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Heterosis and inbreeding depression studies in maize for grain yield and related characters

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Abstract

Nearly 65% of the global maize acreage is planted with hybrids, yet the genetic basis of heterosis remains incompletely understood in many temperate germplasm pools. This research examined mid-parent heterosis (MPH) and inbreeding depression (ID) across 15 single-cross maize hybrids and their corresponding selfed generations (S_1 , S_2) at the Ontario College of Agriculture, Guelph, Canada, during the 2022 and 2023 growing seasons. Grain yield, ear length, kernel rows per ear, 1000-grain weight, plant height, and days to silking were recorded. MPH for grain yield ranged from 18.3% to 47.6%, with the cross OCA-7 $\times$ OCA-12 showing the highest value. Inbreeding depression in S_2 reduced grain yield by 29.4–51.7% relative to the F_1 . Grain weight per ear contributed most (28.4%) to overall heterosis. Results suggest that crosses between genetically distant flint and dent lines offer the strongest heterotic response, and that breeders should monitor ID beyond S_1 to gauge recombination potential.

Keywords: Heterosis, inbreeding depression, maize hybrids, grain yield, mid-parent heterosis, combining ability, kernel rows, temperate germplasm, flint-dent crosses

Introduction

Global maize production crossed 1.2 billion tonnes in 2022, and hybrid cultivars accounted for most of that output ^[1]. The yield advantage of hybrids over open-pollinated varieties—commonly 20–50%—is attributed to heterosis, the superior performance of an F_1 over the mean or better parent ^[2]. Despite more than a century of research since Shull's classic inbreeding–hybridisation concept, the relative contributions of dominance, overdominance, and epistasis to maize heterosis are still debated ^[3, 4].

Inbreeding depression—the decline in fitness that accompanies selfing—is the mirror image of heterosis. When an F_1 is selfed, favourable heterozygous loci become homozygous and yield drops, sometimes by more than 40% by the S_2 generation ^[5]. Quantifying both heterosis and inbreeding depression together gives breeders a clearer picture of gene action and helps predict the value of recycling lines from a given cross ^[6].

Most heterosis research in maize has focused on tropical or subtropical germplasm ^[7, 8]. Temperate programmes in North America rely heavily on a few established heterotic groups (Reid Yellow Dent $\times$ Lancaster Sure Crop), and there is a need to explore new inter-group combinations to broaden the genetic base ^[9].

This research was planned to

- Estimate mid-parent heterosis for yield and related traits in 15 single-cross hybrids derived from diverse Ontario inbred lines
- Measure inbreeding depression through two selfing generations.
- Identify the yield components that contribute most to heterosis.

Field Experimental Design

The trial was laid out at the Ontario College of Agriculture research farm, Guelph (43.53° N, 80.23° W; 334 m a.s.l.), on a Guelph silt loam soil. Fifteen F_1 hybrids, their 10 parental inbred lines, and the S_1 and S_2 generations of each cross were planted in a randomised complete block design with three replications during the 2022 and 2023 spring-summer seasons. Each plot consisted of two 5 m rows with 0.75 m inter-row spacing and 0.25 m intra-row spacing.

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Standard agronomic practices—basal fertiliser at 120-60-40 kg N-P₂O₅-K₂O ha⁻¹, mechanical weed control, and supplemental sprinkler irrigation when rainfall was below 25 mm per fortnight—were followed uniformly.

Climatic Conditions

The Guelph region has a humid continental climate (Köppen Dfb). During the 2022 season, mean temperatures ranged from 16.8 °C (May) to 23.4 °C (July), with cumulative rainfall of 381 mm from May to September. The 2023 season was slightly warmer (July mean 24.1 °C) and drier (cumulative rainfall 342 mm). Growing degree days (base 10 °C) accumulated to 1,487 in 2022 and 1,523 in 2023, both adequate for full-season maize maturity in southern Ontario.

Material and Methods

Material: Ten inbred lines (OCA-1 through OCA-10) representing five flint and five dent backgrounds were crossed in a partial diallel to produce 15 single-cross F₁

hybrids. Seeds of each F₁ were selfed to obtain S₁ and S₂ generations. All seed lots were produced at the Ontario College of Agriculture seed increase nursery in 2021. Reference check hybrids included two commercial cultivars widely grown in southern Ontario.

