2022 Pulse Quality Evaluation

Dry Bean

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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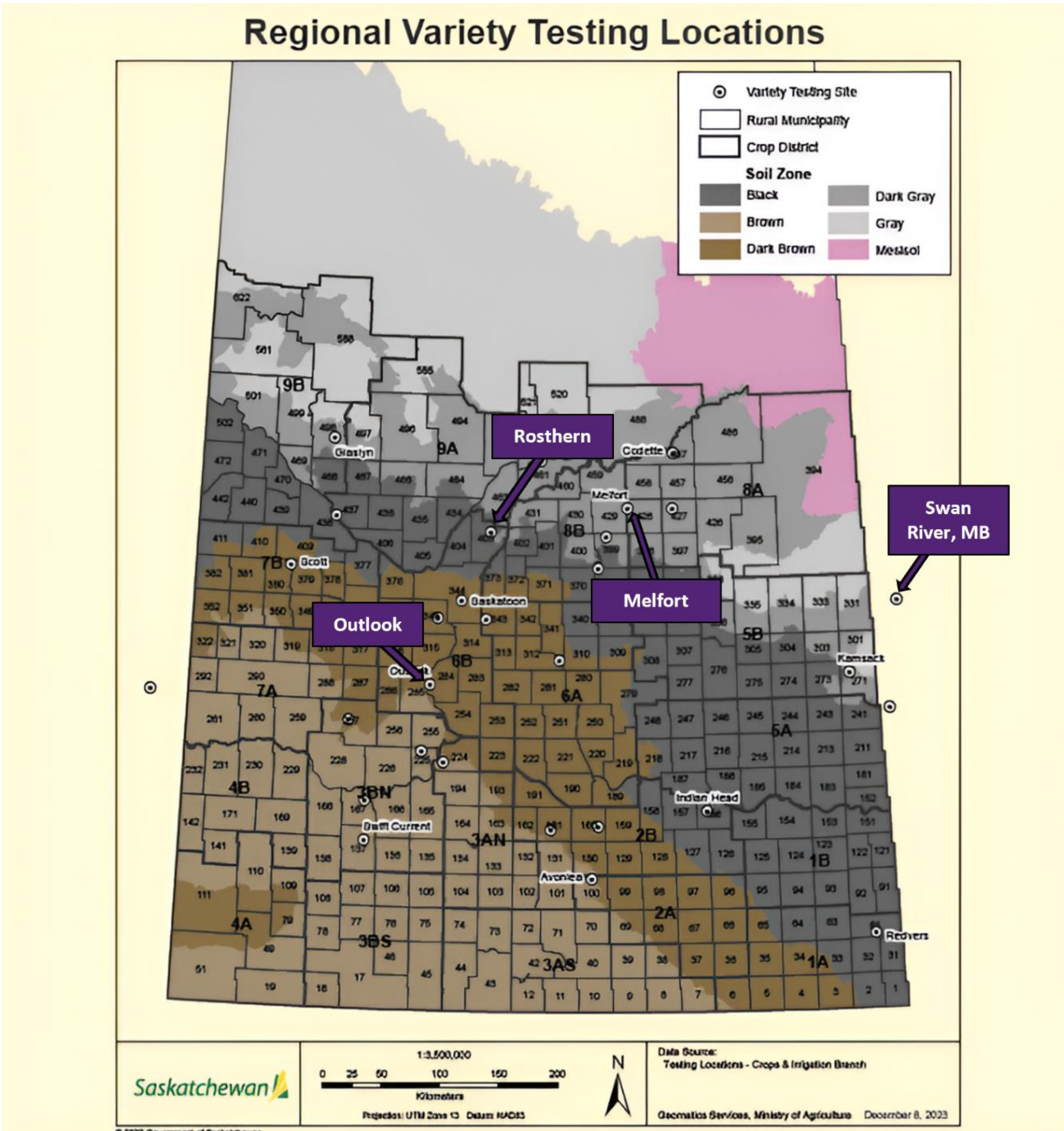
2022 Dry Bean Quality

A total of **96** dry bean samples harvested in **2022** were evaluated. Samples were acquired from Melfort (24 samples), Rosthern (24), Outlook (24), and Swan River (24), including two varieties of black type, one variety of FDJ type, three varieties of navy type, one variety of pinto type, and one variety of yellow type. 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 dry bean samples harvested in 2022 for the Pulse Quality Program.

Crop	Type	Variety		Site	Number of samples
Dry bean	Black	5501CBB-3-2	CDC Blackstrap	Melfort Outlook Rosthern Swan River, MB	96
	FDJ	CDC Ray			
	Navy	ACC Shock CDC Whitetrack	OAC Fusion		
	Pinto	CDC WM-3			
	Yellow	CDC Sunburst			



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.

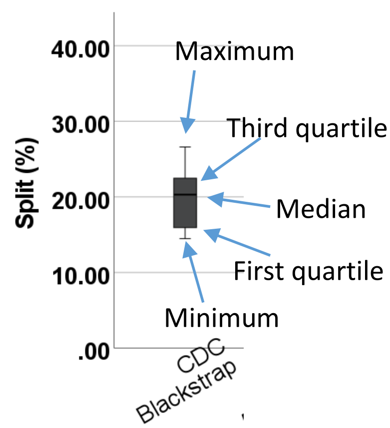
Figure A. Locations for dry bean quality testing in 2022 and the corresponding soil zones. Figure was modified from material provided by the Saskatchewan Ministry of Agriculture.

This report 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, for each bean type by location and for navy bean by variety.

An independent T-test was conducted to identify the differences in the quality parameters for black bean 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 black and yellow beans.

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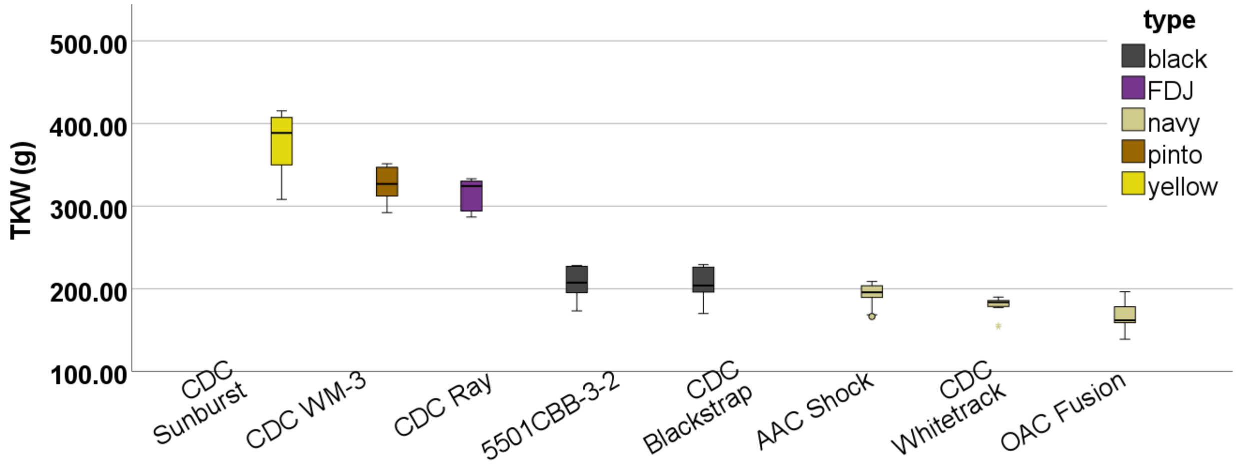
2022 Dry Bean Quality

1. 1000 Seed Weight

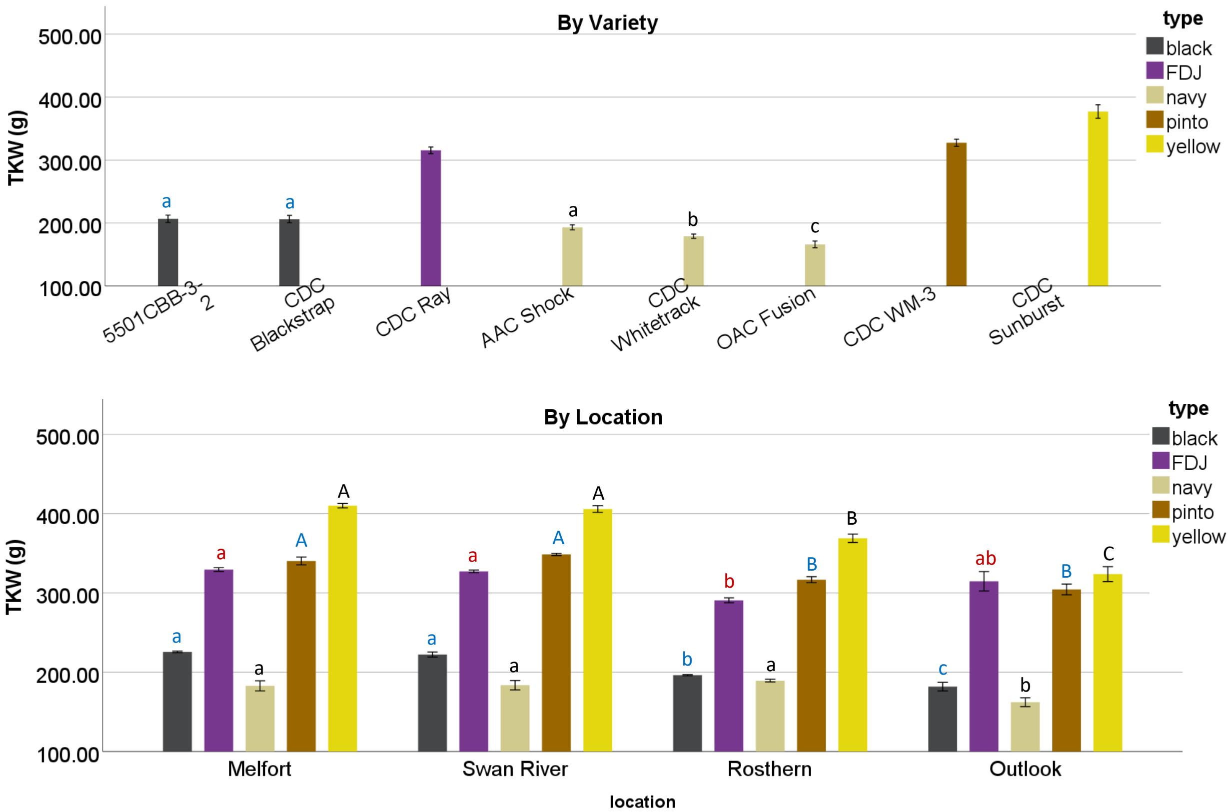
Method: Seed weight is an important parameter to indicate seed size and yield production. This test was conducted by weighing 300 seeds with duplicated measurements per sample, and the 1000 seed weight (TKW) was reported.

