R (%)	> # 18R (%)	> # 16R (%)	> # 14R (%)	Below # 14R (%)
2307-15	1.6 ± 1.1^{de}	28.1 ± 9.6^{d}	48.9 ± 4.6^{ef}	18.2 ± 8.9^{cd}	2.6 ± 1.9^{defg}	0.4 ± 0.2^{c}	0.1 ± 0.1^{bc}
2335-23	0.1 ± 0.2^{fg}	19.8 ± 9.1^{ef}	56.7 ± 6.0^{ab}	20.4 ± 10.6^{c}	2.5 ± 2.0^{efg}	0.3 ± 0.2^{c}	0.1 ± 0.1^{bc}
2336-18	0.2 ± 0.3^{fg}	19.9 ± 8.2^{ef}	55.2 ± 5.1^{abc}	21.3 ± 10.6^{c}	3.0 ± 2.1^{defg}	0.3 ± 0.2^{c}	0.1 ± 0.2^{bc}
2444-6	2.3 ± 1.9^{cd}	43.2 ± 11.2^{b}	42.2 ± 7.0^{g}	10.0 ± 5.5^{gh}	1.9 ± 1.8^{fg}	0.3 ± 0.2^{c}	0.1 ± 0.1^{bc}
3315-6	3.6 ± 2.1^{b}	36.8 ± 9.0^{c}	45.6 ± 8.1^{fg}	12.1 ± 4.2^{fg}	1.7 ± 1.3^{fg}	0.2 ± 0.2^{c}	0.1 ± 0.1^{c}
3385-4	0.1 ± 0.1^{fg}	17.9 ± 7.8^{fg}	58.5 ± 6.7^{a}	20.4 ± 10.8^{c}	2.5 ± 1.5^{efg}	0.4 ± 0.3^{c}	0.1 ± 0.1^{c}
3540-11	0.5 ± 0.4^{efg}	23.1 ± 6.9^{e}	51.5 ± 7.0^{cde}	20.7 ± 8.6^{c}	3.5 ± 2.1^{def}	0.5 ± 0.4^{c}	0.2 ± 0.2^{bc}
3549-2	0.3 ± 0.4^{fg}	14.6 ± 6.4^{g}	51.0 ± 12.1^{de}	28.8 ± 13.6^{b}	4.7 ± 3.2^{d}	0.5 ± 0.4^{c}	0.2 ± 0.2^{bc}
3550-12	0.4 ± 0.4^{fg}	15.0 ± 9.3^{g}	54.0 ± 8.4^{bcd}	25.7 ± 10.9^{b}	4.4 ± 2.2^{de}	0.5 ± 0.3^{c}	0.1 ± 0.1^{bc}
Amit	0.0 ± 0.1^{g}	0.3 ± 0.3^{h}	8.5 ± 5.6^{j}	51.3 ± 12.0^{a}	36.3 ± 15.4^{a}	3.3 ± 2.3^{a}	0.3 ± 0.4^{a}
CDC Lancer	0.6 ± 0.5^{efg}	23.3 ± 8.3^{e}	56.5 ± 4.5^{ab}	16.7 ± 7.4^{de}	2.5 ± 1.5^{efg}	0.3 ± 0.3^{c}	0.1 ± 0.1^{c}
CDC Leader	3.2 ± 2.3^{bc}	34.7 ± 10.9^{c}	45.3 ± 7.2^{fg}	14.0 ± 7.1^{ef}	2.2 ± 0.8^{fg}	0.4 ± 0.3^{c}	0.2 ± 0.3^{ab}
CDC Orion	10.7 ± 4.6^{a}	50.0 ± 6.8^{a}	30.7 ± 7.5^{hi}	7.0 ± 2.5^{h}	1.2 ± 0.8^{g}	0.3 ± 0.3^{c}	0.2 ± 0.1^{bc}
CDC Orkney	1.3 ± 0.9^{def}	29.5 ± 9.3^{d}	51.8 ± 5.6^{cde}	14.8 ± 8.2^{def}	2.1 ± 1.4^{fg}	0.3 ± 0.3^{c}	0.1 ± 0.1^{bc}
CDC Pasqua	11.5 ± 5.5^{a}	50.1 ± 8.0^{a}	30.1 ± 10.4^{hi}	6.7 ± 2.6^{h}	1.2 ± 0.8^{g}	0.2 ± 0.2^{c}	0.2 ± 0.2^{abc}
CDC Pearl	0.0 ± 0.0^{g}	1.3 ± 0.7^{h}	32.4 ± 9.7^{h}	50.4 ± 6.1^{a}	13.9 ± 6.5^{c}	1.6 ± 1.2^{b}	0.3 ± 0.3^{a}
Kasin	0.0 ± 0.0^{g}	0.5 ± 0.5^{h}	27.9 ± 12.5^{i}	53.6 ± 7.1^{a}	16.4 ± 8.8^{b}	1.4 ± 0.7^{b}	0.2 ± 0.2^{abc}

Note: Means within a column followed by different lowercase letters are significantly different ($p<0.05$).

- Seed size distribution results corresponded to TKW.
- CDC Pasqua and CDC Orion had the highest TKW, and over 90% of the seeds retained on the #24, #22, and #20 sieves.
- Amit had the smallest TKW, and over 90% of the seeds retained on the #20, #18, and #16 sieves.
- Other varieties tended to retain on the #22, #20, and #18 sieves.

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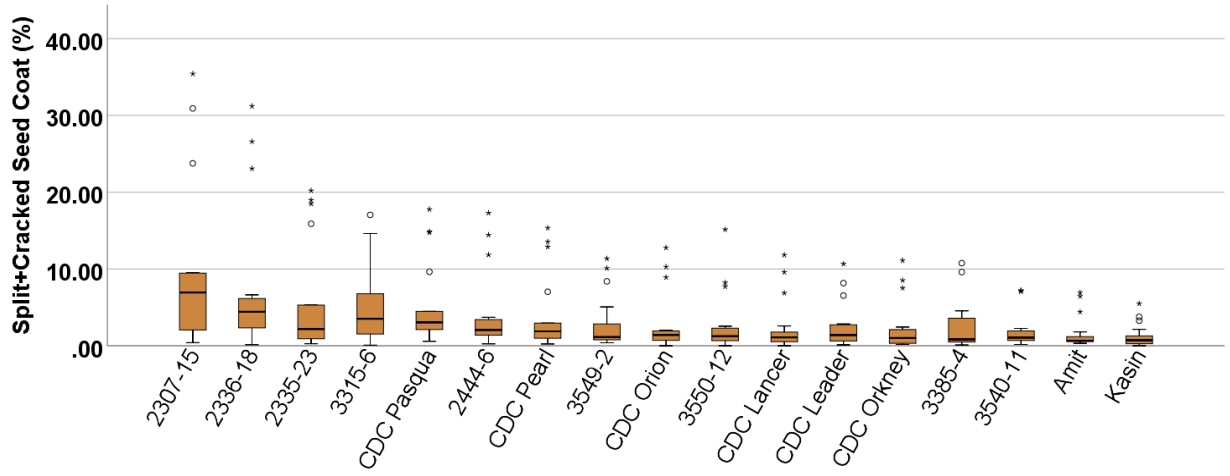
3. Split + Cracked Seed Coat

Method: 100 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. Box and Whisker plot of kabuli chickpeas for the split and cracked seed coat resulting from 6 locations. Results were reported from highest to lowest.



- Kasin, Amit, and line 3540-11 had low amount of split + cracked seed coat and small variability.
- Line 2307-15 had the highest split and cracked seed coat with large variability.

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Figure 1.3.2. Mean split + cracked seed coat (%) of kabuli chickpeas by variety (top) and by location (bottom). Each bar represents mean ± one standard error.

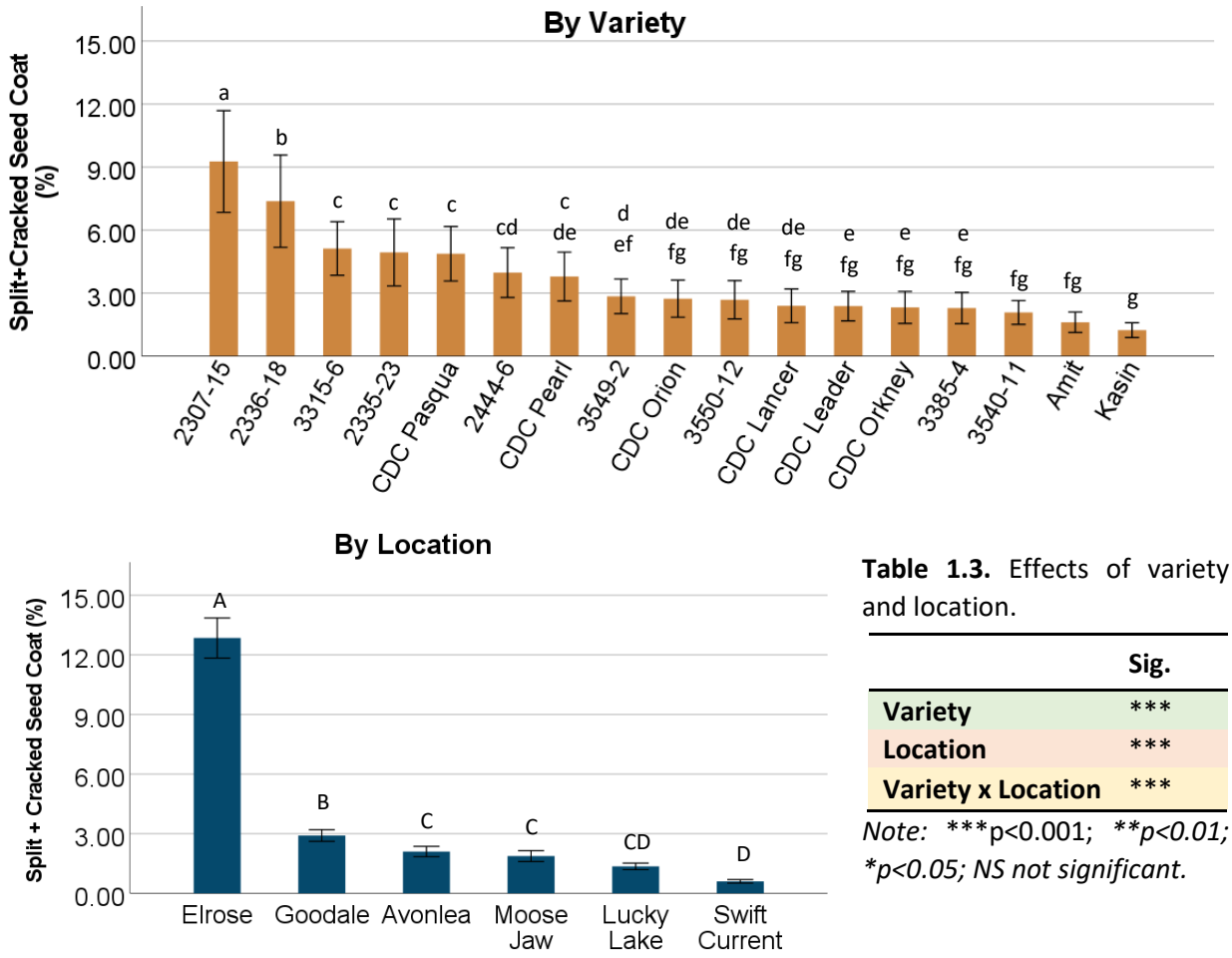

Table 1.3. Effects of variety and location.

	Sig.
Variety	***
Location	***
Variety x Location	***

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

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

By Variety:

- A difference of 8.1% was determined from the largest (line 2307-15, 9.3%) to the smallest (Kasin, 1.2%).

By Location:

- Split + cracked seed coat varied significantly between locations.
- The amount of split + cracked seed coat was extremely high in Elrose (12.9%) and was below 1% for Swift Current. Processing might play a key role.

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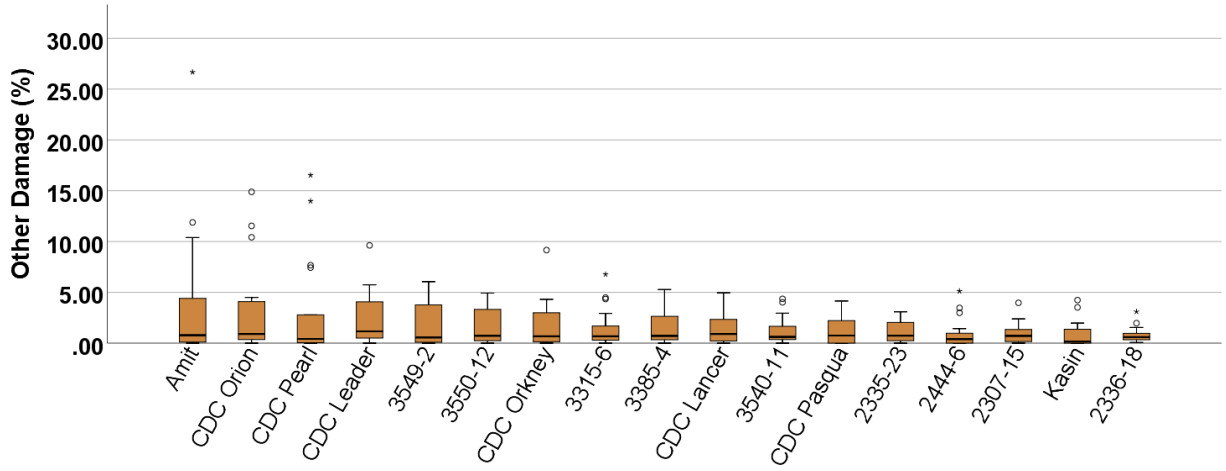
4. Other Damage

Method: 100 grams of each sample was used for evaluation, and damaged seeds were selected by hand. Other damage included chickpeas that are sprouted, shrivelled, heated, frost, and insect damage.

