Crop domestication syndrome explored through seed morphological traits of 13 carrot varieties

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BACKGROUND

Often, selective breeding in crops favors traits like flavor or uniformity at the cost of fitness and natural trait variation (1).

Seed morphology, a key indicator of reproductive fitness and productivity, is one crop trait altered by domestication syndrome (1, 2).

Before domestication, carrots were used as a spice and medicine but now, they are primarily grown for their roots, with varieties bred for different traits (Fig. 1; 3).

Studying intra- and inter-variety variations in carrot seed morphology will clarify the impacts of domestication. It would also shed light on whether current breeding practices are reducing carrot fitness.

Fig. 1. Diversity of colour in carrot varieties.

RESEARCH QUESTIONS

Q1. Do seed morphological traits vary across carrot varieties and represent part of a domestication syndrome?

Q2. If so, does breeding history and/ or other aspects of reproduction (i.e., pollination) explain variation in seed traits?

Q3. Which seed traits are correlated to variety reproductive fitness and productivity?

METHODS

Fig. 2. An Olympus stereo-microscope used to take images

Measured:

- 11 carrot seed traits
- 13 carrot varieties
- 15 seeds each

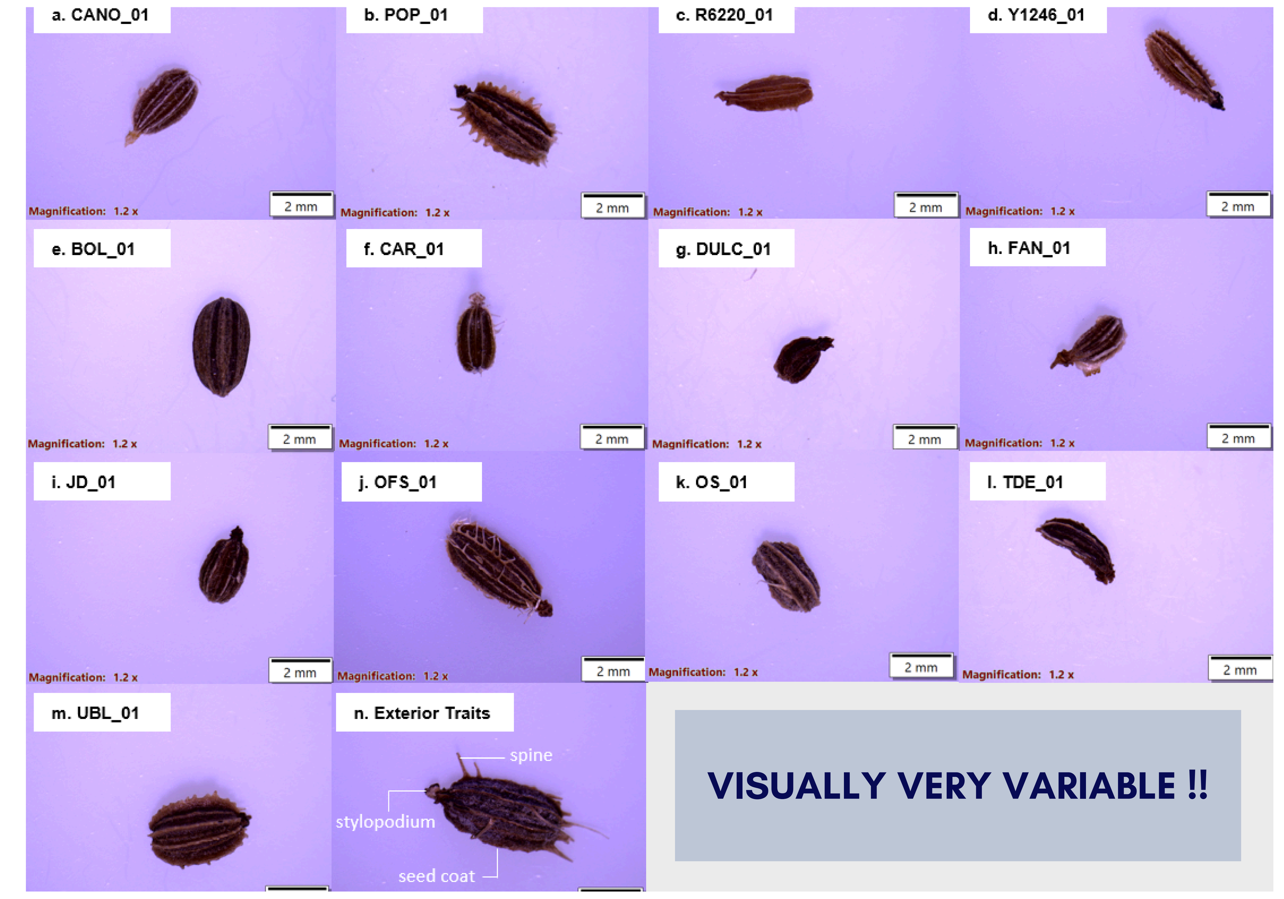

Fig. 3. 13 carrot seed varieties arranged by breeding class: breeding line (a to d), first filial generation (e), open-pollinated (f to m). Image n shows the exterior-related traits that were measured for each seed.

DISCUSSION

Seed Trait Variation

- Seed morphological traits varied significantly across the carrot varieties, with the exception of spine length (*p*=0.0406; Table 1).
  - Spines might be less relevant for cultivated plants due to reduced need of dispersal (4).
- OP varieties had the the most variation in seed traits.
  - OS – highest values in 4 of 5 size-related traits.
  - DULC – lowest values in 4 of 5 size-related traits.
  - Open pollintation (e.g. wind, self or insects) allows for natural genetic recombination and increased variation (5).
- Comparitively, BL and F1 had less variation.
  - Selection for specific traits and reduced variation (6).

Size-related Traits (Fig. 4)

- OFS, OS, and UBL, all OP varieties, ranked highest in all size-related traits except weight, where UBL was the fourth heaviest.
  - These varieties could be likely more fit than others.

Exterior-related Traits (Fig. 5)

- Less clear variety patterns
  - Might be less relevant in cultivated settings or in relation to breeding class.