Results: Figure 1.1. Box and Whisker plot of dry beans for TKW resulting from 4 locations. Results by type were reported from highest to lowest.



- Yellow had the highest TKW and a large variability.
- Both black beans were similar.
- Navy beans were the smallest.

Figure 1.2. Mean TKW of dry beans by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by yellow bean. Capital letters in blue indicated significant differences (p<0.05) by pinto bean. Small letters in black indicated significant differences (p<0.05) by navy bean. Small letters in blue indicated significant differences (p<0.05) by black bean. Small letters in red indicated significant differences (p<0.05) by FDJ bean.

By Variety:

- Yellow was highest in TKW, followed by pinto and FDJ beans.
- No differences were found between both black beans.
- **Navy:** OAC Fusion was 27 g lower than AAC Shock.

By Location: TKW was in general low in Outlook.

- **Black, FDJ, and Pinto beans:** About 40 g difference from highest to lowest was found.
- **Navy:** Seeds from Rosthern, Swan River, and Melfort had the same TKW, but Outlook was 20 g lower.
- **Yellow:** About 40 g difference from highest to lowest.

Table 1. Effects of variety and location.

	Black	Navy
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 dry beans: #22R: 8.73 mm, #20R: 7.94 mm, #18R: 7.14 mm, #16R: 6.35 mm, #14R: 5.56 mm, #12R: 4.76 mm, #10R: 3.97 mm.

Results: Table 2. Seed size distribution (%) of each dry bean variety. Data represent mean ± one standard deviation.

Variety	> # 22R (%)	> # 20R (%)	> # 18R (%)	> # 16R (%)	> # 14R (%)	> # 12R (%)	> # 10R (%)	Below # 10R (%)
5501CBB-3-2	0.0 ± 0.0[a]	0.0 ± 0.0[a]	1.1 ± 1.0[a]	42.7 ± 17.0[a]	48.6 ± 12.0[a]	7.4 ± 6.3[a]	0.2 ± 0.1[a]	0.0 ± 0.0[a]
CDC Blackstrap	0.0 ± 0.0[a]	0.0 ± 0.0[a]	1.5 ± 1.1[a]	44.4 ± 15.2[a]	47.6 ± 11.9[a]	6.3 ± 4.4[a]	0.2 ± 0.1[a]	0.0 ± 0.0[a]
CDC Ray	0.4 ± 0.3	13.4 ± 4.4	49.9 ± 5.1	32.5 ± 7.7	3.3 ± 1.6	0.4 ± 0.3	0.1 ± 0.1	0.0 ± 0.0
AAC Shock	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0[a]	20.5 ± 9.7[a]	63.9 ± 3.5[a]	15.0 ± 10.1[c]	0.6 ± 0.6[b]	0.0 ± 0.0[c]
CDC Whitetrack	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0[a]	9.1 ± 4.4[b]	64.7 ± 10.0[a]	24.9 ± 11.4[b]	1.2 ± 0.9[b]	0.1 ± 0.1[b]
OAC Fusion	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0[a]	0.1 ± 0.1[c]	27.7 ± 12.5[b]	66.4 ± 8.9[a]	5.6 ± 3.8[a]	0.2 ± 0.2[a]
CDC WM-3	2.4 ± 1.5	42.7 ± 15.4	44.5 ± 9.8	9.0 ± 6.7	1.1 ± 1.5	0.2 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
CDC Sunburst	2.7 ± 2.1	25.0 ± 11.2	47.1 ± 3.7	22.1 ± 10.1	2.7 ± 2.6	0.3 ± 0.2	0.0 ± 0.1	0.0 ± 0.0

Note: Small letters indicated significant differences ($p<0.05$) between black bean varieties. Capital letters indicated significant differences ($p<0.05$) between navy bean varieties.

- CDC Sunburst (yellow), CDC WM-3 (pinto), and CDC Ray (FDJ) retained onto sieves #20 to #16.
- Both black and AAC Shock (navy) tended to fall into #16 to #12 sieves.
- The other two navy beans retained onto sieves #14 and #12.

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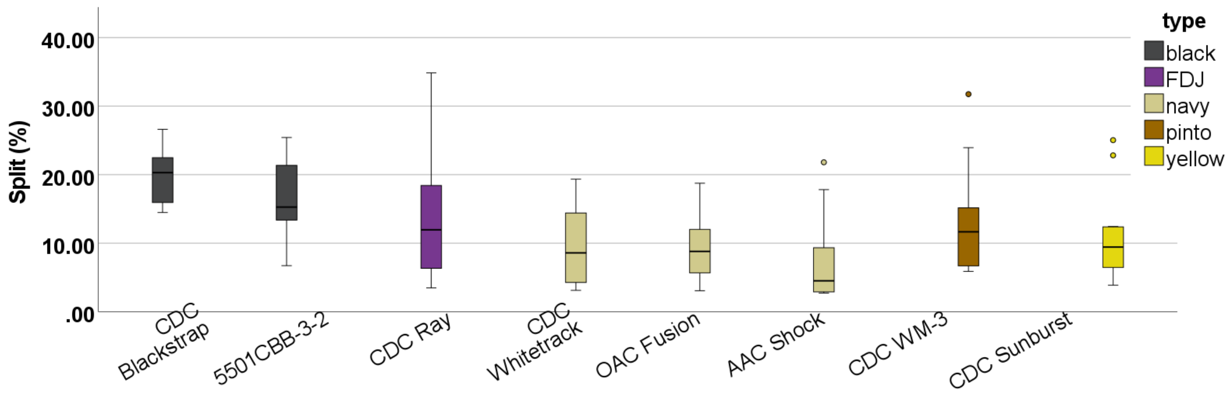
3. Split

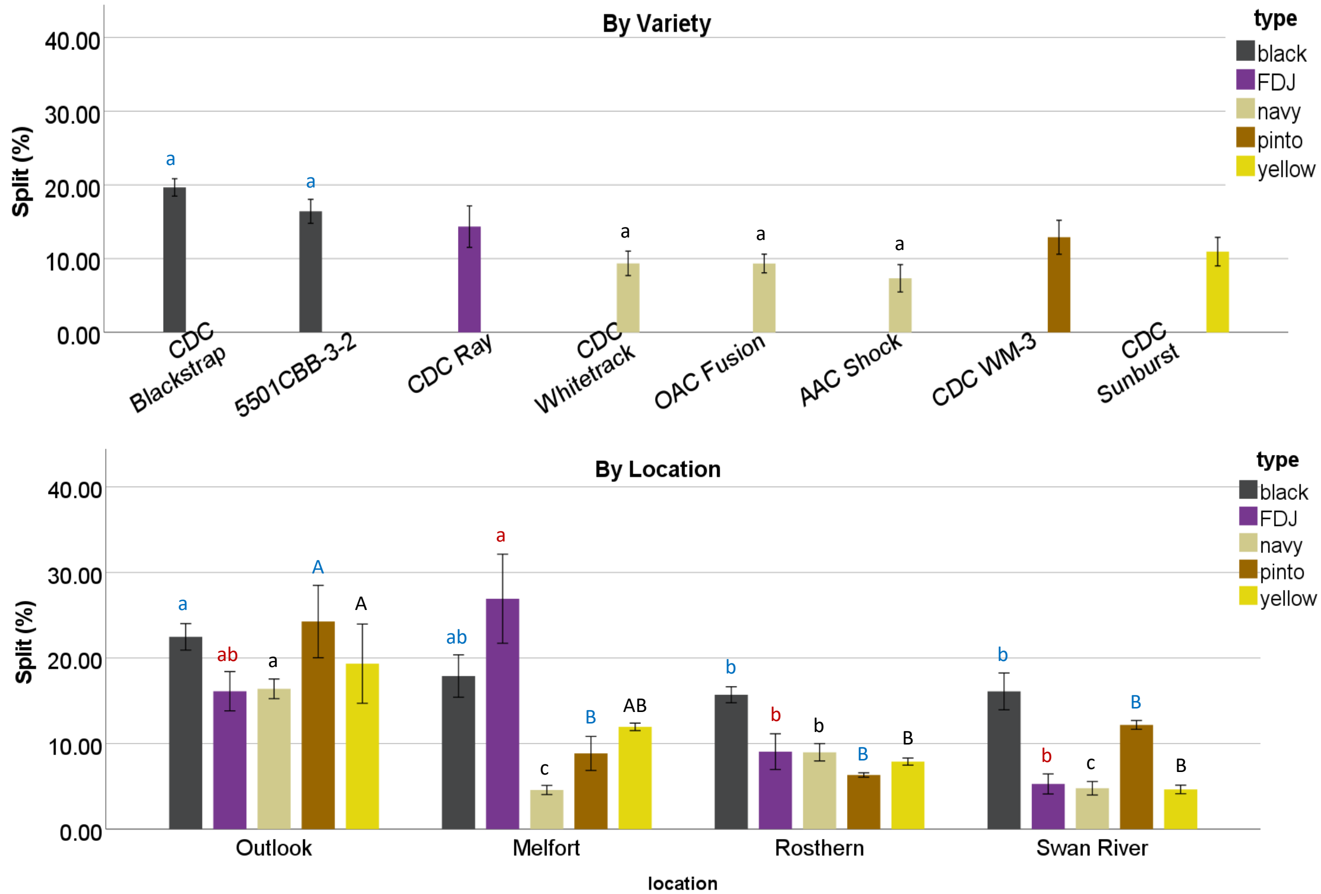
Method: 100 grams of each sample was used for evaluation, and damaged seeds were selected by hand. Results included splits, cracks, seed coat damage, partially missing hull, and partially missing cotyledon.