Results: Figure 1.4.1. Box and Whisker plot of kabuli chickpeas for other damage resulting from 6 locations. Results were reported from highest to lowest.



- Line 2336-18, Kasin, line2307-15, and line 2444-6 had low amount of other damage with small variability.
- Amit and CDC Orion had the highest other damage.

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

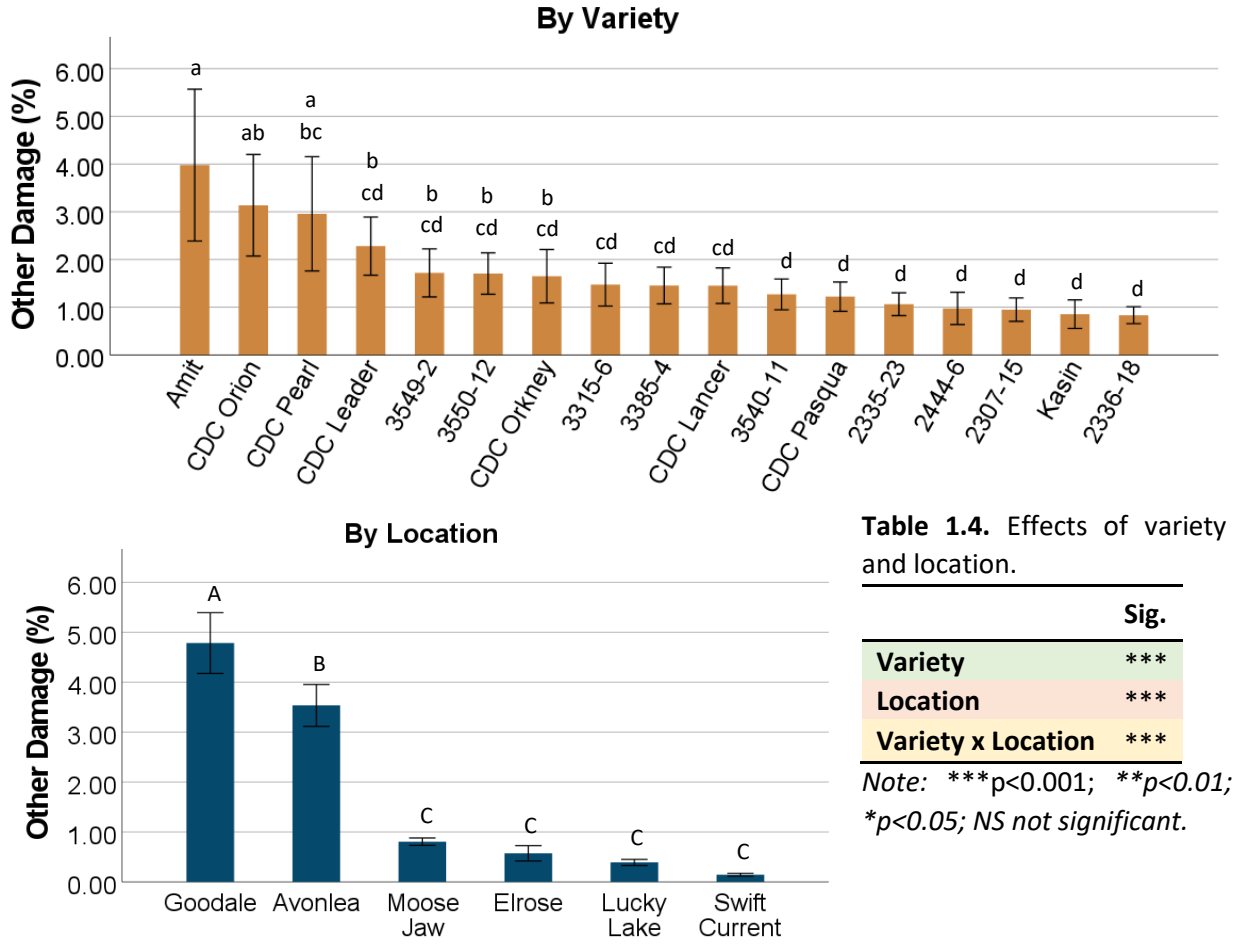

Table 1.4. Effects of variety and location.

	Sig.
Variety	***
Location	***
Variety x Location	***

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

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

By Variety:

- Except Amit, CDC Orion, CDC Pearl, and CDC Leader, mean other damage for other varieties was below 2%.

By Location:

- Other damage varied significantly between locations.

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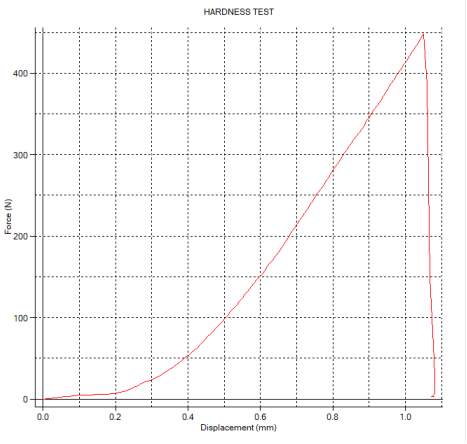
5. Hardness of Whole Seed

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

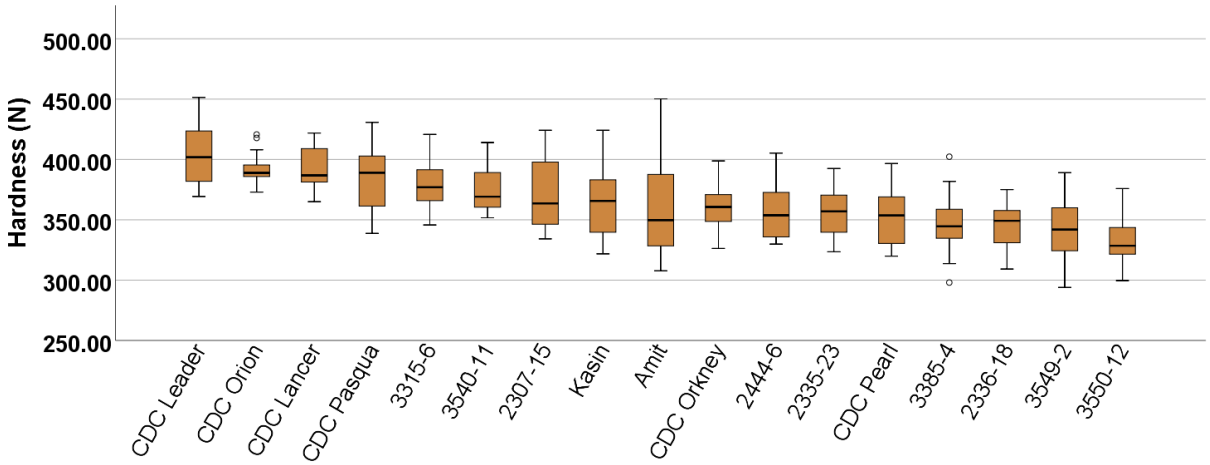


Method:

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 kabuli chickpeas for seed hardness (N) resulting from 6 locations. Results were reported from highest to lowest.



- CDC Leader had the largest hardness, while line 3550-12 had the lowest hardness.
- CDC Orion had very small variability in hardness, while Amit showed a large 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.

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

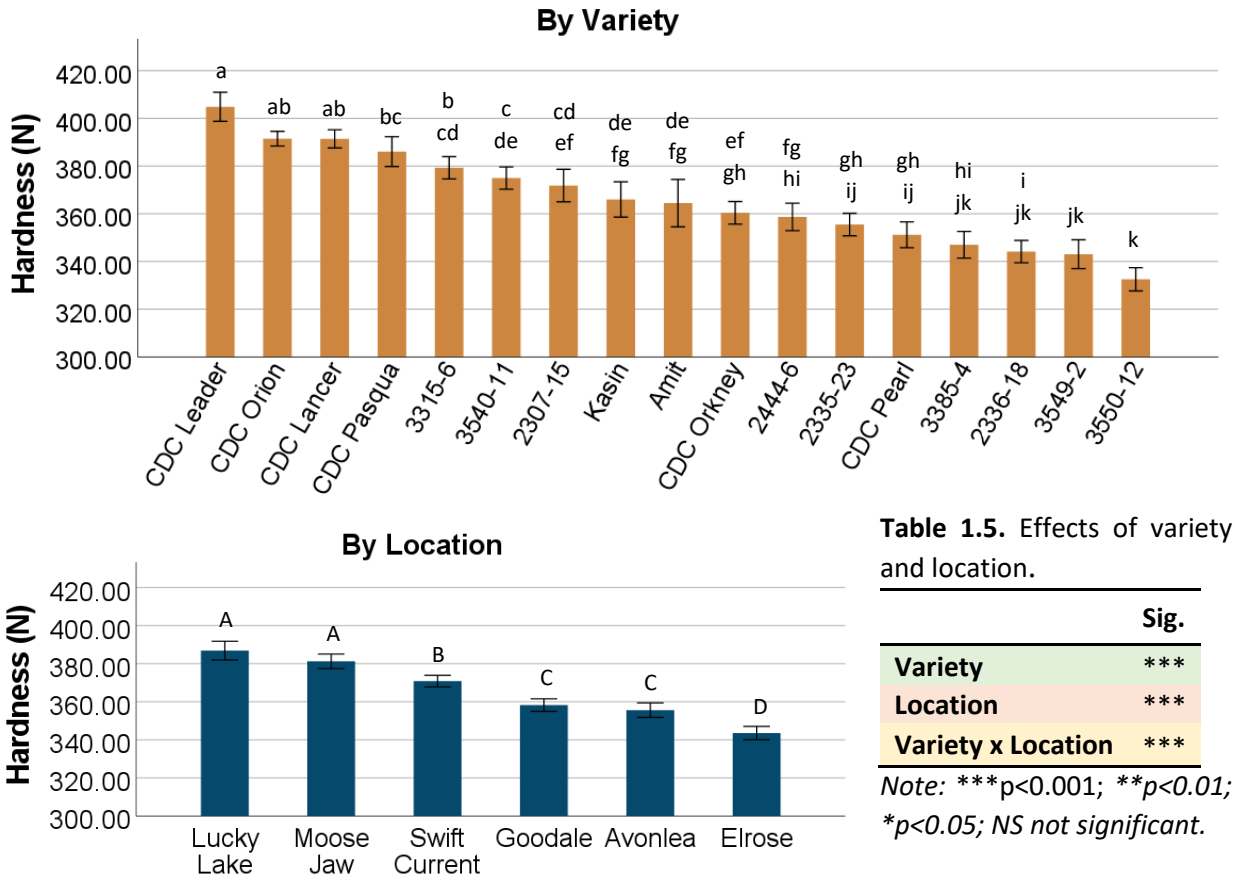

Table 1.5. Effects of variety and location.

	Sig.
Variety	***
Location	***
Variety x Location	***

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

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

By Variety:

- Mean hardness varied significantly between varieties.
- Hardness of CDC Leader (largest) was 72 N higher than line 3550-12 (lowest).

By Location:

- Location also impacted the hardness.
- A difference of ~40 N was determined from the largest (Lucky Lake & Moose Jaw) to the smallest (Elrose).

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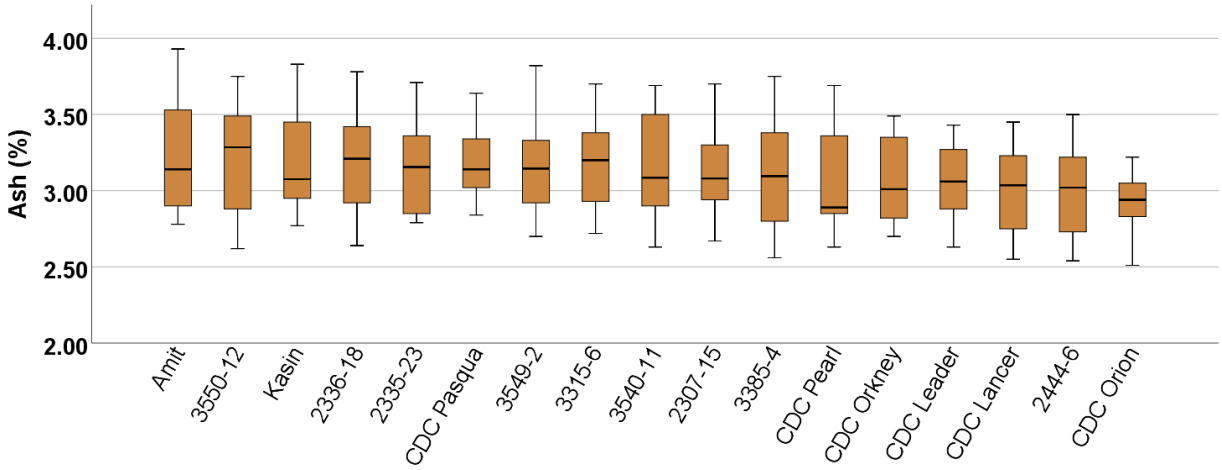
6. Ash Content

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.).