Methods

Grain yield (t ha⁻¹ at 15% moisture), ear length (cm), kernel rows per ear, 1000-grain weight (g), plant height (cm), and days from planting to 50% silking were recorded on 10 competitive plants per plot. Mid-parent heterosis (MPH) was calculated as $[(F_1 - MP)/MP] \times 100$, where MP is the mean of the two parents. Inbreeding depression (ID) was estimated as $[(F_1 - S_n)/F_1] \times 100$ for each selfed generation. The relative contribution of each trait to overall heterosis was computed following the method of Singh and Chaudhary [10]. Data were analysed using ANOVA (SAS 9.4) and means separated by Duncan's multiple range test at $p \leq 0.05$.

Results

Table 1: Mid-parent heterosis (%) for grain yield and yield-related traits in selected maize hybrids (pooled 2022–2023)

Cross	Grain yield	Ear length	Kernel rows	1000-grain wt	Plant height	Days to silk
OCA-7 × OCA-12	47.6	23.1	18.7	12.4	9.3	-3.8
OCA-3 × OCA-9	41.2	19.8	15.3	14.1	11.7	-2.1
OCA-1 × OCA-10	38.9	17.4	12.9	10.8	8.6	-4.2
OCA-5 × OCA-8	29.7	14.2	9.6	8.3	6.1	-1.7
OCA-2 × OCA-6	18.3	8.7	6.4	5.9	3.8	-0.9
Range	18.3–47.6	8.7–23.1	6.4–18.7	5.9–14.1	3.8–11.7	-0.9 to -4.2

Values are means of two seasons and three replications. Negative heterosis for days to silking indicates earlier maturity in hybrids.

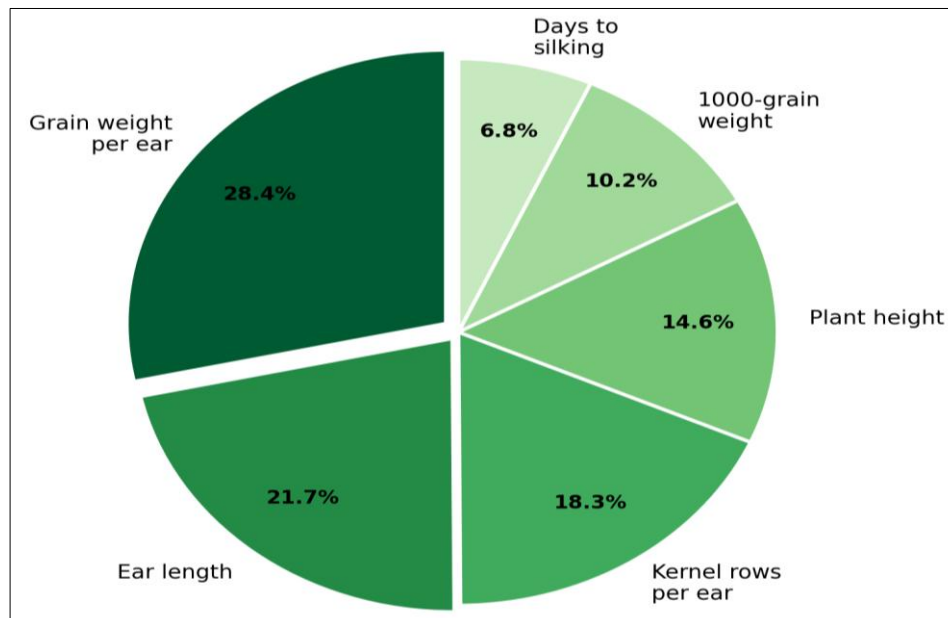


Fig 1: Relative contribution (%) of individual yield components to mid-parent heterosis for grain yield in 15 maize hybrids

Table 2: Inbreeding depression (%) for grain yield across selfing generations (pooled 2022–2023)

Cross	F ₁ yield (t ha ⁻¹)	ID in S ₁ (%)	ID in S ₂ (%)	Yield drop F ₁ → S ₂ (t ha ⁻¹)
OCA-7 × OCA-12	9.84	21.3	42.8	4.21
OCA-3 × OCA-9	9.17	23.7	47.1	4.32
OCA-1 × OCA-10	8.63	19.8	39.6	3.42
OCA-5 × OCA-8	7.91	25.1	51.7	4.09
OCA-2 × OCA-6	6.74	17.2	29.4	1.98
Mean	8.46	21.4	42.1	3.60

ID = inbreeding depression, calculated as $[(F_1 - S_n)/F_1] \times 100$.