Results: Figure 3.1. The Box and Whisker plot of dry beans for the split resulting from 4 locations. Results by type were reported from highest to lowest.



- Black type had high split level.
- Very large variability was observed in CDCD Ray (FDJ).
- Navy types in general had lower split.

Figure 3.2. Mean split of dry beans by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by yellow bean. Capital letters in blue indicated significant differences (p<0.05) by pinto bean. Small letters in black indicated significant differences (p<0.05) by navy bean. Small letters in blue indicated significant differences (p<0.05) by black bean. Small letters in red indicated significant differences (p<0.05) by FDJ bean.

By Variety:

- Split was above 7% for all varieties.
- Both black types were above 15%.
- No statistical difference was observed in the black types and the navy types.

By Location:

- The amount of split for all bean types was extremely high in Outlook.

Table 3. Effects of variety and location.

	Black	Navy
Variety	*NS*	*NS*
Location	*	***
Variety x Location	*NS*	*NS*

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

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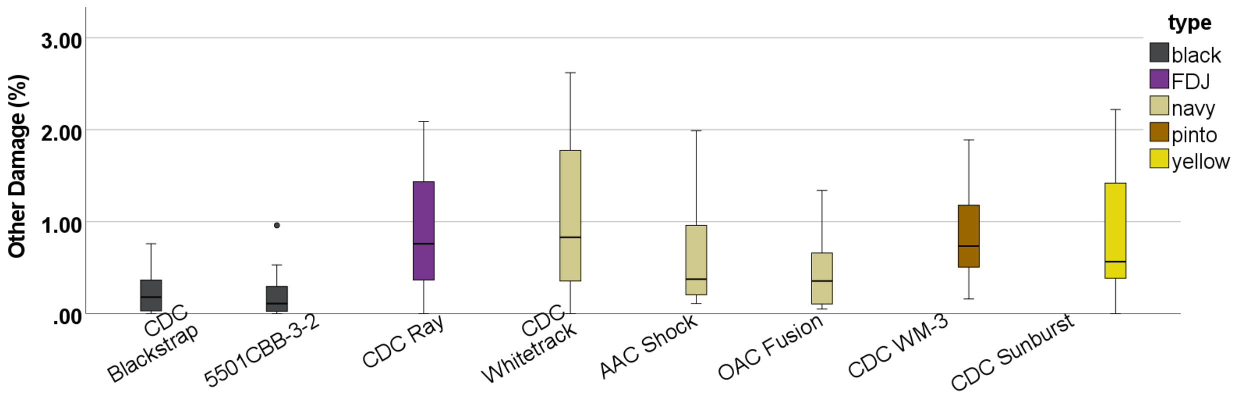
4. Other Damage

Method: 100 grams of each sample was used for evaluation, and damaged seeds were selected by hand. Other damage included sprouting, distinct immaturity, distinct deterioration or discolouration by weather or disease, insect damage, heat damage, and any other damage that affects appearance.

Results: Figure 4.1. Box and Whisker plot of dry beans for other damage resulting from 4 locations. Results by type were reported from highest to lowest.



- Black beans had the lowest other damage.
- CDC Whitetrack (navy) had the highest other damage, followed by CDC Ray (FDJ) and CDC Sunburst (yellow).

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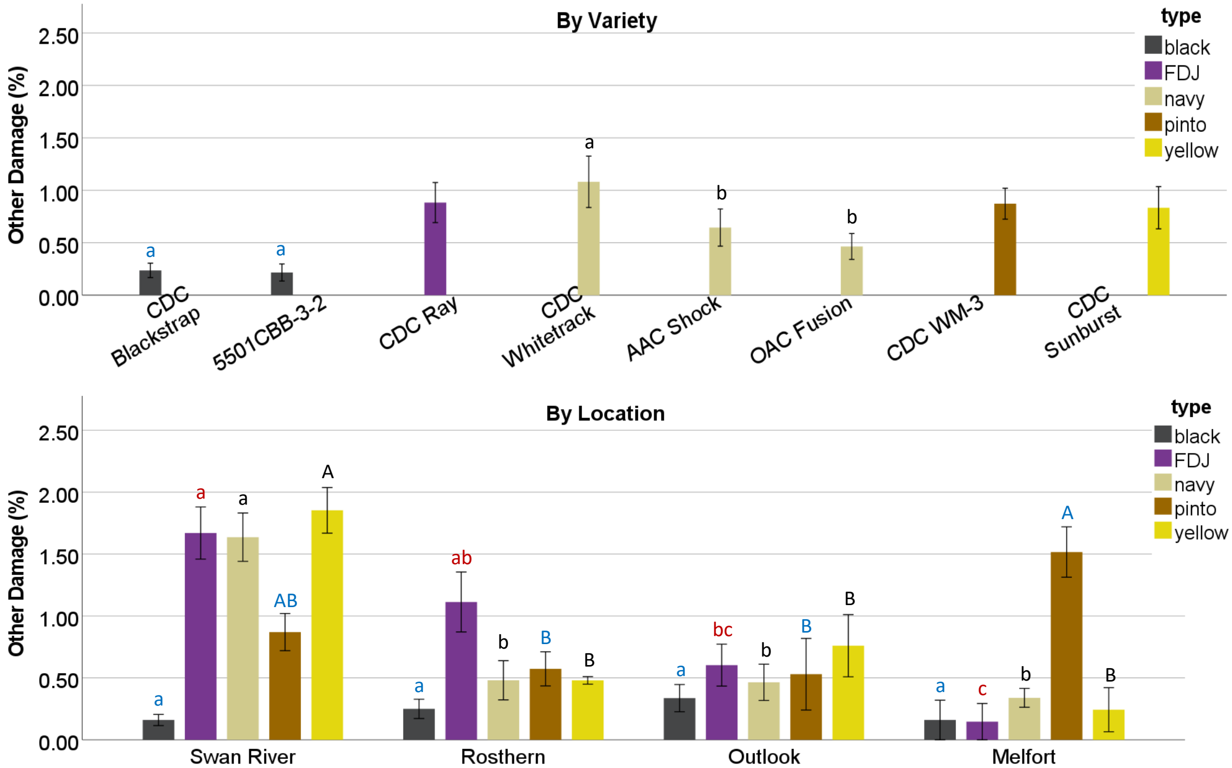
Figure 4.2. Mean other damage of dry beans by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: <u>Capital letters in black</u> indicated significant differences (p<0.05) by yellow bean. <u>Capital letters in blue</u> indicated significant differences (p<0.05) by pinto bean. <u>Small letters in black</u> indicated significant differences (p<0.05) by navy bean. <u>Small letters in blue</u> indicated significant differences (p<0.05) by black bean. <u>Small letters in red</u> indicated significant differences (p<0.05) by FDJ bean.

By Variety: CDC Whitetrack was 1.1%. All other varieties were below 1%.

By Location:

- Other damage of black beans remained low in all locations.
- For other types, Swan River in general had a higher damage.

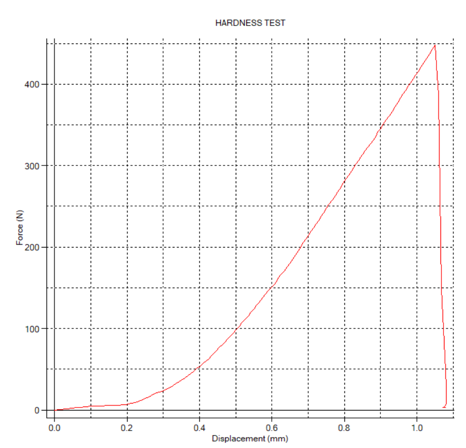
Table 4. Effects of variety and location.