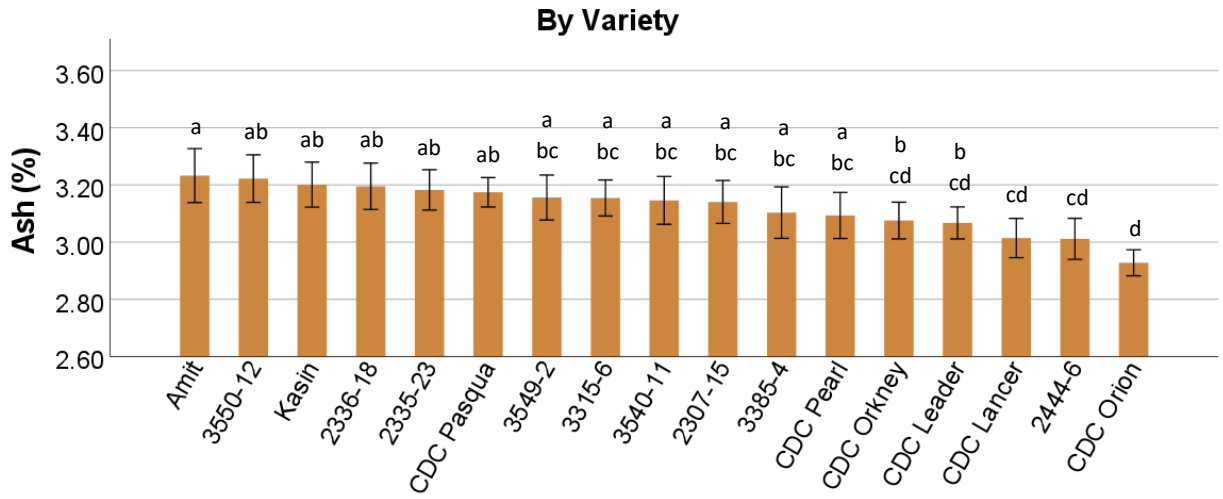
Results: Figure 1.6.1. Box and Whisker plot of kabuli chickpeas for ash content (%) resulting from 6 locations. Results were reported from highest to lowest.



- Ash content ranged from 2.5% to 4%.
- CDC Orion had the lowest ash content with small 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 kabuli chickpeas by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



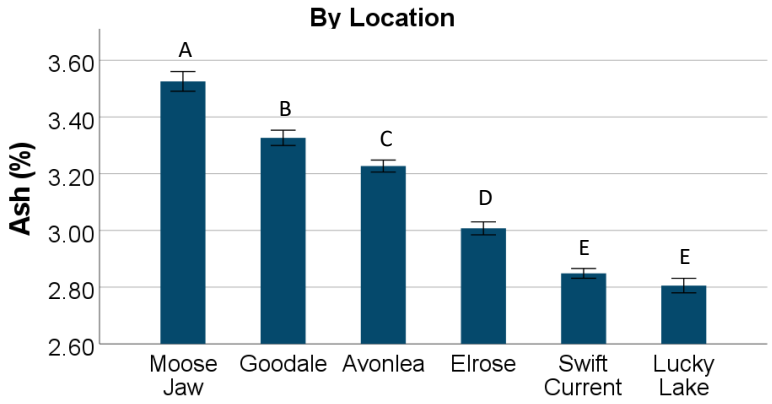


Table 1.6. Effects of variety and location.

	Sig.
Variety	***
Location	***
Variety x Location	***

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

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

By Variety:

- Only CDC Orion had ash below 3%.
- Ash for other varieties ranged from 3% to 3.2%.

By Location:

- Location effect played a role.
- A difference of 0.7% was determined from the largest (Moose Jaw) to the smallest (Lucky Lake & Swift Current).

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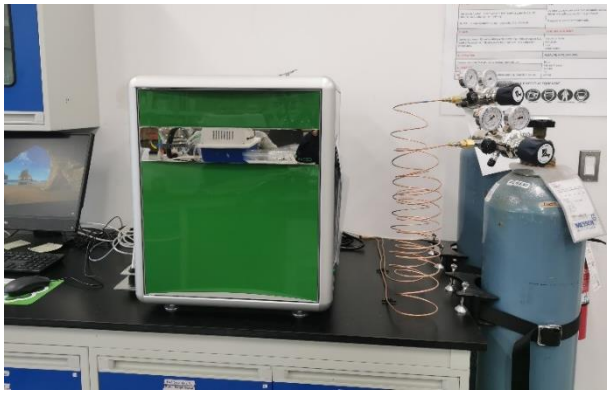
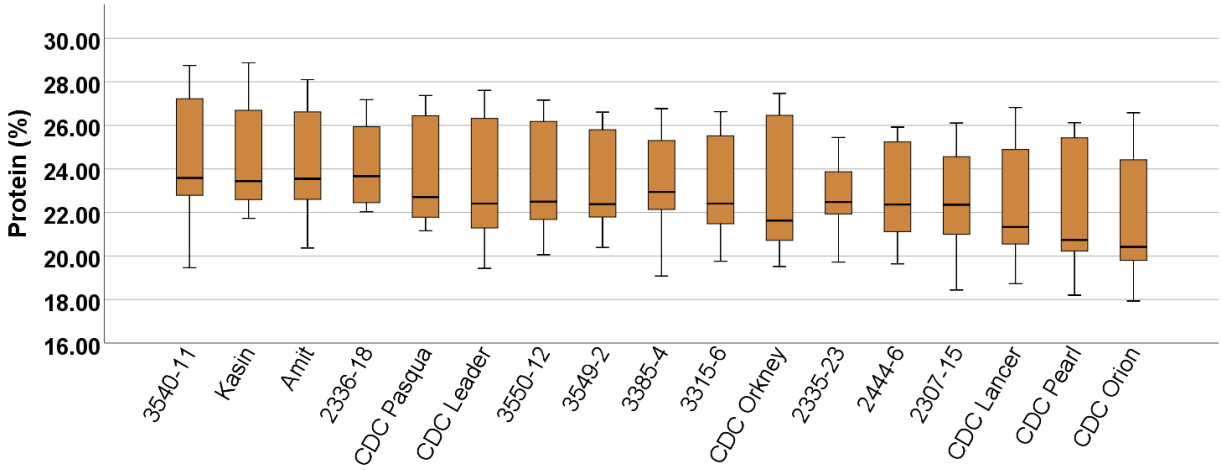
7. Protein Content

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 1.7.1. Box and Whisker plot of kabuli chickpeas for protein content (%) resulting from 6 locations. Results were reported from highest to lowest.



- Large variability of protein content was found in all varieties.

[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 kabuli chickpeas by variety (top) and by location (bottom). Each bar represents mean ± one standard error.

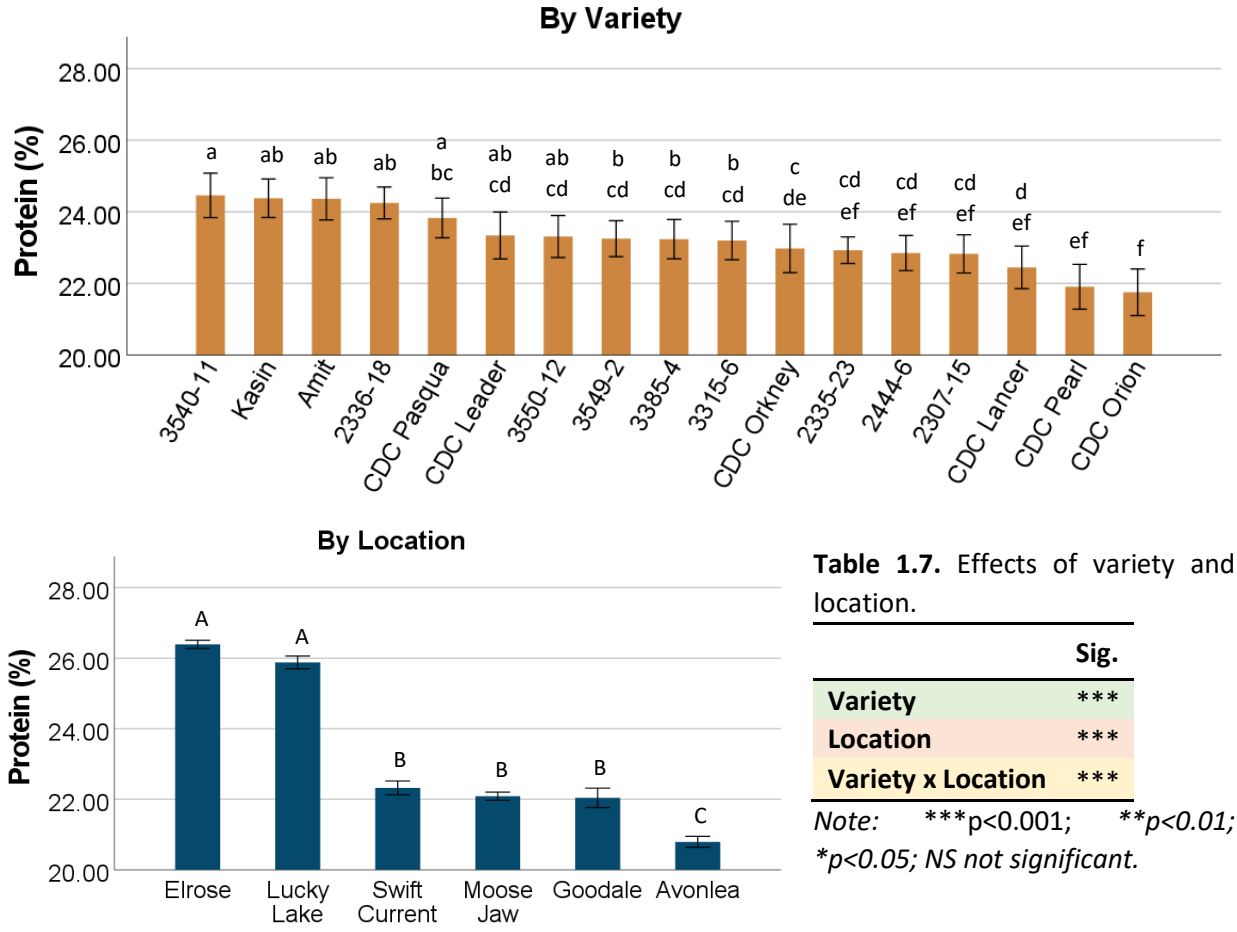


Table 1.7. Effects of variety and location.

	Sig.
Variety	***
Location	***
Variety x Location	***

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

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

By Variety:

- Protein contents of four varieties (line 3540-11, Kasin, Amit, and line 2336-18) were above 24%.
- Protein contents of CDC Orion and CDC Pearl were below 22%.

By Location:

- Location effect played a significant role.
- Protein of Elrose and Lucky Lake was over 5% higher than Avonlea.

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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.

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

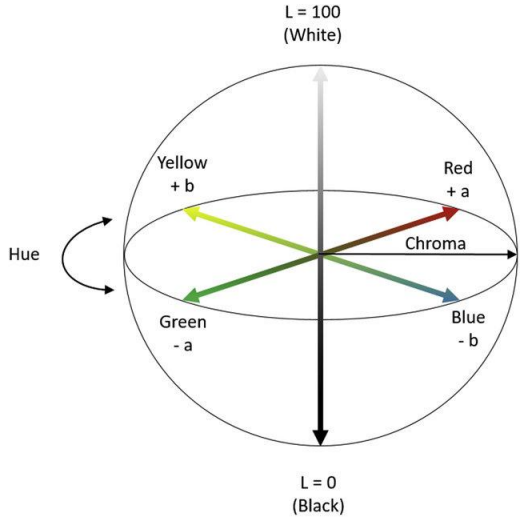
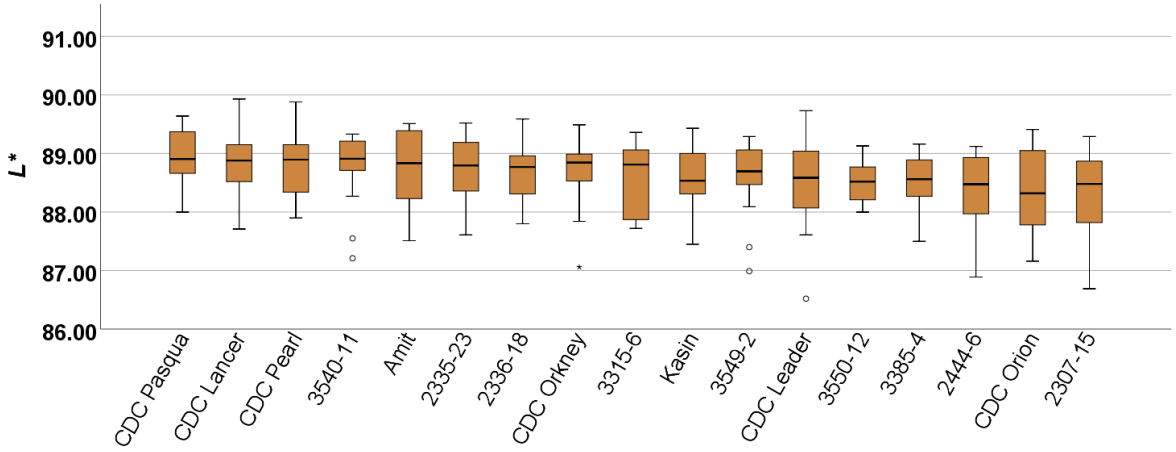


Figure 1.8.1. The CIELAB color spacediagram[3].

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

Results: Figure 1.8.2. Box and Whisker plot of kabuli chickpeas for lightness resulting from 6 locations. Results were reported from highest to lowest.



- Lightness of chickpea was all below 90.

[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.