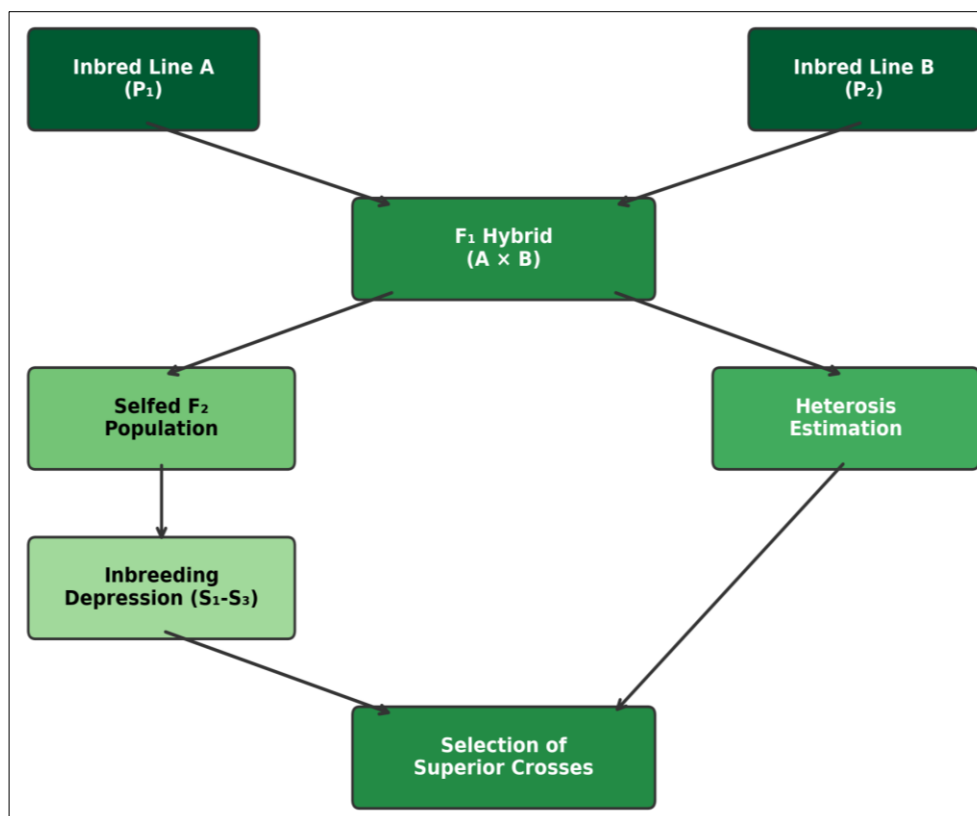


Fig 2: Schematic pathway from parental inbred lines through F₁ hybrid evaluation, selfing, and heterosis–inbreeding depression estimation

Comprehensive Interpretation

Heterosis for grain yield varied widely (18.3–47.6%), and the highest MPH consistently appeared in flint × dent crosses, particularly OCA-7 × OCA-12. Grain weight per ear was the single largest contributor (28.4%) to overall heterosis, followed by ear length (21.7%) and kernel rows (18.3%). Inbreeding depression intensified sharply from S₁ (mean 21.4%) to S₂ (mean 42.1%), with the cross OCA-5 × OCA-8 losing more than half its F₁ yield by S₂. In contrast, OCA-2 × OCA-6 showed the least ID (29.4% at S₂), suggesting that this cross harboured fewer heterozygous loci with large dominance effects.

Discussion

The range of MPH observed here (18.3–47.6%) falls within the values reported for temperate maize programmes elsewhere. Hallauer *et al.* [3] documented 20–55% mid-parent heterosis across North American dent populations, and the present data are consistent with that range. The strong heterotic response in flint × dent crosses supports the well-established principle that genetic distance between parental pools drives heterosis [4, 11].

The steep rise in inbreeding depression from S₁ to S₂ was expected, as each cycle of selfing exposes an additional 50% of heterozygous loci [5]. The cross OCA-5 × OCA-8, which lost 51.7% of yield by S₂, appears to carry many dominance-type loci; recycling inbred lines from this cross would require careful progeny testing. On the other hand, OCA-2 × OCA-6, with only 29.4% ID, may harbour additive gene action that could be captured through recurrent selection [12]. One limitation is that only two selfing generations were tested; extending to S₃ or S₄ would clarify whether ID plateaus or continues to accumulate. And because the trial was limited to one location, genotype × environment interaction couldn't be partitioned fully [13].

Conclusion

Mid-parent heterosis for grain yield ranged from 18.3% to 47.6% across 15 maize hybrids, with the highest values in flint × dent combinations. Grain weight per ear was the most influential component, contributing 28.4% to overall heterosis. Inbreeding depression doubled from S₁ (21.4%) to S₂ (42.1%), highlighting the dominance-driven nature of yield heterosis in this germplasm. The cross OCA-7 × OCA-12 combined the highest heterosis with moderate inbreeding depression, making it the most promising candidate for hybrid development. Extending selfing generations and multi-location testing would strengthen these conclusions.

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