	Black	Navy
Variety	*NS*	***
Location	*NS*	***
Variety x Location	*NS*	*NS*

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

5. Hardness of Whole Seed

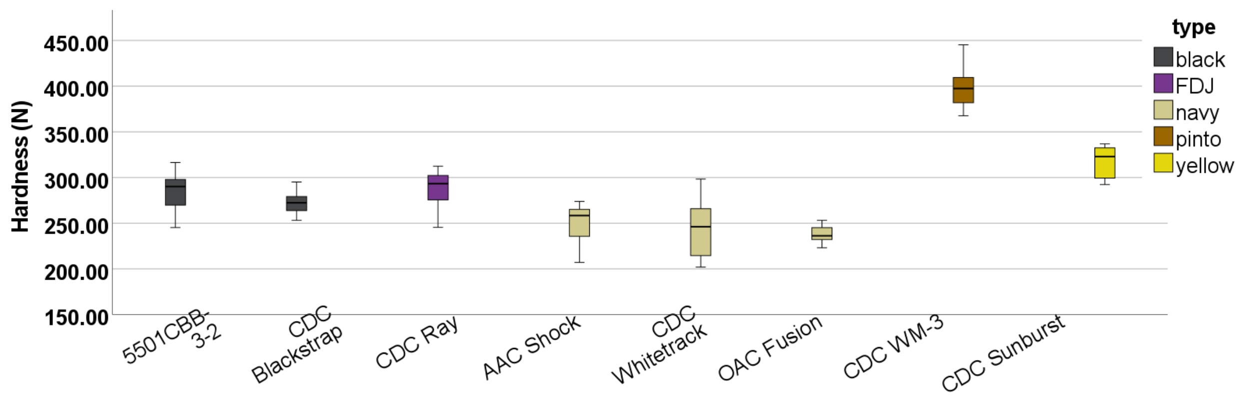
Seed hardness is an important parameter to indicate milling yield and cooking quality. Seed hardness is affected by seed size, shape, density, composition, etc.



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 5.1. Box and Whisker plot of dry beans for seed hardness (N) resulting from 4 locations. Results by type were reported from highest to lowest.

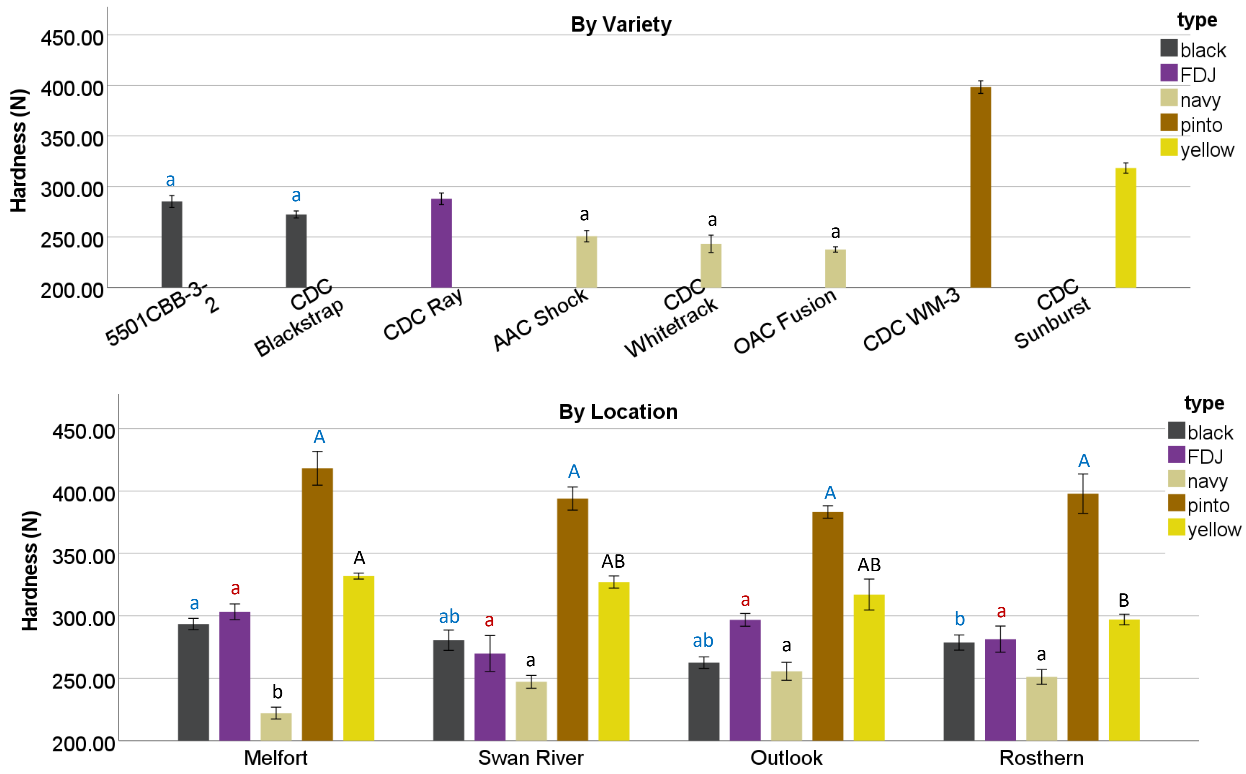


- CDC WM-3 (pinto) was very high in hardness, followed by CDC Sunburst (yellow).
- Navy beans had lower hardness.

[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 5.2. Mean seed hardness of dry beans by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by yellow bean. Capital letters in blue indicated significant differences (p<0.05) by pinto bean. Small letters in black indicated significant differences (p<0.05) by navy bean. Small letters in blue indicated significant differences (p<0.05) by black bean. Small letters in red indicated significant differences (p<0.05) by FDJ bean.

By Variety:

- No statistical difference was observed in the black types and the navy types.
- Hardness of CDC WM-3 (pinto) was 80 N higher than CDC Sunburst (yellow), over 100 N higher than black and FDJ, and 150 N higher than navy type.

By Location:

- No difference was found in FDJ and pinto seeds acorss 4 locations.
- A 30 N difference was found from highest to lowest fro black, navy, and yellow types.

Table 5. Effects of variety and location.

	Black	**Navy**
Variety	*	*NS*
Location	*	***
Variety x Location	*NS*	*NS*

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

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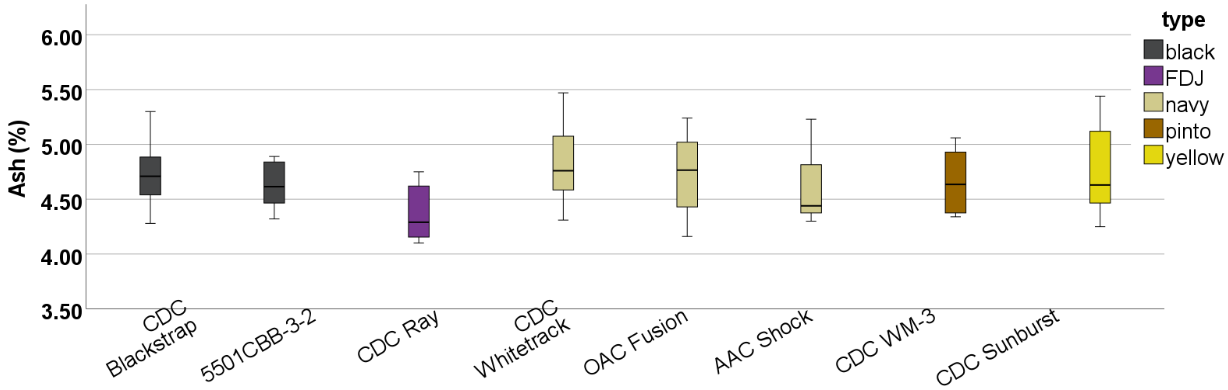
6. Ash Content

Method: Ash content (%) was determined using AACC 08-01.01[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.).

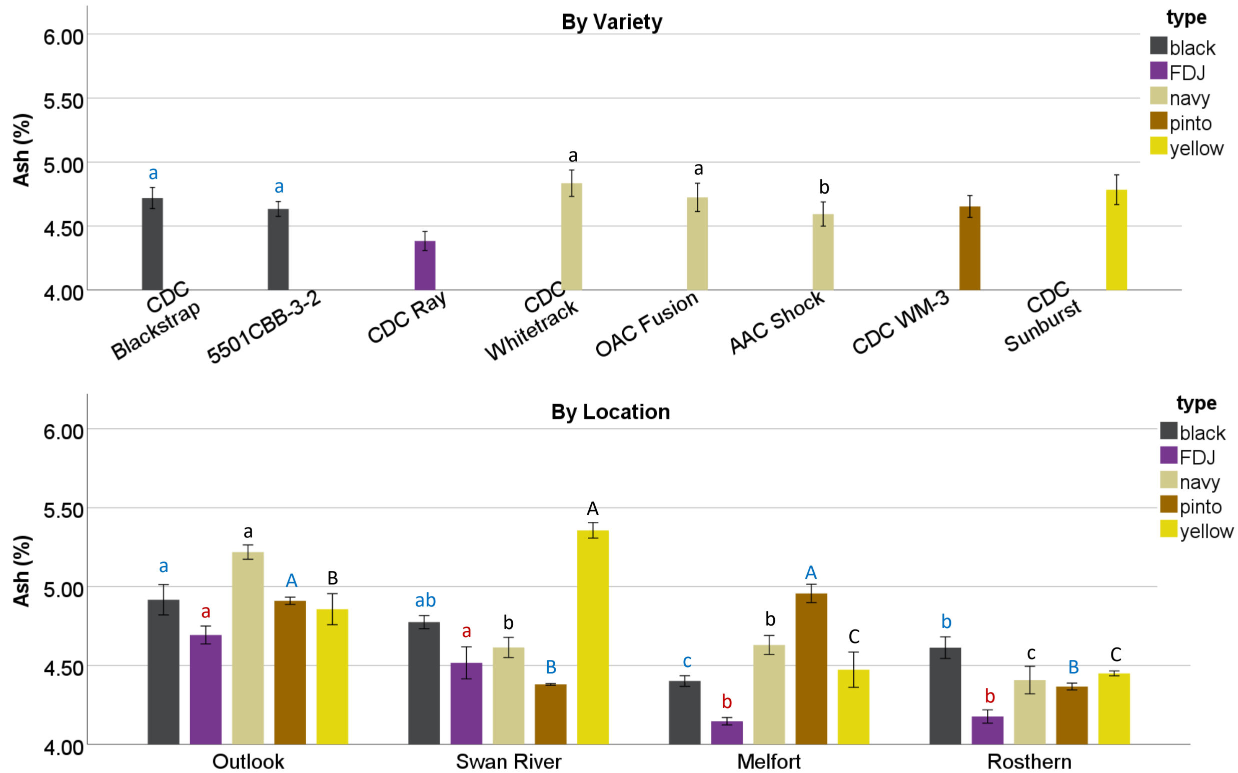
Results: Figure 6.1. Box and Whisker plot of dry beans for ash content (%) resulting from 4 locations. Results by type were reported from highest to lowest.