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

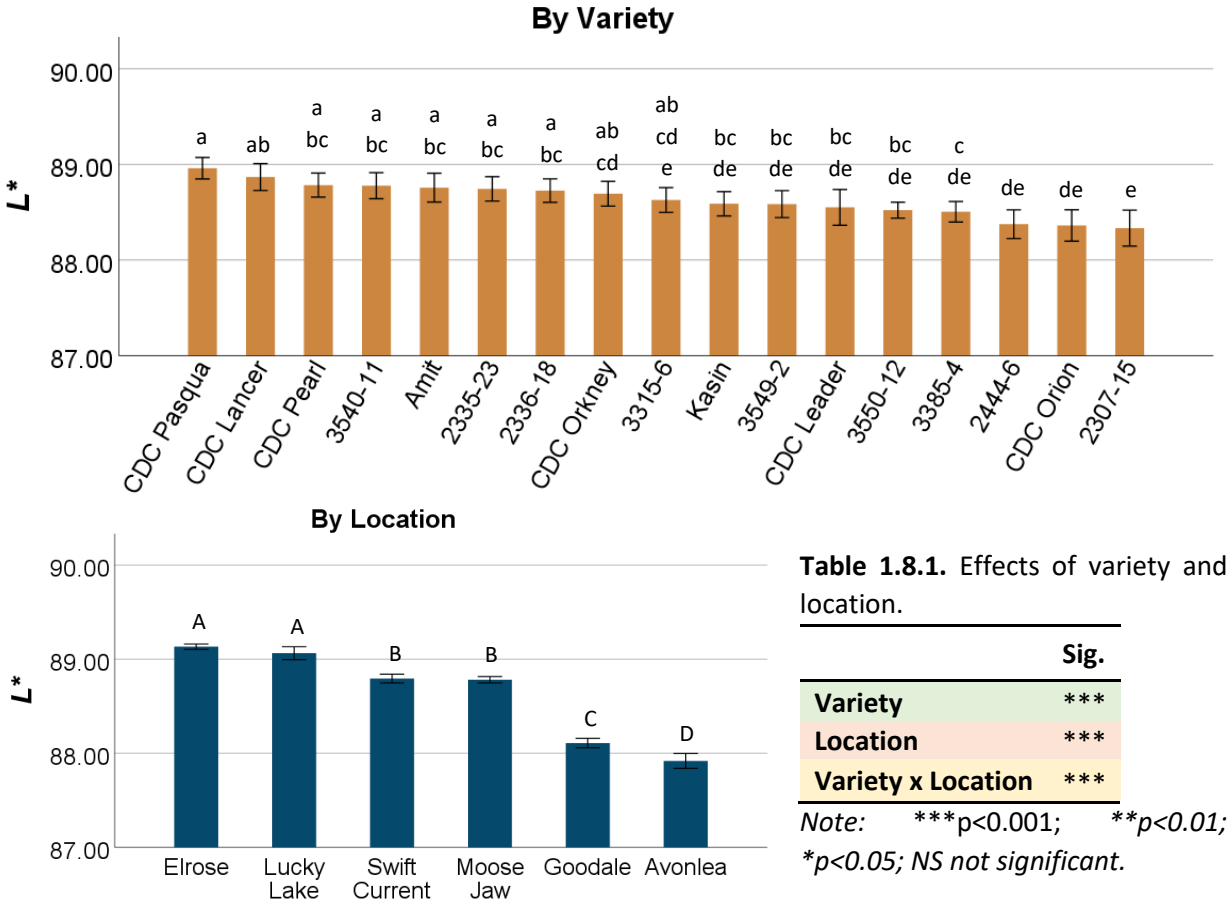


Table 1.8.1. Effects of variety and location.

	Sig.
Variety	***
Location	***
Variety x Location	***

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

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

By Variety:

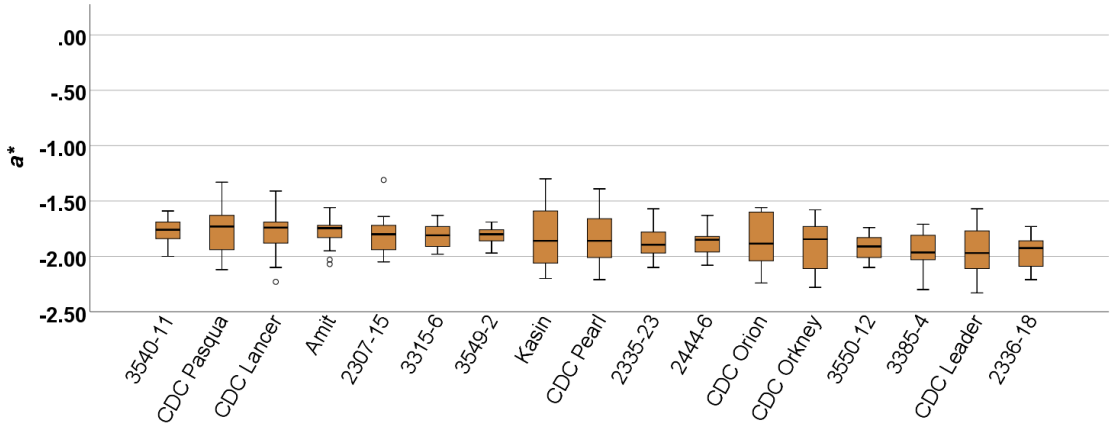
- Lightness from highest to lowest was only 0.6 unit in difference.

By Location:

- A difference of 1.2 units was determined from highest to lowest.

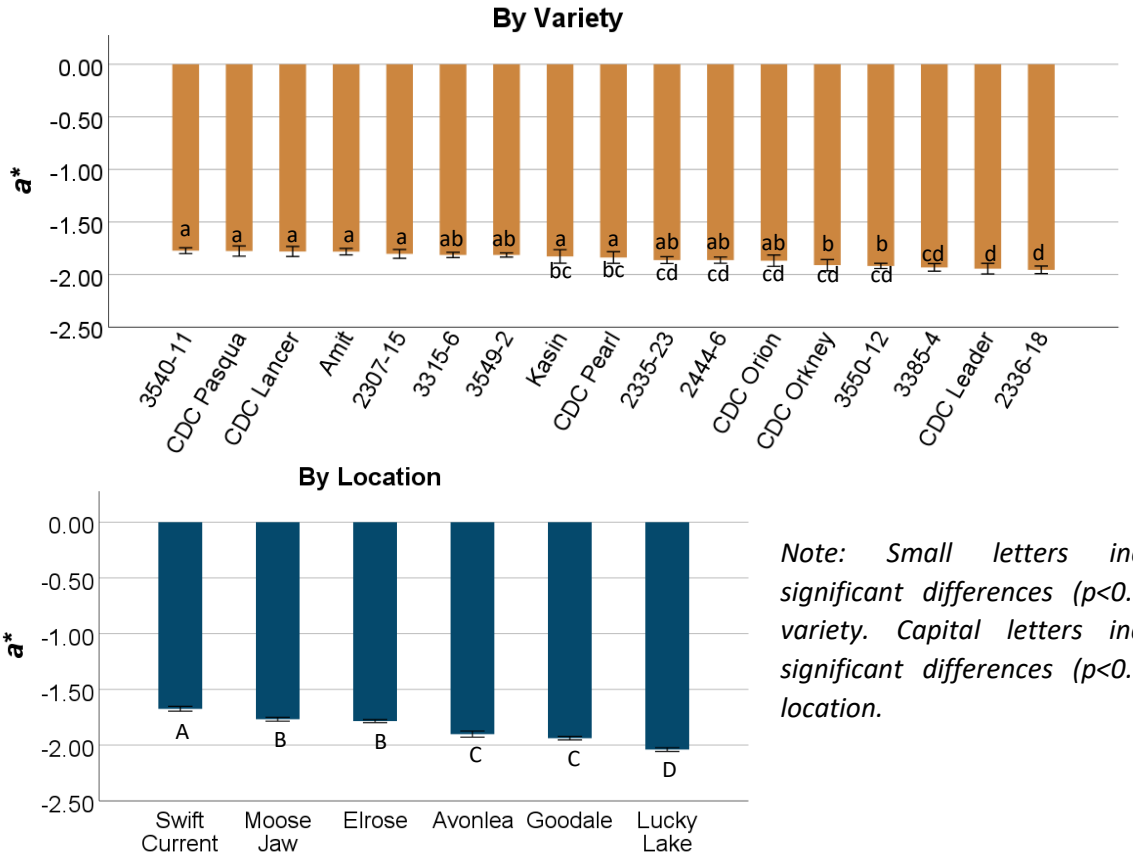
b) ***a*:*** red (+) to green (-)

Results: Figure 1.8.4. Box and Whisker plot of kabuli chickpeas for *a** resulting from 6 locations. Results were reported from highest to lowest.



- Line 3540-11 had the least greenness with small variability.

Figure 1.8.5. Mean *a** of kabuli chickpeas by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



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

By Variety: A difference of 0.2 unit only was determined from highest to lowest.

By Location: A difference of 0.3 unit only was determined from highest to lowest.

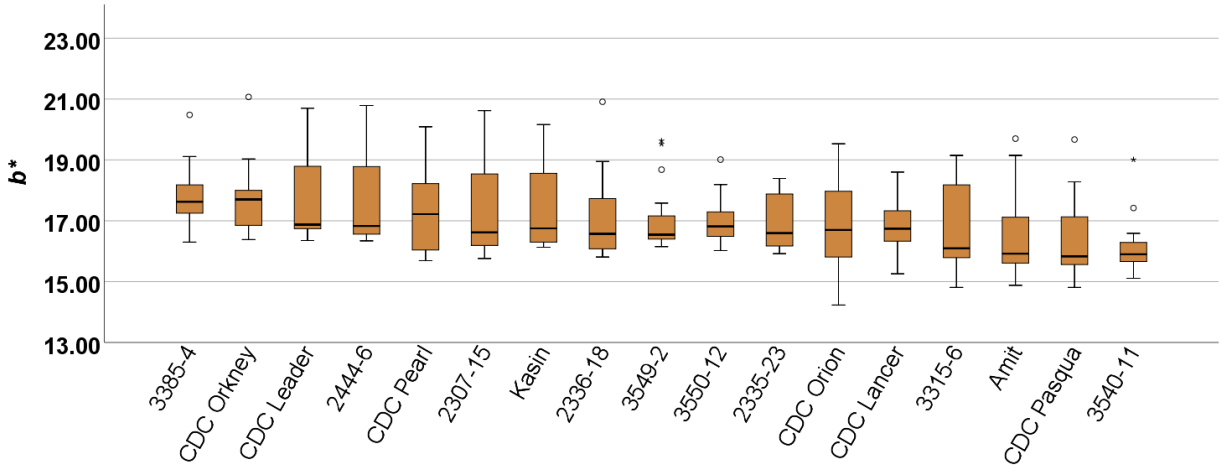
Table 1.8.2. Effects of variety and location.

	Sig.
Variety	***
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 kabuli chickpeas for *b** resulting from 6 locations. Results were reported from highest to lowest.



- Line 3540-11 had a low *b** value and a small variability.
- CDC Orion had a large variability.

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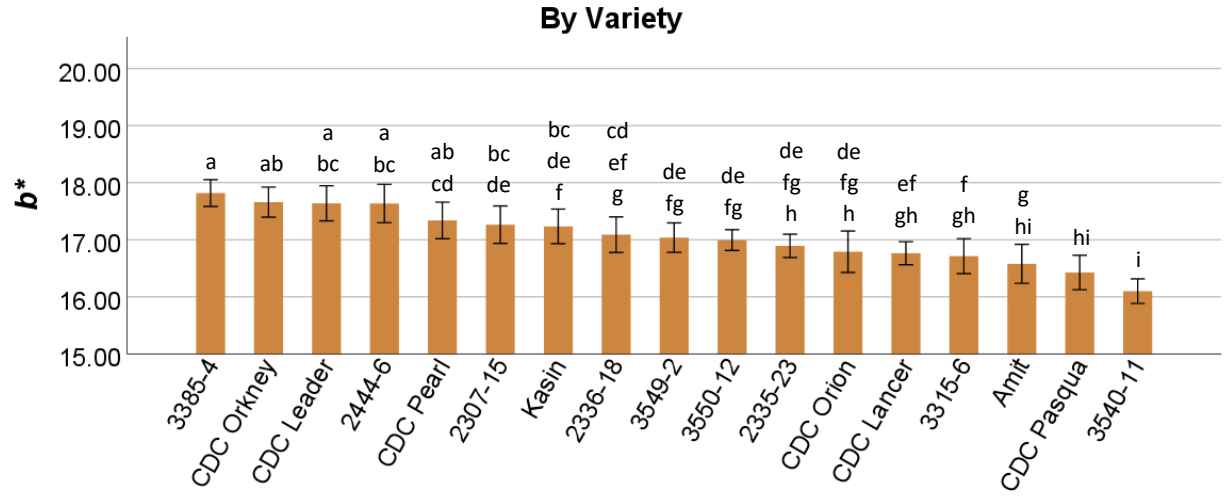
Figure 1.8.7. Mean *b** of kabuli chickpeas by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



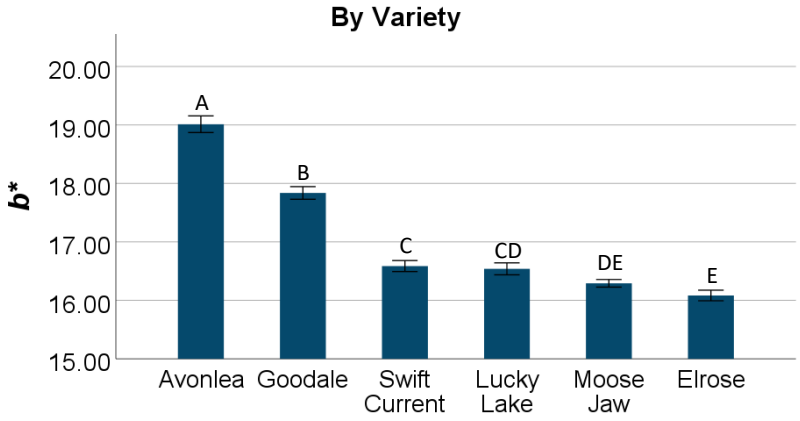


Table 1.8.3. Effects of variety and location.

	Sig.
Variety	***
Location	***
Variety x Location	***

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

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

By Variety:

- Yellowness of chickpeas from line 3385-4 (highest) was 1.7 units higher than line 3540-11 (lowest).

By Location:

- Yellowness of chickpeas from Avonlea (highest) was 3 units higher than Elrose (lowest).

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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:

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

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 kabuli chickpeas for Hausner ratio resulting from 6 locations. Results were reported from highest to lowest.