- BOL was lowest in all -> Might be related to hybrid breeding.

Shape-related Traits (Fig. 6)

- BOL (F1) – highest circularity and roundness; lowest aspect ratio (AR).
  - More circular -> Hybrid breeding favours uniformity of traits, seemingly including seed traits (6).
- Y1246 (BL) – lowest circularly and roundness; highest AR.
  - More elongated
  - Was also very light -> Need more research to further determine if selective breeding could be affecting this variety.

Research Significance:

Research was conducted as part of the Canadian Organic Vegetable Improvement (CANOVI) variety trials project. It is important to understand impacts to plant fitness and biodiversity, especially in organic farming which is more sustainable. Carrots are also one of the top vegetables grown in Canada, making it an important crop to study.

FUTURE STUDIES

- Further statistics to determine which varieties display the observed differences and determine strength of correlation to breeding class.
- Link morphological markers to data retrieved from hyperspectral imaging.
- Germination tests of each seed would provide more information on how seed traits affect reproductive fitness.

RESULTS

Varieties by Breeding Class

1. Breeding Line Varieties (BL): CANO, POP, R6220, Y1246
2. First Filial Generation Hybrid (F1): BOL
3. Open-Pollinated (OP): CAR, DULC, FAN, JD, OFS, OS, TDE, UBL

Key Findings:

- Significant statistical difference in 10 of 11 traits.
- Order of statistical significance in seed traits: Size > Shape > Exterior.
- Less variation in breeding line varieties vs open pollinated.
- Not much difference between specialty and orange nantes carrots.

Table 1. Descriptive statistics on selected seed traits. The mean, standard deviation (SD), minimum and maximum trait values, and coefficient of variation (CV) are presented for each trait. ANOVA F and p values are also included.

	Trait	Mean	SD	Minimum	Maximum	CV	ANOVA F (p value)
Size traits	Length (mm)	3.37	0.72	1.95	5.29	21.44	20.42 (<0.001)
	Width (mm)	1.64	0.39	0.72	2.99	24.03	14.89 (<0.001)
	Area (mm^2)	4.27	1.75	1.41	10.44	40.99	23.93 (<0.001)
	Perimeter (mm)	9.24	1.83	5.45	13.93	19.81	21.82 (<0.001)
	Mean Weight (mg)	1.99	1.07	0.10	5.40	53.90	19.88 (<0.001)
Exterior traits	Seed Coat Width (mm)	0.10	0.11	0.00	0.44	106.75	5.94 (<0.001)
	Spine Length (mm)	0.18	0.28	0.00	1.95	156.50	1.87 (0.0406)
	Stylopodium Length (mm)	0.50	0.31	0.00	1.12	61.79	6.60 (<0.001)
Shape traits	Aspect Ratio	2.12	0.52	1.28	4.51	24.66	11.48 (<0.001)
	Circularity/Compactness	0.61	0.09	0.36	0.82	15.55	10.90 (<0.001)
	Roundness	0.47	0.11	0.20	0.74	22.51	7.47 (<0.001)