- CDC Ray (FDJ) had a lower ash.
- Both black beans 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 6.2. Mean ash of dry beans by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



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By Variety:

- Ash for CDC Ray was 4.4%, and all other varieties ranged from 4.6% to 4.8%.

By Location:

- Location effect played a role. Seeds from Outlook in general had a higher ash, while seeds from Rosthern had a lower ash.

Table 6. Effects of variety and location.

	Black	Navy
Variety	*NS*	***
Location	***	***
Variety x Location	**	**

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

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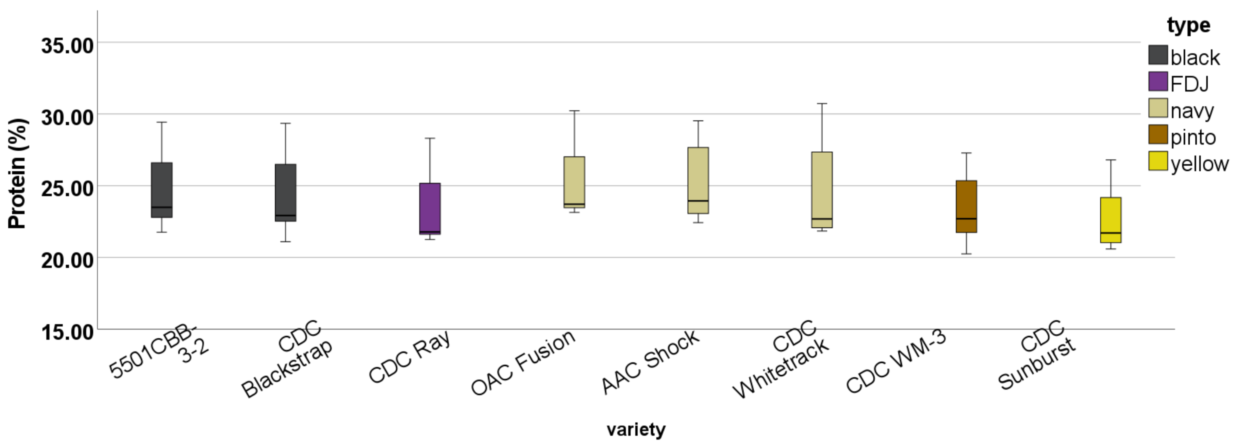
7. Protein Content

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.).

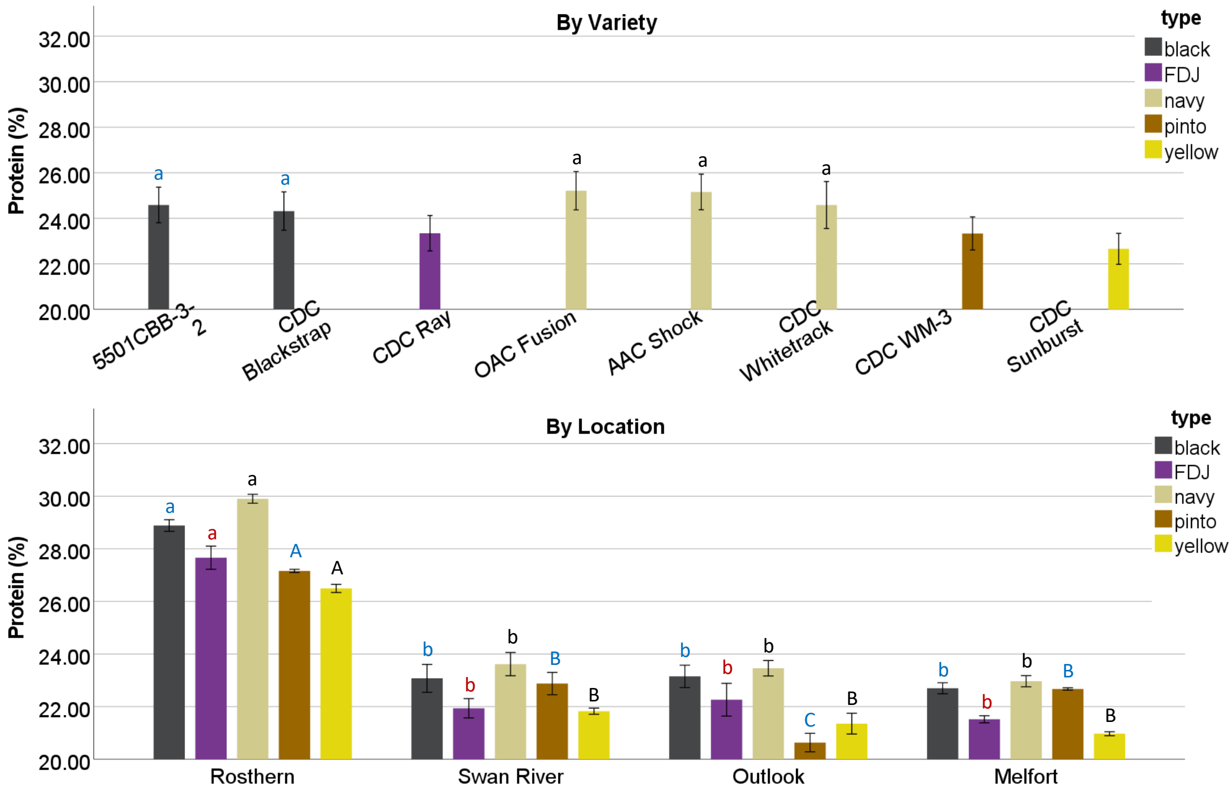
Results: Figure 7.1. Box and Whisker plot of dry beans for protein content (%) resulting from 4 locations. Results by type were reported from highest to lowest.



- Protein of navy and black beans were higher.
- CDC Ray, CDC WM-3, and CDC Sunburst had lower protein.

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

Figure 7.2. Mean protein of dry beans by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



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By Variety:

- No statistical difference was observed in the black types and the navy types.

By Location:

- Protein from Rosthern was 6-7% higher than the other three locations.
- The other three locations were similar.

Table 7. Effects of variety and location.

	Black	Navy
Variety	*NS*	*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. 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 (-)

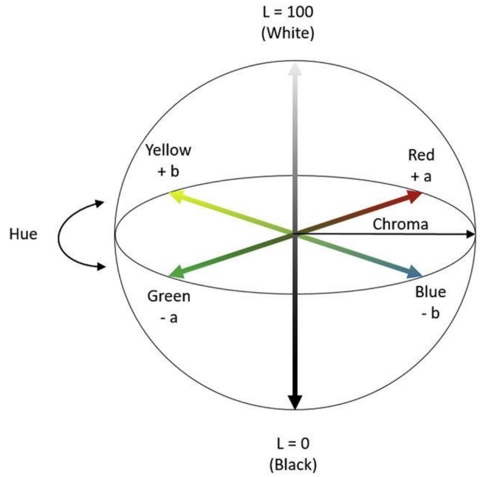
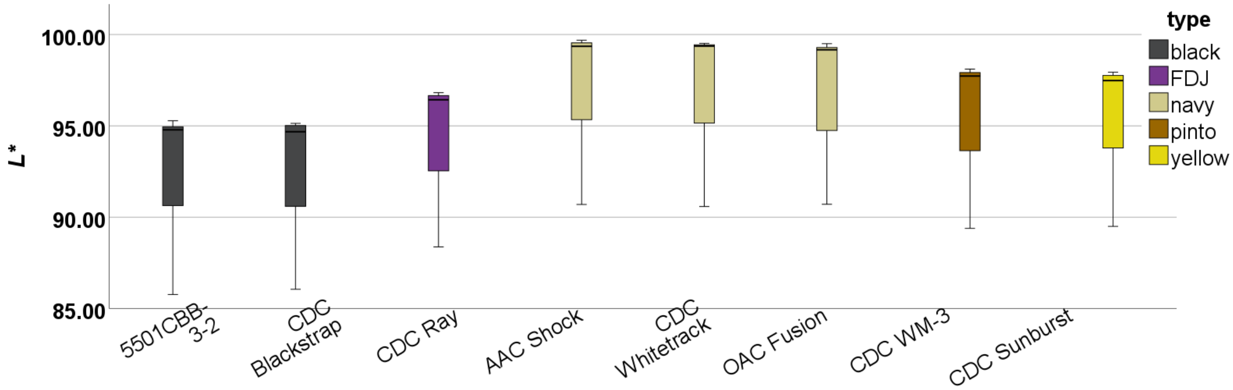


Figure 8.1. The CIELAB color spacediagram[3].