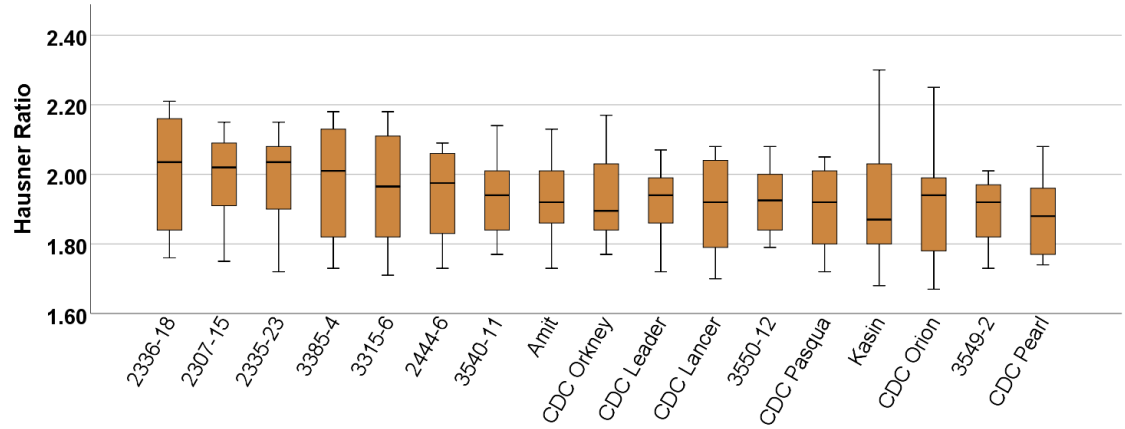
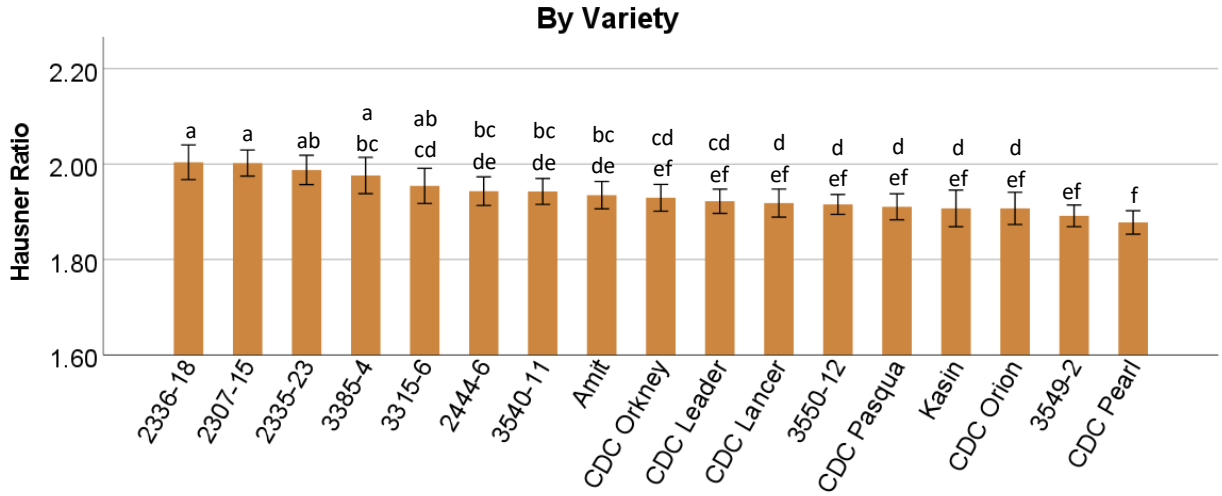
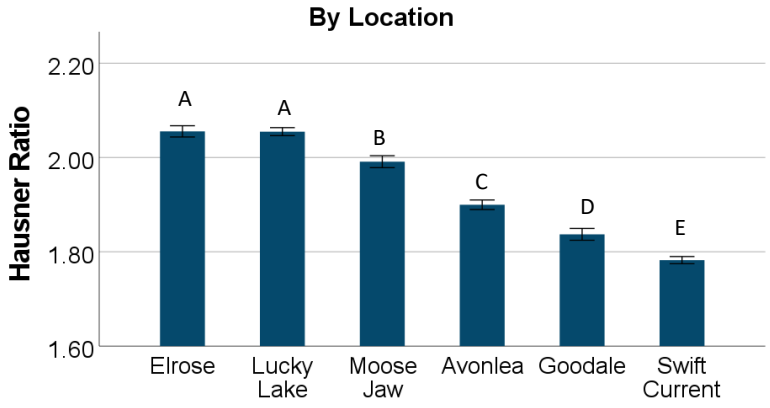


Figure 1.9.2. Mean Hausner ratio of kabuli chickpeas by variety (top) and by location (bottom). Each bar represents mean ± one standard error.





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

- The results of Hausner ratio for all varieties across all locations were all greater than 1.6, suggesting all chickpea 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 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 kabuli chickpea flours for D_{90} and $D_{4,3}$ values resulting from 6 locations. Results were reported from highest to lowest.

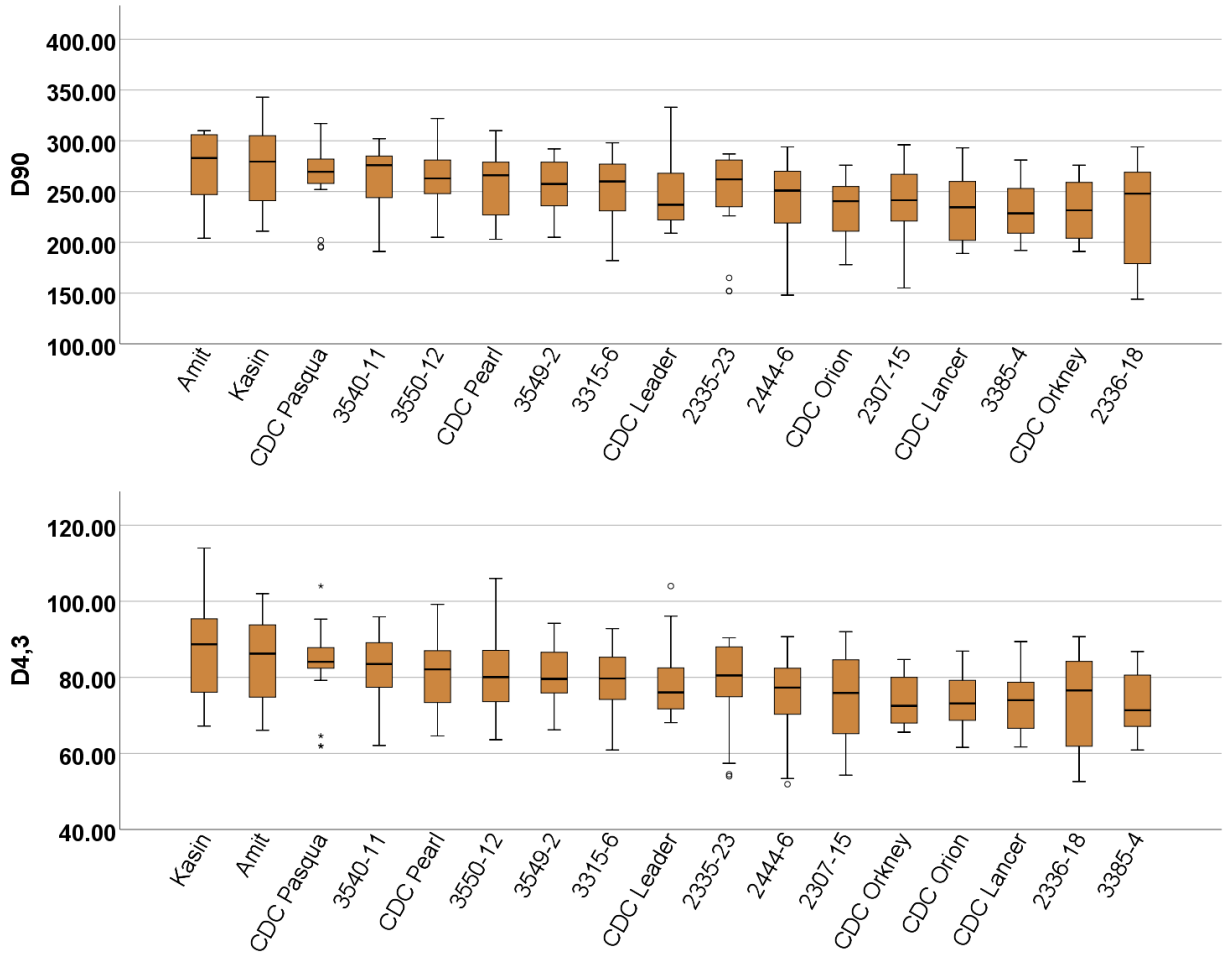
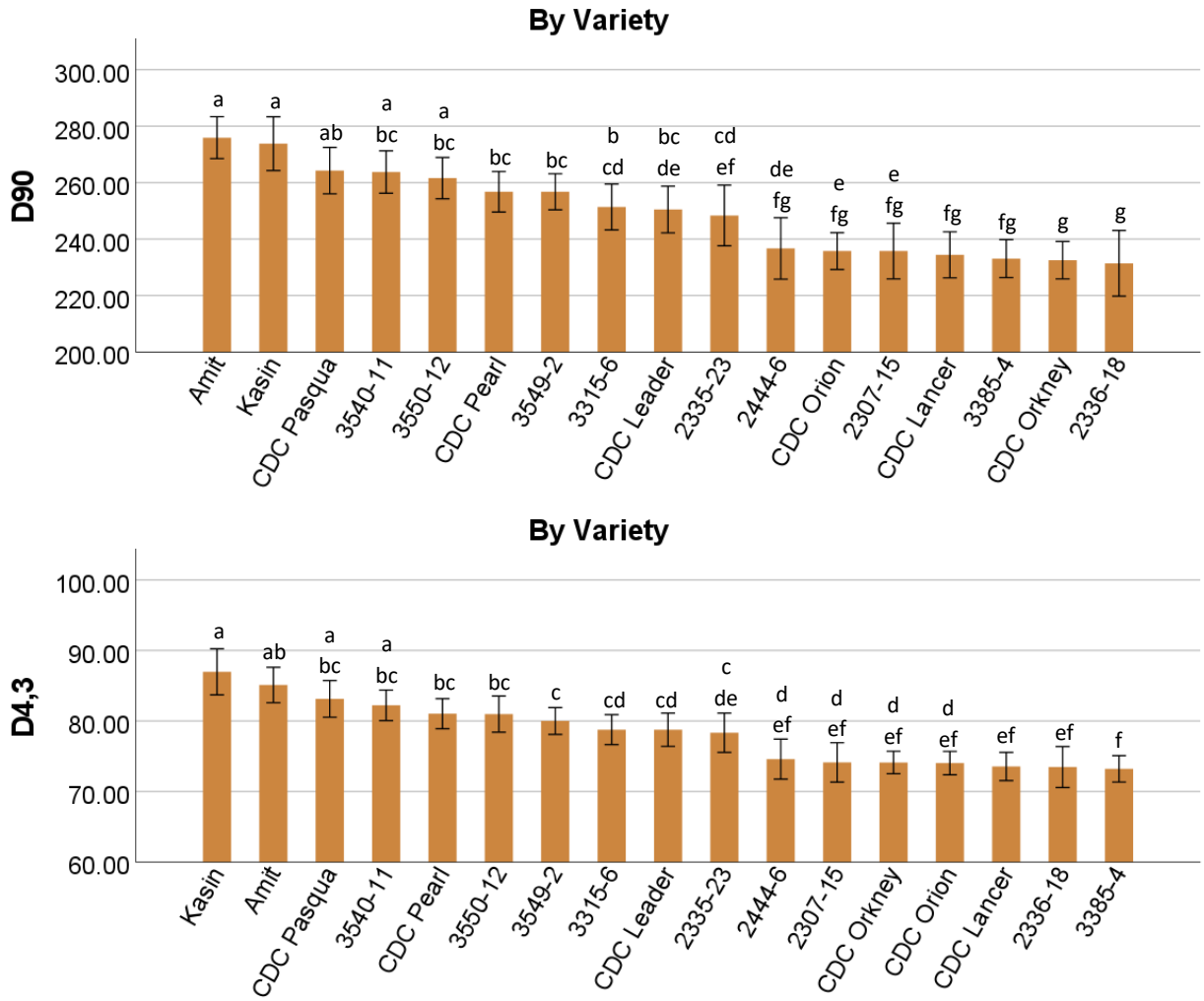


Figure 1.10.2. D_{90} (µm, top) and $D_{4,3}$ (µm, bottom) of kabuli chickpea flours by variety. Each bar represents mean ± one standard error.



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

- **D_{90}:** All below 280 µm.
- **$D_{4,3}$:** The mean diameter of all flours was below 90 µm.