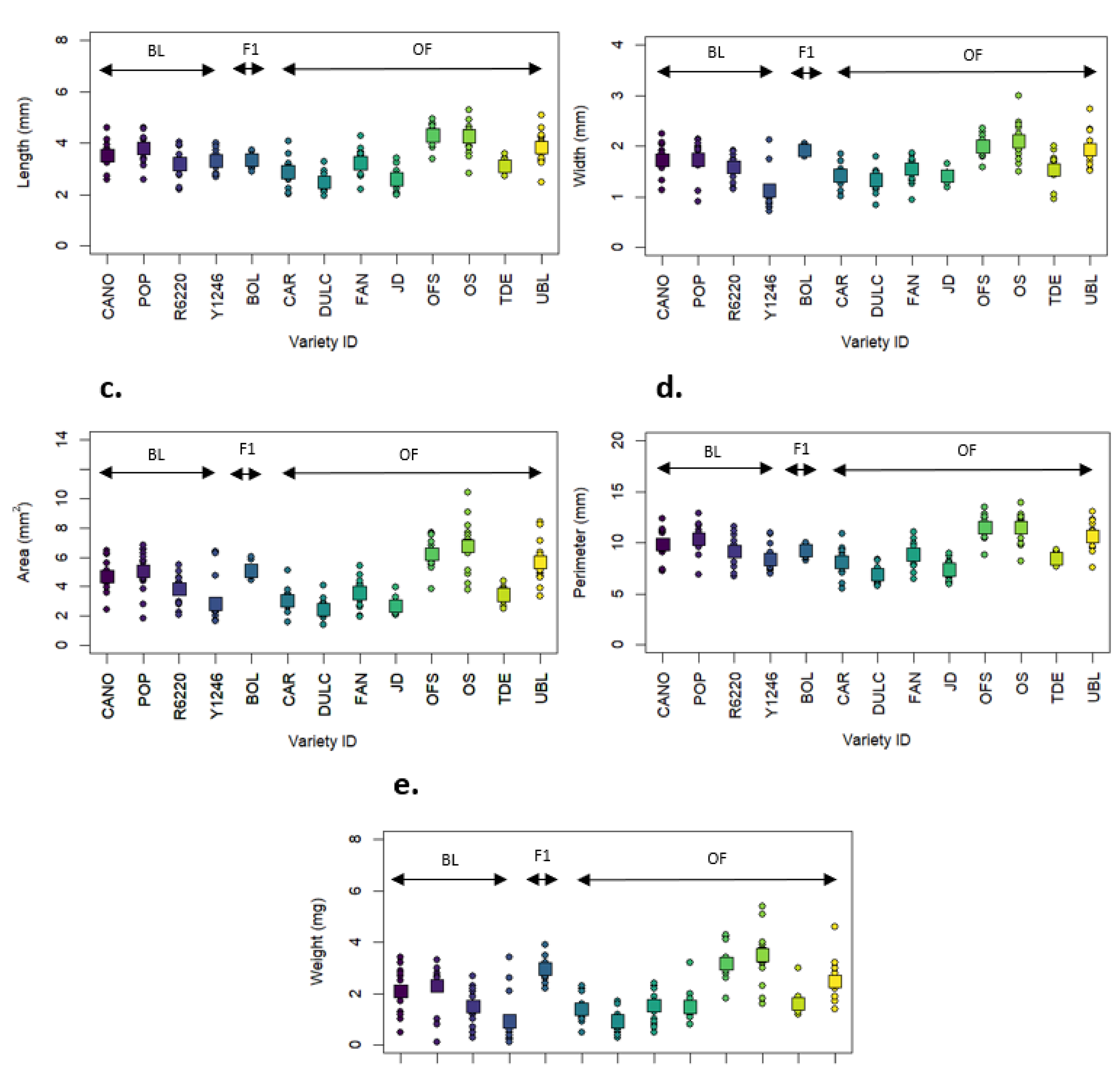

Fig. 4. Size-related seed traits. Measurements include length (mm), width (mm), area (mm2), perimeter (mm), and weight (mg) of each variety (a to e respectively). Varieties are classified by breeding class: BL, F1, and OF.