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

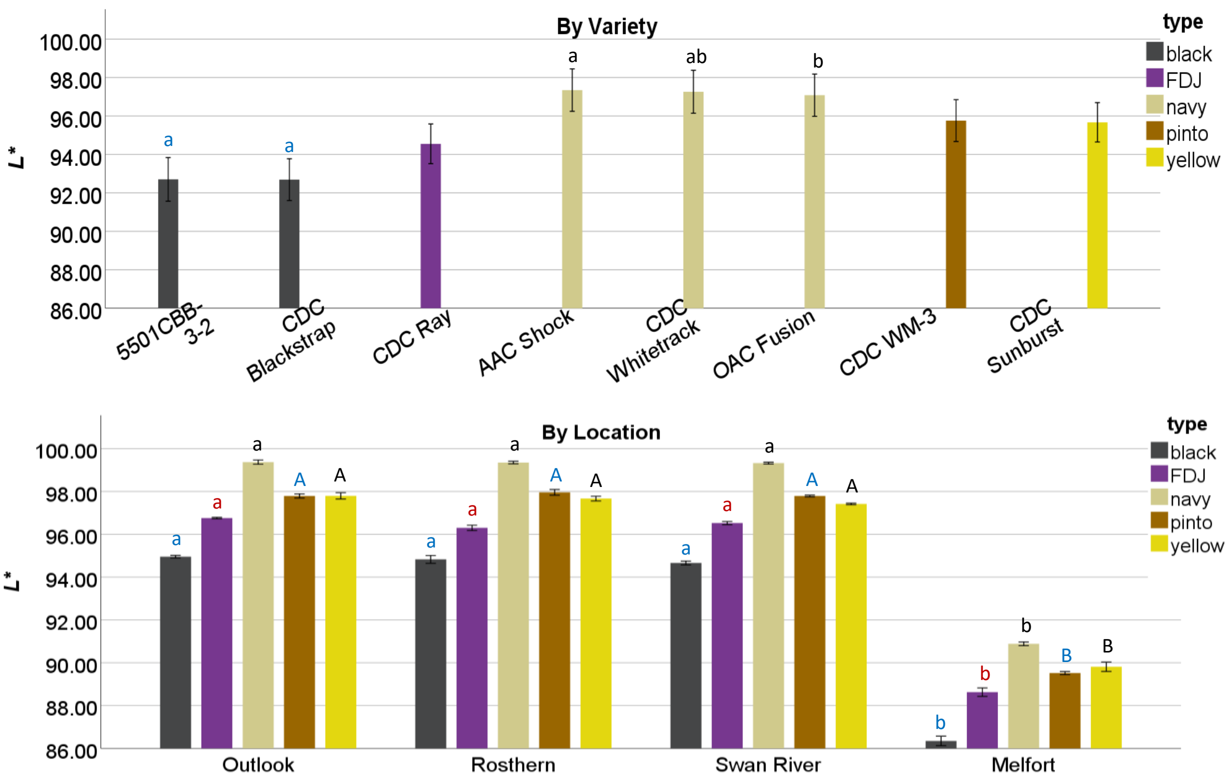
Results: Figure 8.2. Box and Whisker plot of dry beans for lightness resulting from 4 locations. Results by type were reported from highest to lowest.



- Some lower lightness values were observed in each variety.

[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 8.3.1. Mean lightness of dry beans by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by yellow bean. Capital letters in blue indicated significant differences (p<0.05) by pinto bean. Small letters in black indicated significant differences (p<0.05) by navy bean. Small letters in blue indicated significant differences (p<0.05) by black bean. Small letters in red indicated significant differences (p<0.05) by FDJ bean.

By Variety:

- The black type had a lower lightness; in contrast, the navy type had higher lightness, which could be relative to their seed coat color.

By Location:

- Outlook, Rosthern, and Swan River were similar.
- Melfort was about 9 units lower than the other three locations (p<0.05).

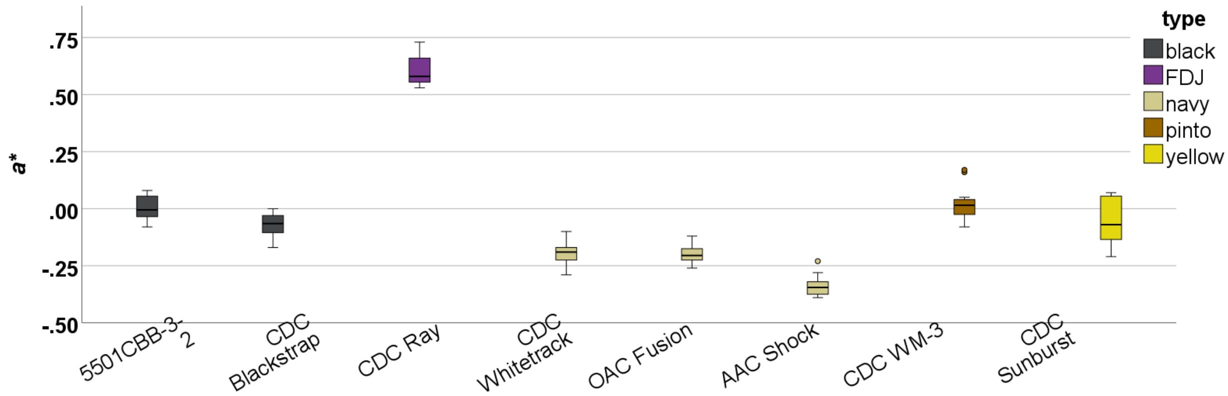
Table 8.1. Effects of variety and location.

	Black	Navy
Variety	*NS*	*
Location	***	***
Variety x Location	*NS*	*NS*

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

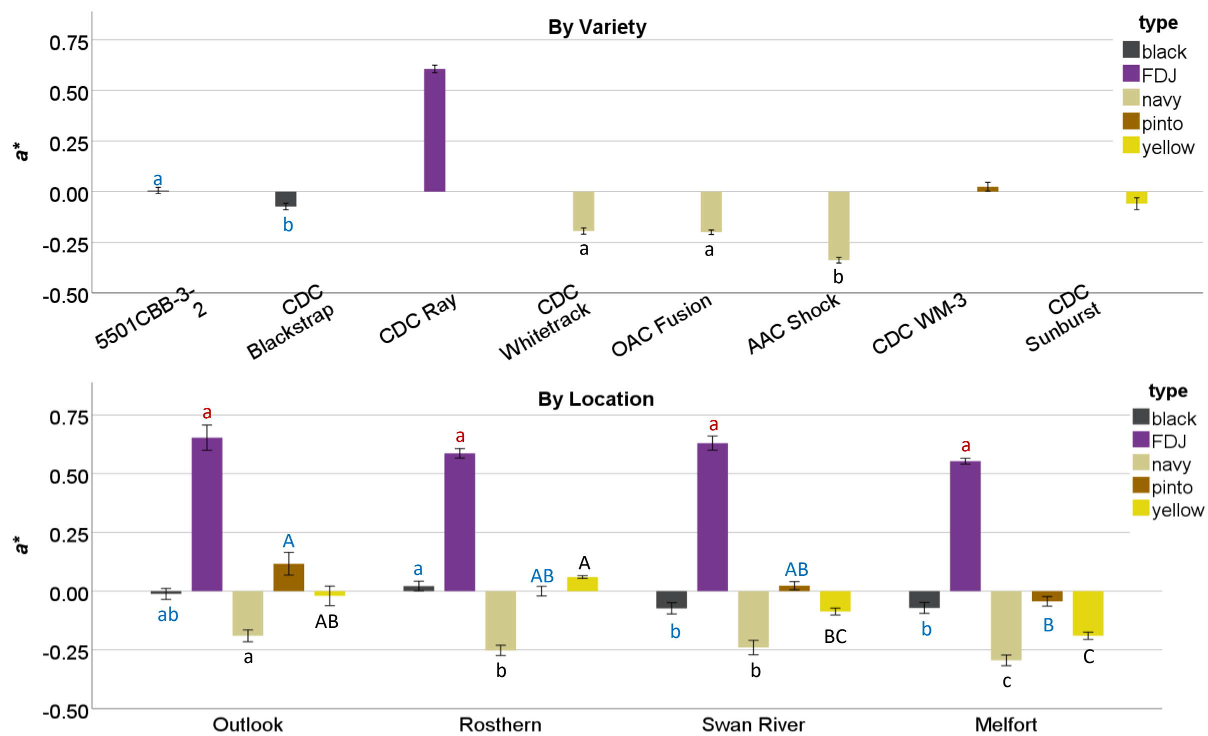
2) ***a*:*** red (+) to green (-)

Results: Figure 8.4. Box and Whisker plot of dry beans for *a** resulting from 4 locations. Results by type were reported from highest to lowest.