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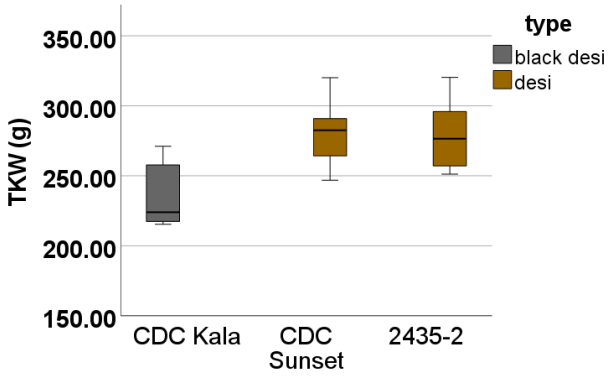
2) Black desi + Desi Chickpea

1. 1000 Seed Weight

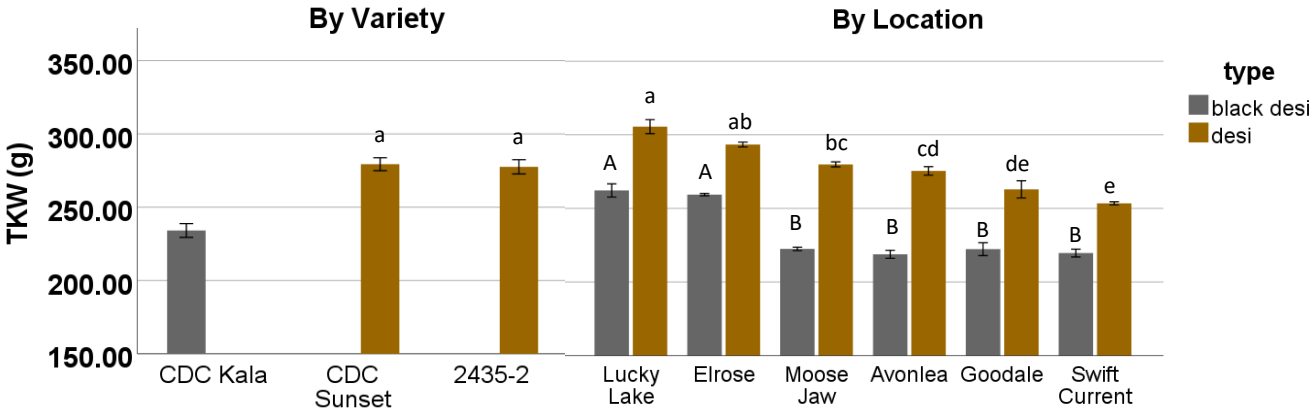
Method: Seed weight is important to indicate seed size and yield production. This test was conducted by weighing 300 seeds with duplicated measurements per sample. The 1000 seed weight (TKW) was reported.

Results: Figure 2.1.1. Box and Whisker plot of black desi and desi chickpeas for TKW from 6 locations.



Both desi varieties were larger than the black desi (i.e., CDC Kala).

Figure 2.1.2. Mean TKW 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 location for desi type. Capital letters indicated significant differences (p<0.05) by location for black desi.

By Variety: TKW was the same.for both desi. Black desi was smaller.

By Location:

- **Black desi:** Lucky Lake and Elrose had higher TKW, TKW for other locations were the same.
- **Desi:** A difference of 52 g was observed from highest to lowest.

Table 2.1. Effects of variety and location.

	Desi
Variety	NS
Location	***
Variety x Location	NS

*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 evaluation:

a. #22R: 8.73 mm
b. #20R: 7.94 mm
c. #18R: 7.14 mm
d. #16R: 6.35 mm
e. #14R: 5.56 mm

Results:

Table 2.2. Seed size distribution (%) of each black desi and desi chickpea variety. Data represent mean ± one standard deviation.

Variety	> # 22R (%)	> # 20R (%)	> # 18R (%)	> # 16R (%)	> # 14R (%)	Below # 14R (%)
CDC Kala	0.1 ± 0.3	16.2 ± 8.6	58.2 ± 5.0	23.8 ± 10.9	1.6 ± 1.2	0.2 ± 0.2
2435-2	1.2 ± 0.9[a]	25.0 ± 9.0[a]	55.7 ± 9.3[a]	16.5 ± 5.5[a]	1.4 ± 0.9[a]	0.3 ± 0.3[a]
CDC Sunset	2.2 ± 0.0[a]	29.6 ± 9.5[a]	50.7 ± 9.2a[a]	15.7 ± 4.8[a]	1.6 ± 1.2[a]	0.3 ± 0.2[a]

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

- Unlike most kabuli varieties, the black desi and desi varieties tended to retain on the #20, #18, and #16 sieves.

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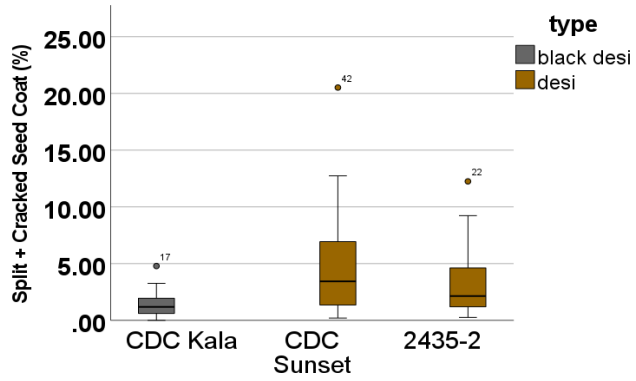
3. Split + Cracked Seed Coat

Method: 100 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.

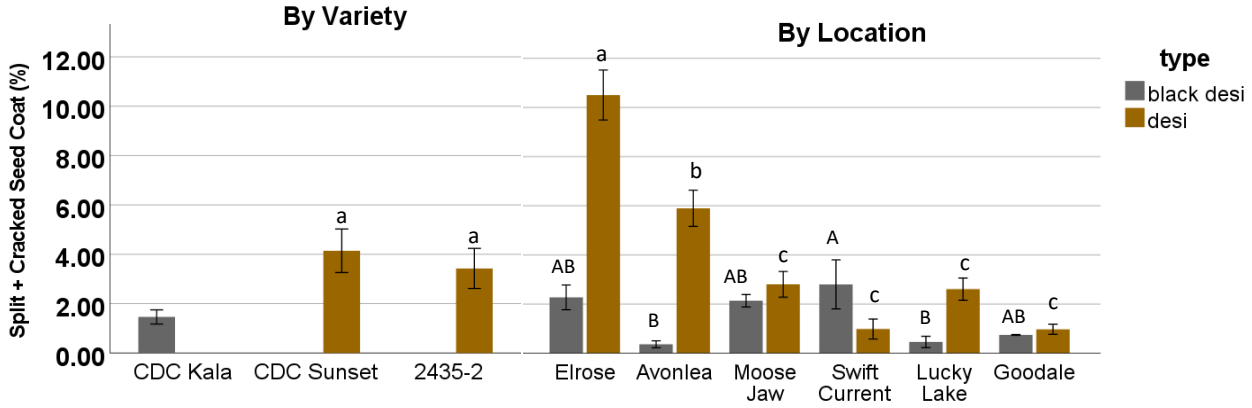
Results: Figure 2.3.1. Box and Whisker plot of split + cracked seed coat from 6 locations.



Black desi: CDC kala had a low level of split + cracked seed coat.

Desi: CDC Sunset had a larger variability than line 2435-2.

Figure 2.3.2. Mean split + cracked seed coat 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 location for desi type. Capital letters indicated significant differences (p<0.05) by location for black desi.

By Variety: Both desi varieties were the same. Black desi was smaller.

By Location:

- **Black desi:** All locations were below 3%.
- **Desi:** Elrose was extreme high (10%), while Goodale and Swift Current were below 1%.

Table 2.3. Effects of variety and location.

	Desi
Variety	*
Location	***
Variety x Location	NS

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

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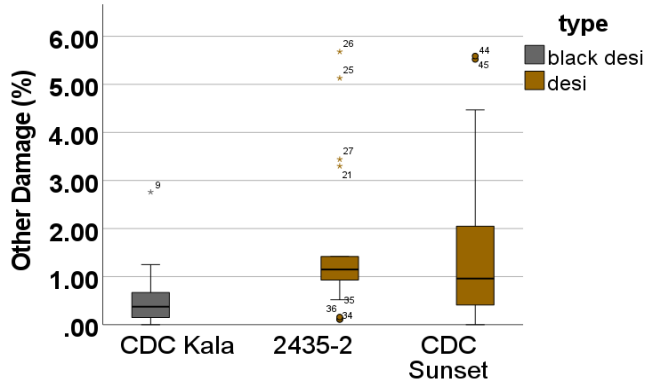
4. Other Damage

Method: 100 grams of each sample was used for evaluation, and damaged seeds were selected by hand. Other damage included chickpeas that are sprouted, shrivelled, heated, frost, and insect damage.

Results: Figure 2.4.1. Box and Whisker plot of other damage from 6 locations.

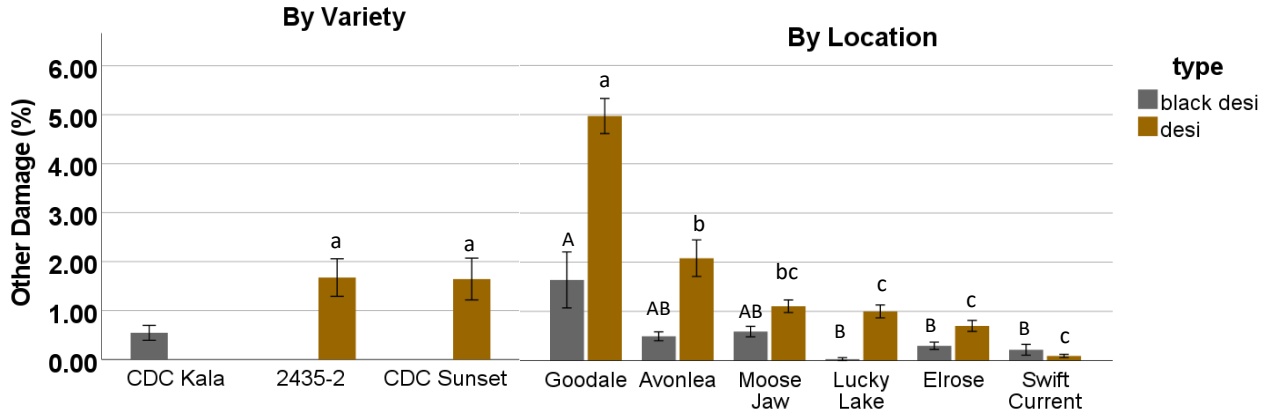


Black desi: CDC kala had a low level of other damage.

Desi: CDC Sunset had a large variability. Extreme outliners were observed in both varieties.

.

Figure 2.4.2. 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 location for desi type. Capital letters indicated significant differences (p<0.05) by location for black desi.

By Variety: Both desi varieties were the same. Black desi was smaller.

By Location:

- **Black desi:** A difference of 1.6% was found from highest to lowest.
- **Desi:** Swift Current were below 0.1%, which was 4.9% lower than Goodale.

Table 2.4. Effects of variety and location.

	Desi
Variety	NS
Location	***
Variety x Location	NS

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

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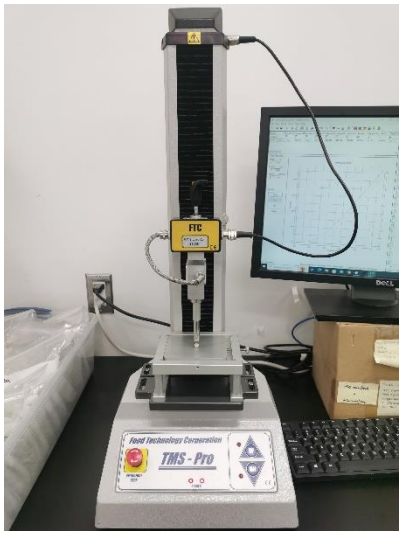
5. Hardness of Whole Seed

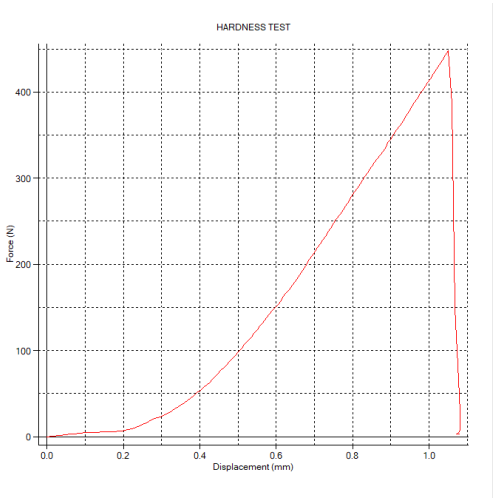
Seed hardness is an important parameter to indicate milling yield and cooking quality. Seed hardness is affected by seed size, shape, density, composition, etc.

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)[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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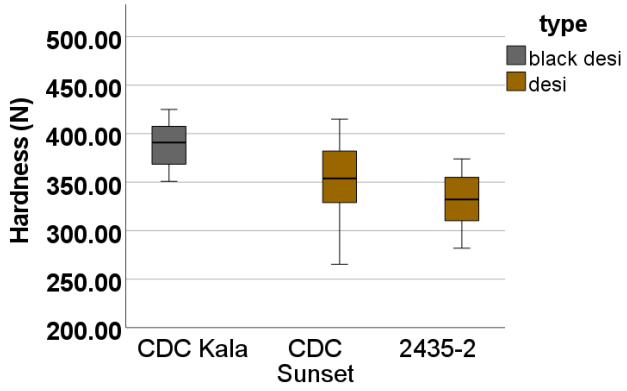
Results:

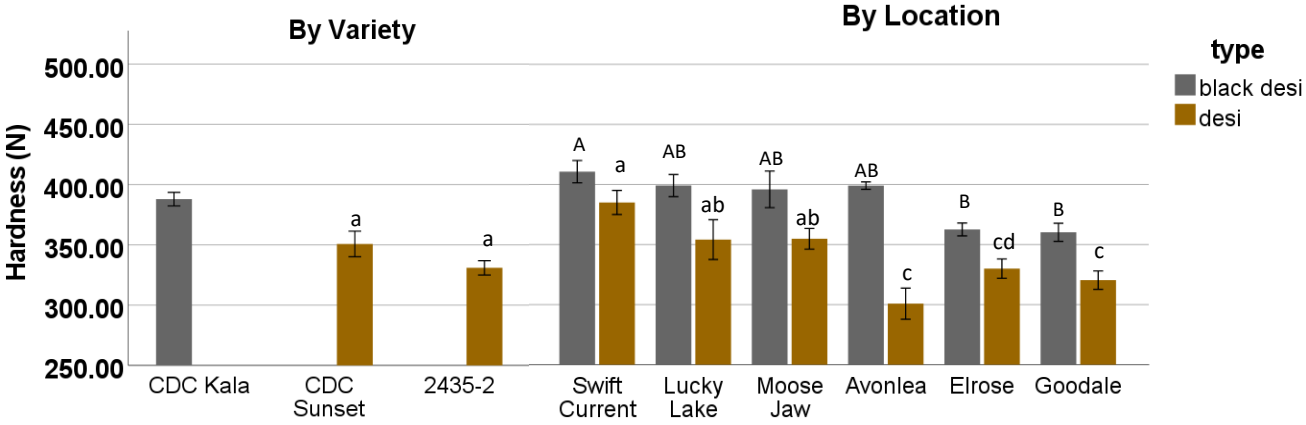
Figure 2.5.1. Box and Whisker plot of black desi and desi chickpea hardness resulting from 6 locations.