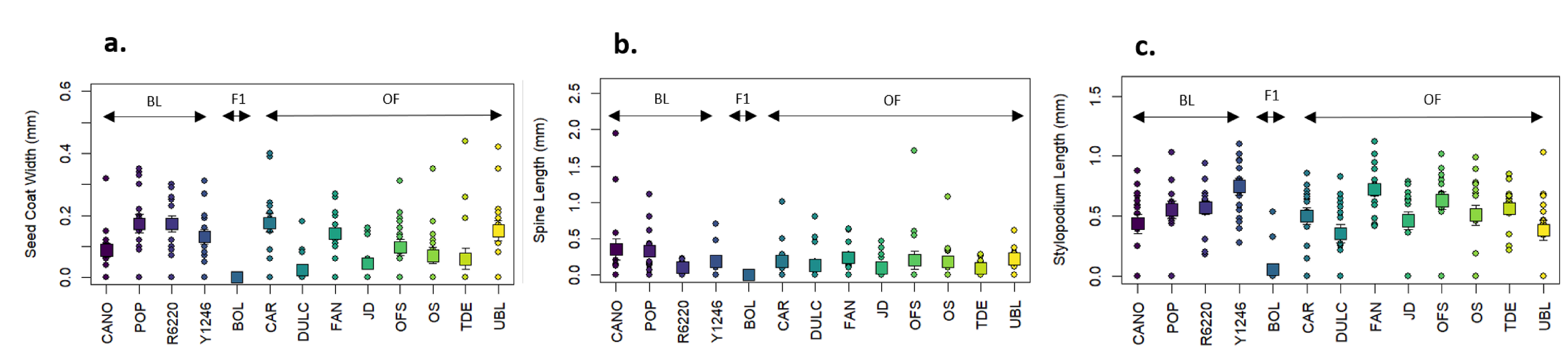

Fig. 5. Exterior-related seed traits. Measurements include seed coat width (mm), spine length (mm), and stylopodium length (mm) of each variety (a to c respectively). Varieties are classified by breeding class: BL, F1, and OF.

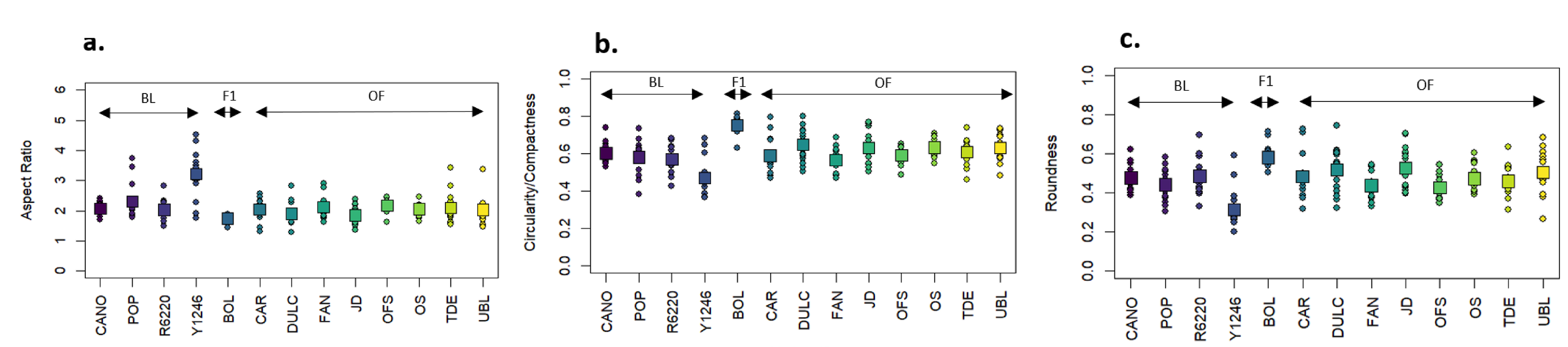

Fig. 6. Shape-related seed traits. Measurements include aspect ratio, circularity/compactness and roundness of each variety (a to c respectively). Varieties are classified by breeding class: BL, F1, and OF.

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CITED LITERATURE

(1) Meyers et al., 2012 (2) Baroux & Grossniklaus, 2019 (3) Ellison, 1970 (4) Kadluczka & Grzebelus, 2022 (5) Vargas-Mendoza et al., 2015 (6) Colombo & Galmarini, 2017