- All were closed to zero except CDC Ray and AAC Shock.

Figure 8.5.1. Mean *a** of dry beans by variety and by location. Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by yellow bean. Capital letters in blue indicated significant differences (p<0.05) by pinto bean. Small letters in black indicated significant differences (p<0.05) by navy bean. Small letters in blue indicated significant differences (p<0.05) by black bean. Small letters in red indicated significant differences (p<0.05) by FDJ bean.

By Variety:

- CDC Ray (FDJ) showed a weak redness, which might be due to the seed coat color.

Location: The difference from highest to lowest for each seed type was below 0.3 unit.

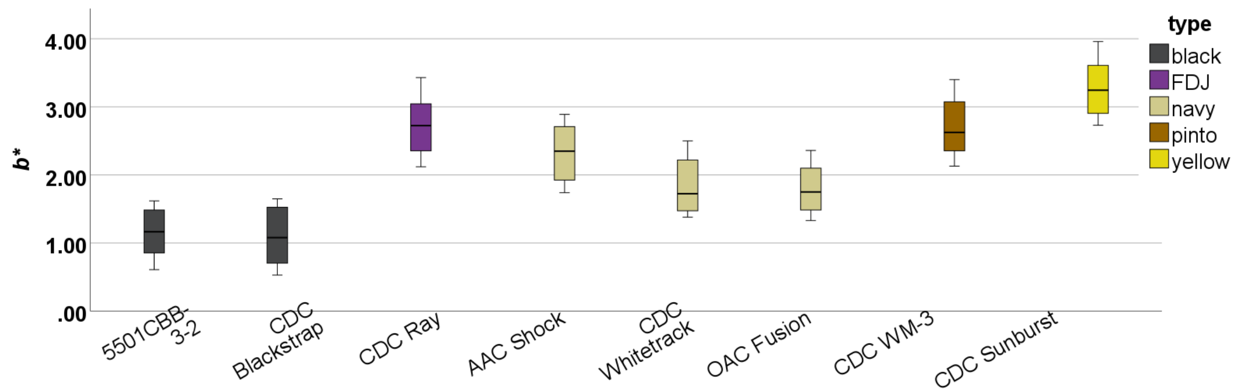
Table 8.2. Effects of variety and location.

	Black	Navy
Variety	***	***
Location	**	***
Variety x Location	*NS*	*NS*

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

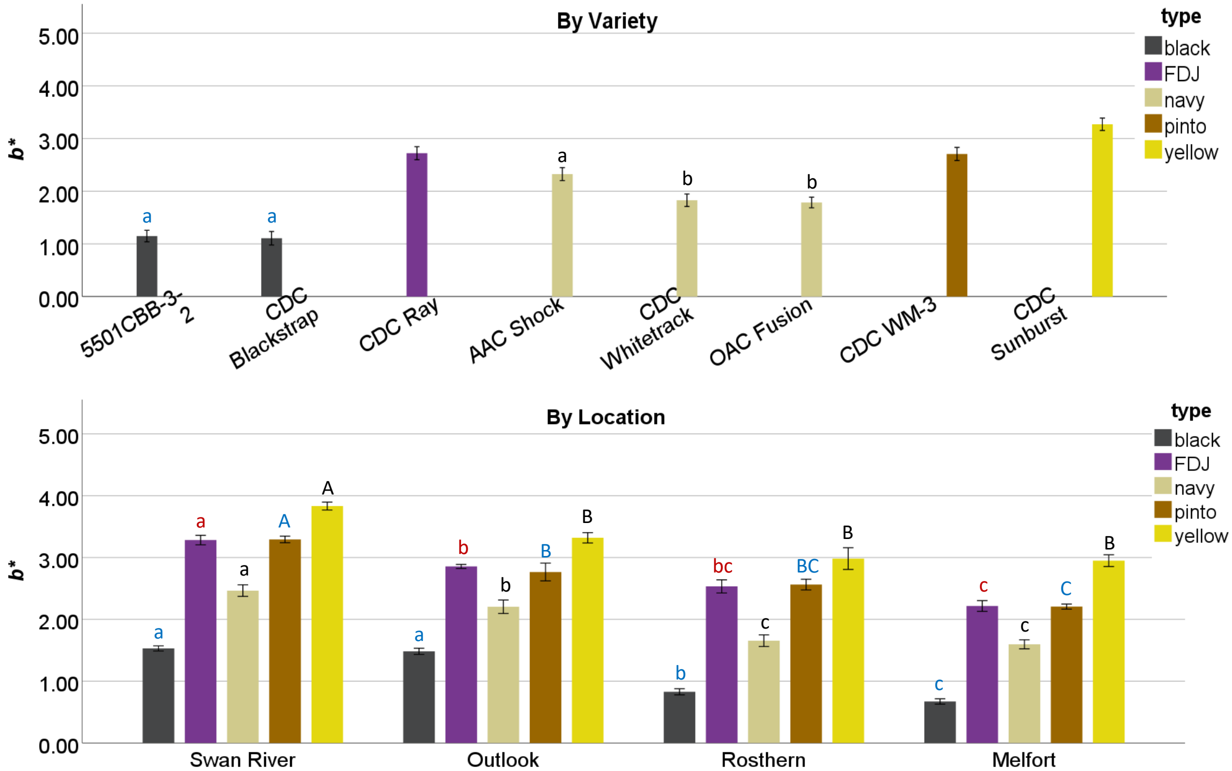
3) ***b*:*** yellow (+) to blue (-)

Results: Figure 8.6. Box and Whisker plot of dry beans for *b** resulting from 4 locations. Results by type were reported from highest to lowest.



- Black beans had the lowest *b** values.
- Overall, *b** values for beans were low compared to other pulses.

Figure 8.7. Mean *b** of dry beans by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by yellow bean. Capital letters in blue indicated significant differences (p<0.05) by pinto bean. Small letters in black indicated significant differences (p<0.05) by navy bean. Small letters in blue indicated significant differences (p<0.05) by black bean. Small letters in red indicated significant differences (p<0.05) by FDJ bean.

By Variety:

- CDC Sunburst had a higher yellowness due to the yellow seed coat.
- The b* values remained low compared to other pulses due to the off-white cotyledon.

By Location:

- The difference from highest (Swan River) to lowest (Melfort) was about 1 unit for all bean types.

Table 8.3. Effects of variety and location.

	Black	Navy
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[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

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Results: Figure 9.1. Box and Whisker plot of dry beans for Hausner ratio resulting from 4 locations. Results by type were reported from highest to lowest.

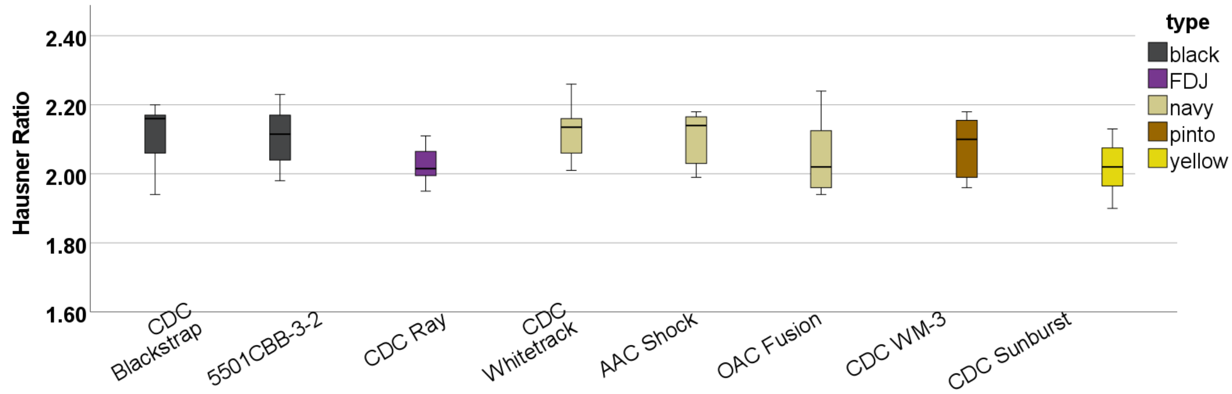
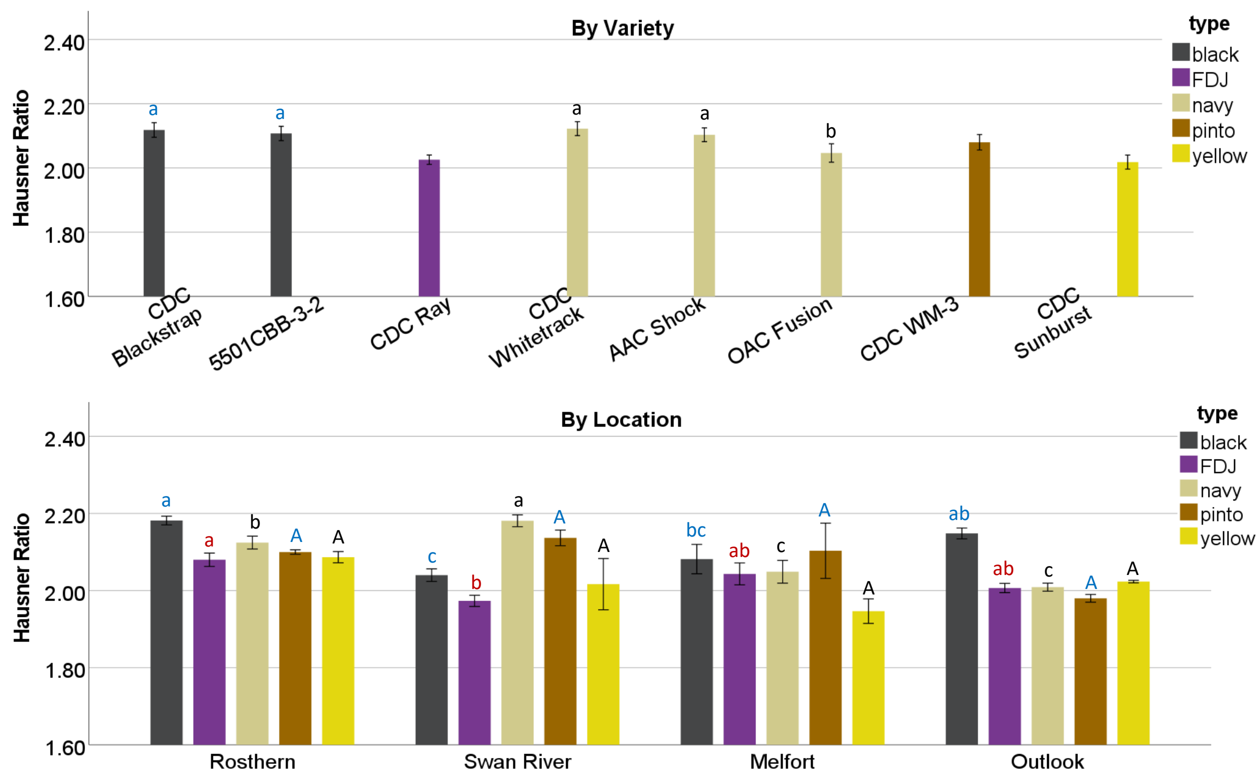