Black desi: CDC kala had a small variability.

Desi: CDC Sunset had a larger variability than line 2435-2.

Figure 2.5.2 Mean hardness of black desi and desi chickpeas 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 location for desi type. Capital letters indicated significant differences (p<0.05) by location for black desi.

By Variety: Both desi varieties were the same. Black desi was larger.

By Location:

- **Black desi:** A difference of 50 N was found from highest to lowest.
- **Desi:** A difference of 65 N was determined from highest to lowest.

Table 2.5. Effects of variety and location.

	Desi
Variety	**
Location	***
Variety x Location	***

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

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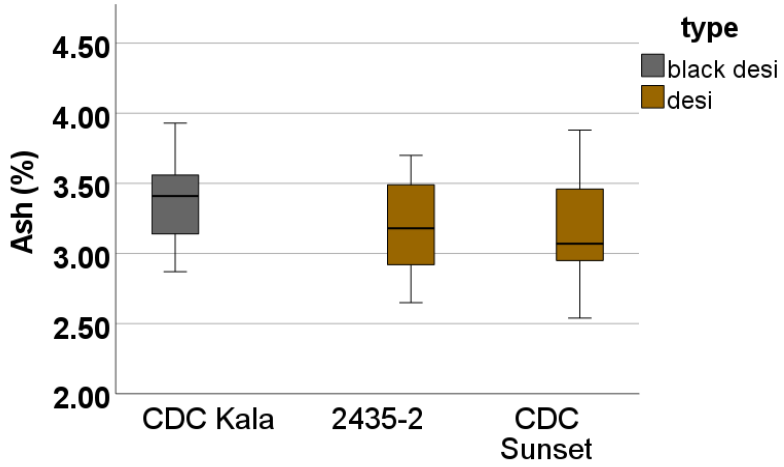
6. Ash Content

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 black desi and desi chickpeas for ash content from 16 locations.



For desi, CDC Sunset and line 2435-2 were similar.

[6] 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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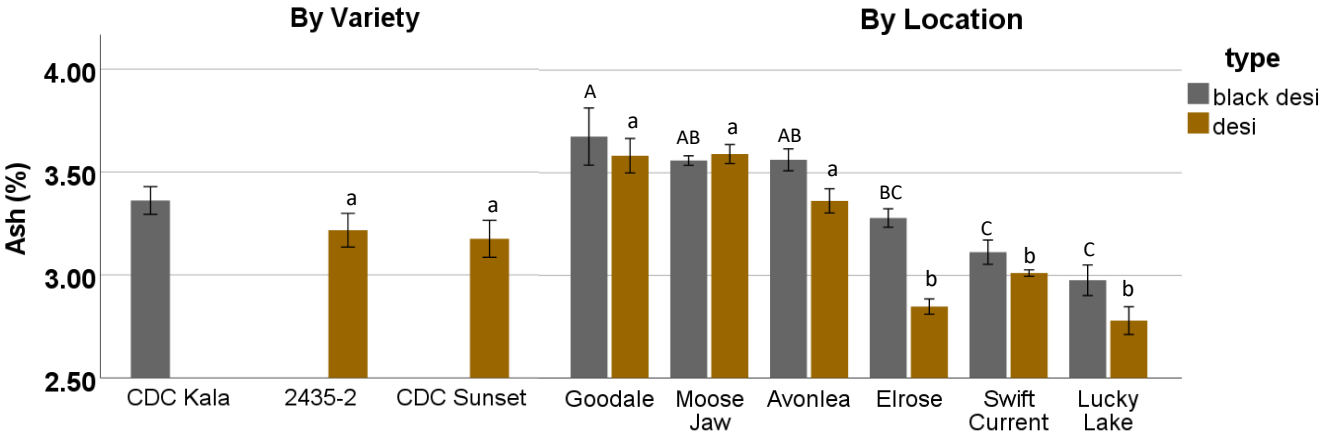
Figure 2.6.2. Mean ash content of black desi and desi chickpeas by variety (left) and by location (right). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by variety and location for desi type. Capital letters indicated significant differences (p<0.05) by location for black desi.

By Variety: Ash for desi varieties were 3.2% and for black desi was 3.4%.

By Location:

- **Black desi:** A difference of 0.7% was observed from highest to lowest.
- **Desi:** The higher three locations ranged from 3.4-3.6%. The lower three ranged from 2.8-3.0%.

Table 2.6. Effects of variety and location.

	Desi
Variety	NS
Location	***
Variety x Location	NS

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

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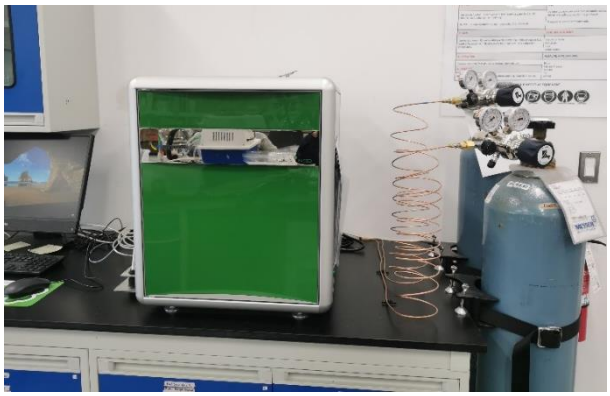
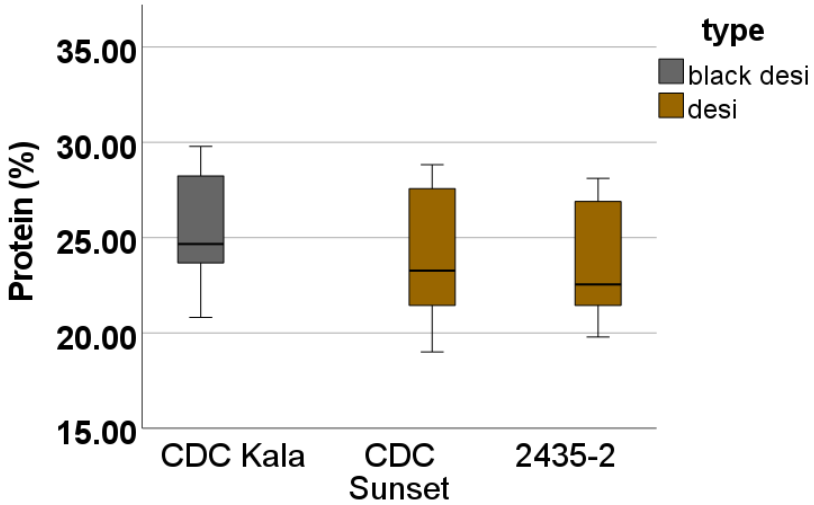
7. Protein Content

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.).



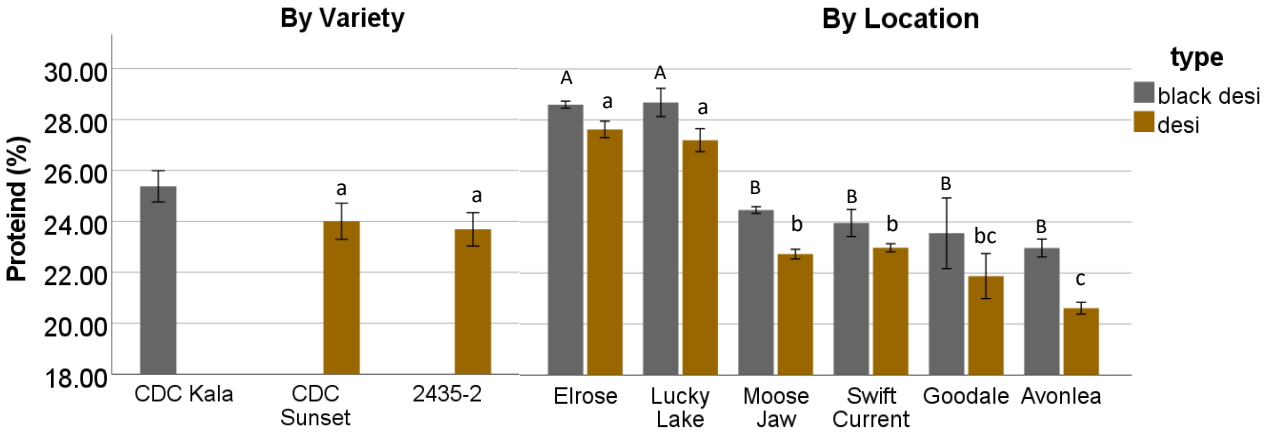
Results: Figure 2.7.1. Box and Whisker plot of black desi and desi chickpeas for protein content resulting from 6 locations.



CDC Kala was higher. The two desi were similar.

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

Figure 2.7.2. Mean protein (%) of black desi and desi chickpeas 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 location for desi type. Capital letters indicated significant differences (p<0.05) by location for black desi.

By Variety: Both desi varieties were the same. Black desi was larger.

By Location:

- **Black desi:** Protein for Elrose and Lucky Lake were ~4% higher than the other four locations.
- **Desi:** A difference of ~7% was determined from the highest (Elrose & Lucky Lake) to the lowest (Avonlea).

Table 2.7. Effects of variety and location.

	Desi
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 (-)

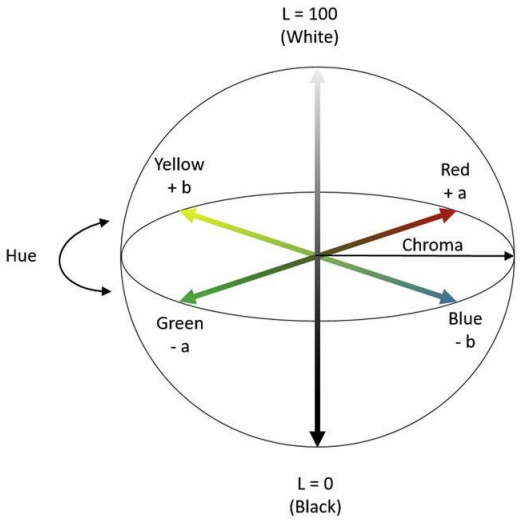
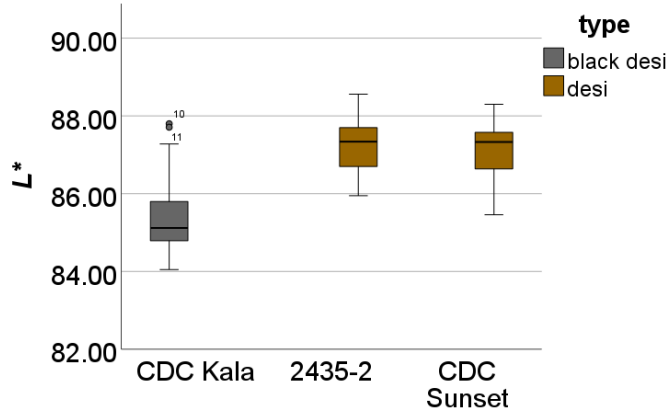


Figure 2.8.1. The CIELAB color spacediagram[7].

[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.

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

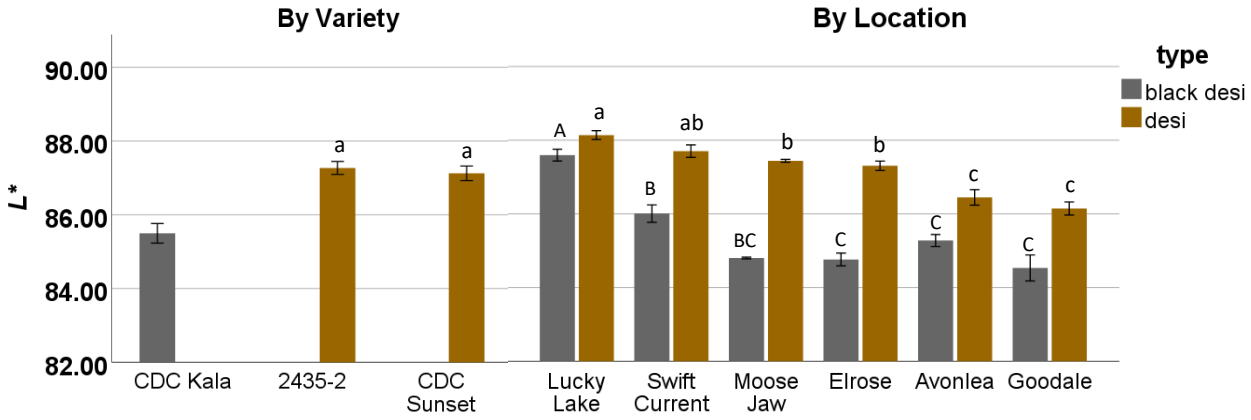
Results: Figure 2.8.2. The Box and Whisker plot of black desi and desi chickpeas for *L** values resulting from 6 locations.



CDC Sunset and line 2435-2 were similar.

CDC Kala had a lower lightness.

Figure 2.8.3. 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 location for desi type. Capital letters indicated significant differences (p<0.05) by location for black desi.

By Variety: Both desi varieties were the same. Black desi was lower.

By Location:

- **Black desi:** Lucky Lake was 3 units higher than Elrose, Avonlea, and Goodale.
- **Desi:** A difference of 2 units was determined from the highest (Lucky Lake) to the lowest (Avonlea & Goodale).

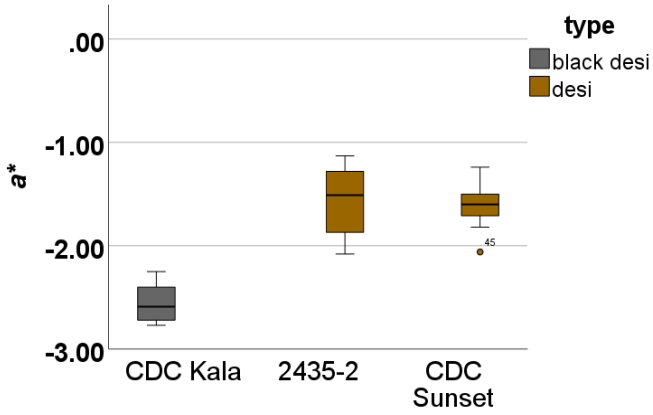
Table 2.8.1. Effects of variety and location.

	Desi
Variety	NS
Location	***
Variety x Location	NS

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

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

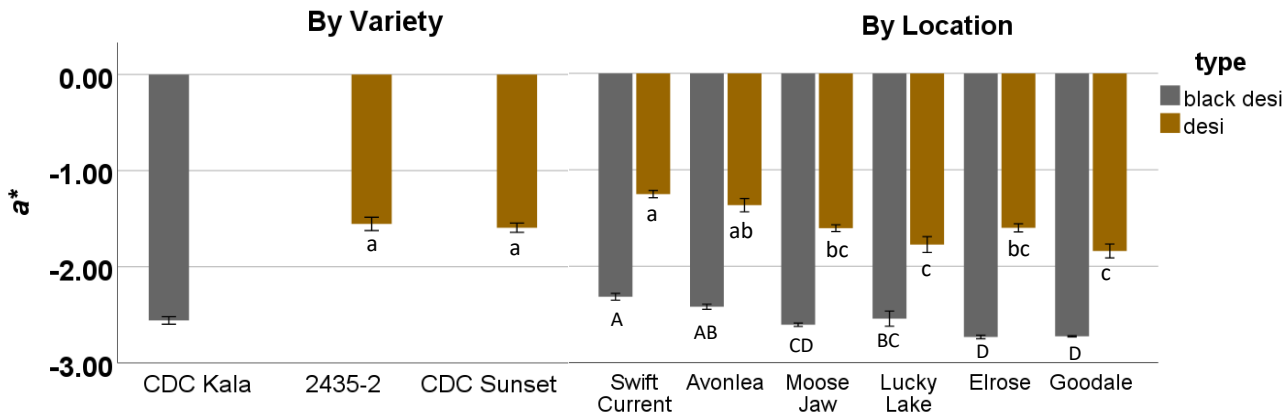
Results: Figure 2.8.4. The Box and Whisker plot of black desi and desi chickpeas for *a** values resulting from 6 locations.



Line 2435-2 had a larger variability.

CDC Kala had a stronger greenness.

Figure 2.8.5. 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 location for desi type. Capital letters indicated significant differences (p<0.05) by location for black desi.

By Variety: Both desi varieties were the same. Black desi was lower.

By Location:

- **Black desi:** Only 0.4 unit difference was determined from the highest to the lowest.
- **Desi:** Only 0.6 unit difference was determined from the highest to the lowest.

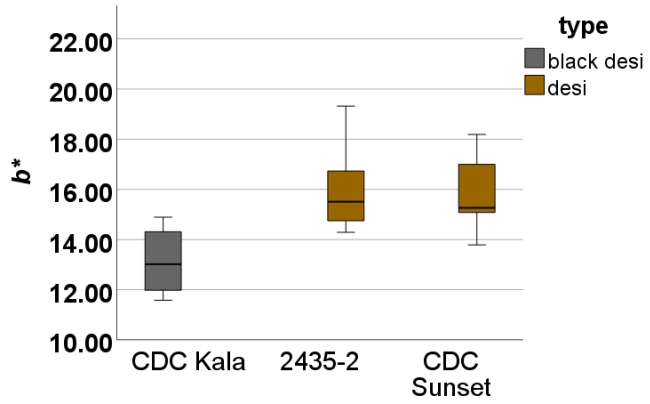
Table 2.8.2. Effects of variety and location.

	Desi
Variety	NS
Location	***
Variety x Location	NS

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

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

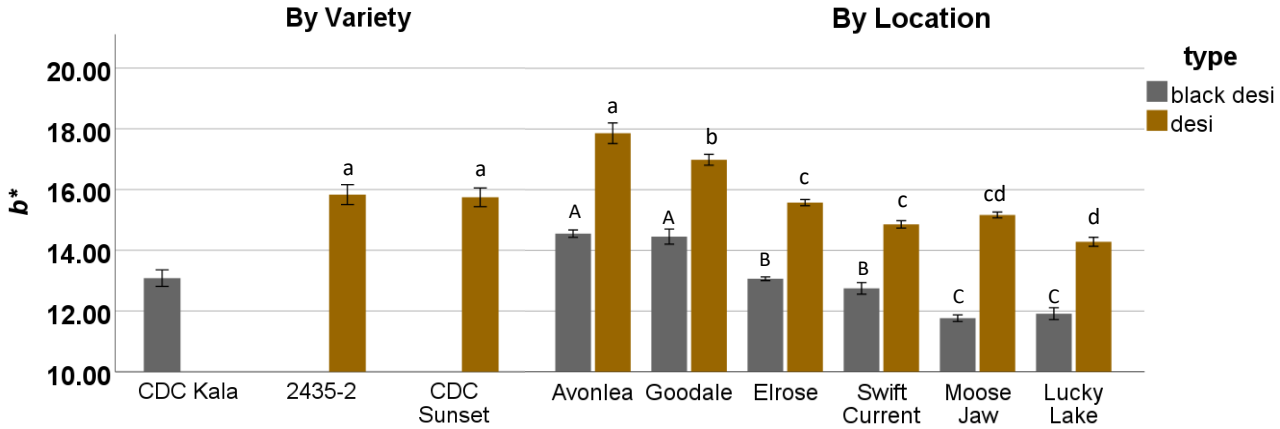
Results: Figure 2.8.6. Box and Whisker plot of black desi and desi chickpeas for *b** values from 6 locations.



CDC Sunset and line 2435-2 were similar.

CDC Kala had less yellowness.

Figure 2.8.7. Mean *b** value of black desi and desi chickpeas 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 location for desi type. Capital letters indicated significant differences (p<0.05) by location for black desi.

By Variety: Both desi varieties were the same. Black desi was lower.

By Location:

- **Black desi:** Avonle and Goodale were ~2.5 units higher than Moose Jaw and Lucky Lake.
- **Desi:** A difference of 3.6 units was determined from the highest to the lowest.

Table 2.8.3. Effects of variety and location.

	Desi
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[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:

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

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

Results: Figure 2.9.1. Box and Whisker plot of black desi and desi chickpeas for Hausner ratio from 6 locations.

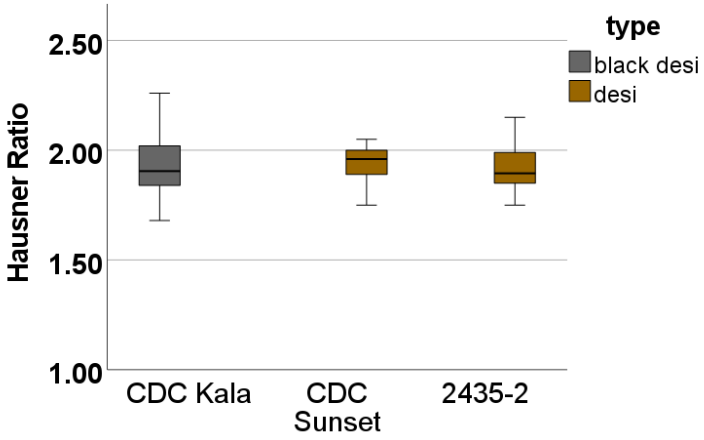
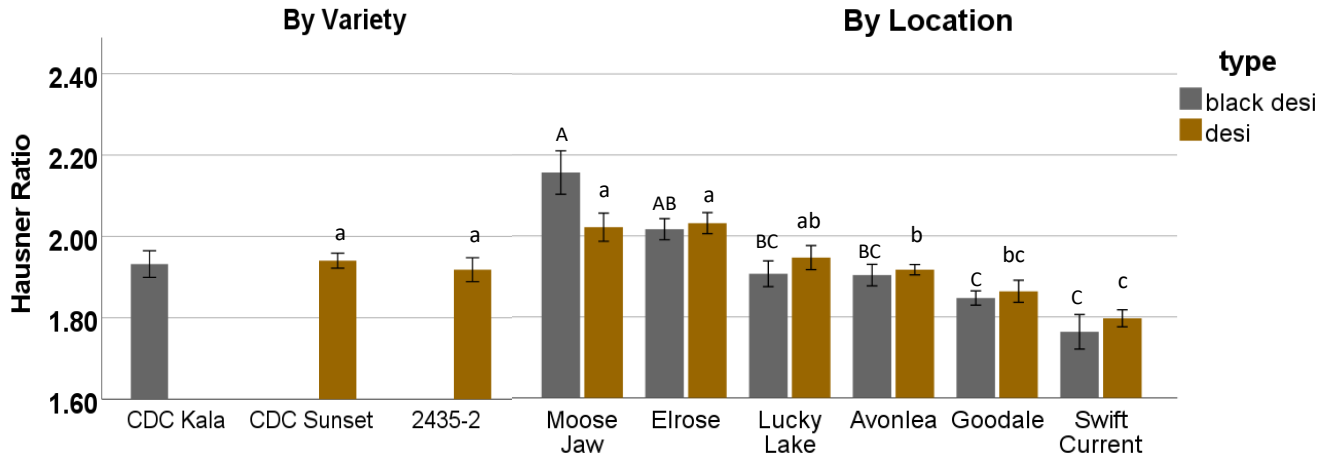


Figure 2.9.2. Mean Hausner ratio of black desi and desi chickpeas by variety (left) and by location (right). Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences (p<0.05) by variety and location for desi type. Capital letters indicated significant differences (p<0.05) by location for black desi.

- 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 2.10.1. Box and Whisker plot of black desi and desi chickpeas for D_{90} (µm, left) and $D_{4,3}$ (µm, right) resulting from 6 locations.

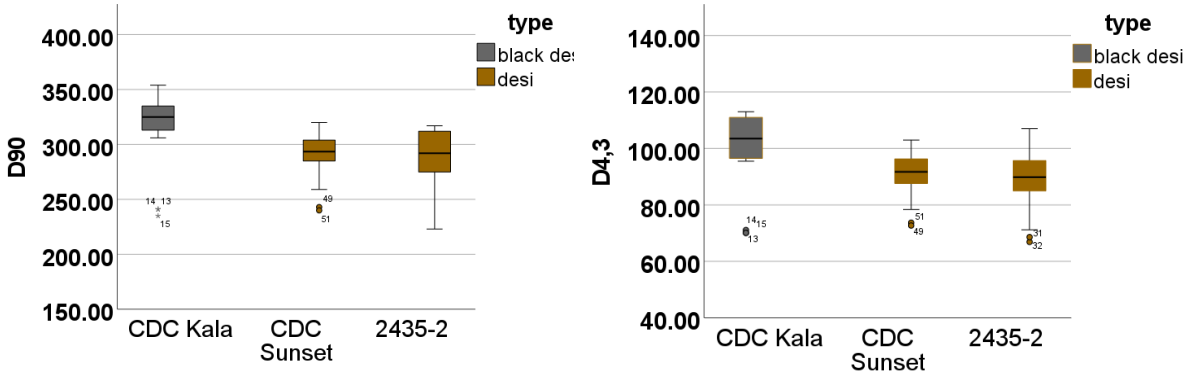
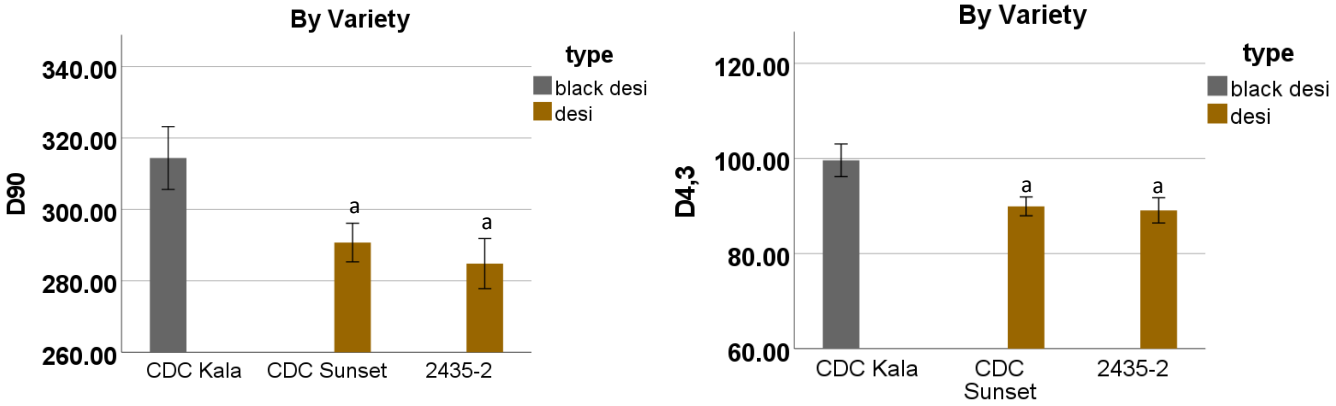


Figure 2.10.2. D_{90} (µm, left) and $D_{4,3}$ (µm, right) of black desi and desi chickpea flours by variety. Each bar represents mean ± one standard error.



Note: Small letters indicated significant differences ($p<0.05$) by variety for desi type.

- **D_{90}:** Both desi varieties were below 300 µm. Black desi was below 320 µm.
- **$D_{4,3}$:** The mean diameter of desi flours was below 90 µm and for black desi was below 100 µm.