Figure 9.2. Mean Hausner ratio of dry beans by variety (top) and by location (bottom). Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by yellow bean. Capital letters in blue indicated significant differences (p<0.05) by pinto bean. Small letters in black indicated significant differences (p<0.05) by navy bean. Small letters in blue indicated significant differences (p<0.05) by black bean. Small letters in red indicated significant differences (p<0.05) by FDJ bean.

- The results of Hausner ratio for 8 varieties across 4 locations were all greater than 1.6, suggesting all faba bean 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 10.1. Box and Whisker plot of dry beans for D_{90} and $D_{4,3}$ values resulting from 4 locations. Results by type were reported from highest to lowest.

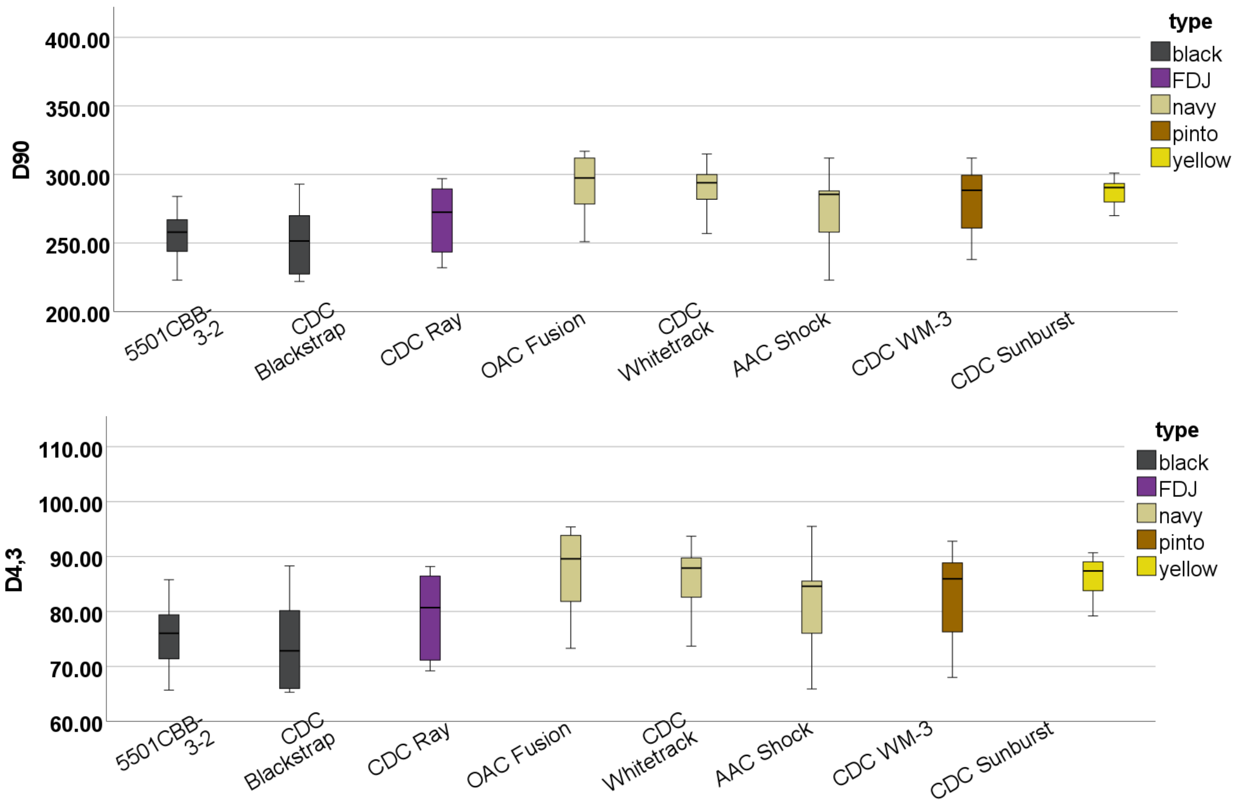

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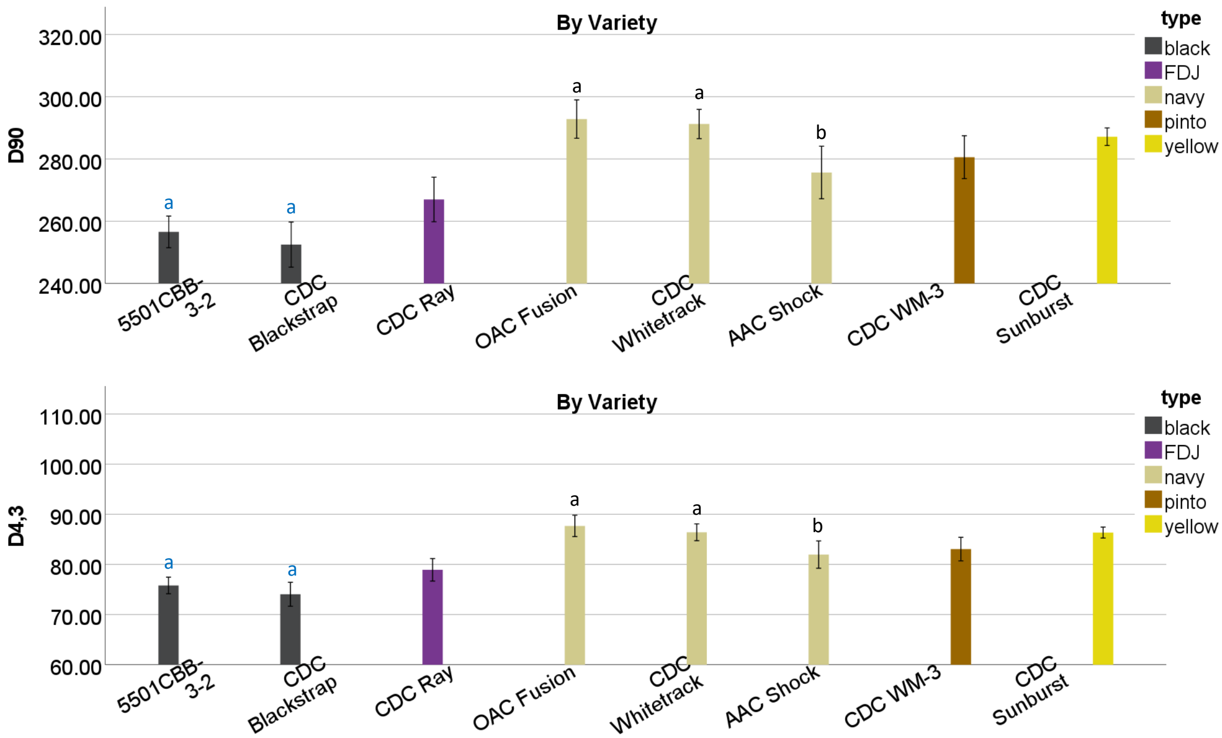
Figure 10.2. D_{90} (µm, top) and $D_{4,3}$ (µm, bottom) of dry bean flours by variety. Each bar represents mean ± one standard error.



Note: Capital letters in black indicated significant differences (p<0.05) by yellow bean. Capital letters in blue indicated significant differences (p<0.05) by pinto bean. Small letters in black indicated significant differences (p<0.05) by navy bean. Small letters in blue indicated significant differences (p<0.05) by black bean. Small letters in red indicated significant differences (p<0.05) by FDJ bean.

- **D_{90}:** All were below 300 µm, and the black beans were below 260 µm.
- **$D_{4,3}$:** The mean diameters of all flours were below 90 µm.