

ASSESSMENT OF HETEROSIS PERFORMANCE IN SUNFLOWER HYBRIDS DERIVED FROM INBRED PARENTAL LINES

Danil-Marian STANCIU, Lizica SZILAGYI, Costică CIONTU

University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd,
District 1, 011464, Bucharest, Romania

Corresponding author email: danil.stanciu@agro.usmav.ro

Abstract

*This study investigates the expression of heterosis in sunflower (*Helianthus annuus* L.) hybrids by analyzing their performance in comparison with newly developed parental inbred lines. The experiment was conducted under field conditions in Romania, within the experimental fields of the Agricultural Research Company Fundulea. A total of four sunflower hybrids and their corresponding parental inbred lines were evaluated. Key agronomic traits, including seed yield and selected morphological characteristics, were recorded and subjected to statistical analysis. Heterosis effects were quantified relative to both mid-parent and better-parent values, providing a comprehensive assessment of hybrid vigor. The results indicated consistent positive heterosis across most traits, with several hybrids surpassing their parental lines. Significant differences among genotypes ($p < 0.05$) emphasized the influence of genetic background on heterosis expression. Variability among hybrid combinations further highlighted the importance of selecting genetically diverse and complementary parental lines for breeding programs.*

Key words: sunflower hybrids, heterosis, inbred lines, hybrid vigor, genetic variability.

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the most important oilseed crops worldwide, playing a key role in vegetable oil production due to its high oil content and adaptability to diverse environmental conditions (Seiler, 2007; Kaya et al., 2009). The increasing global demand for vegetable oils has intensified the need for developing high-yielding and stable sunflower hybrids (Skoric et al., 2007).

One of the most efficient approaches to improve crop performance is the exploitation of heterosis, also known as hybrid vigor. Heterosis refers to the superior performance of hybrid offspring compared to their parental lines, particularly in terms of yield, growth rate, and stress tolerance (Shull, 1908; Hochholdinger & Hoecker, 2007). The magnitude of heterosis is strongly influenced by the genetic divergence between parental lines and their combining ability (Melchinger, 1999).

The development of inbred lines is a fundamental step in hybrid breeding programs. Through repeated self-fertilization, a high degree of homozygosity is achieved, allowing the fixation of desirable traits and the creation of

genetically stable parental forms (Wright et al., 2013). These inbred lines serve as the genetic basis for hybrid combinations, where their interaction determines the level of heterosis expressed.

In sunflower breeding, fertility restorer (Rf) lines are essential for the production of commercial hybrids, especially when used in combination with cytoplasmic male sterile (CMS) lines (Skoric et al., 2007). The selection of genetically diverse and complementary parental lines is crucial for maximizing heterosis and improving agronomic performance.

Given the importance of hybrid vigor in increasing productivity, it is necessary to evaluate the performance of newly developed inbred lines and their hybrid combinations under field conditions. Such studies provide valuable information regarding the efficiency of breeding methods and the potential of genetic material for future breeding programs.

Therefore, the aim of this study was to assess the expression of heterosis in sunflower hybrids derived from newly developed inbred parental lines. The research focused on the evaluation of key agronomic traits, including yield and oil-related parameters, in order to identify superior

hybrid combinations and to highlight the influence of genetic background on heterosis expression.

MATERIALS AND METHODS

Study location and experimental conditions

The research was conducted in 2025 under field conditions within the Agricultural Research Company Fundulea, located in Fundulea, Călărași County, Romania. The specific pedoclimatic conditions of the area allowed the evaluation of the biological material under conditions representative for sunflower cultivation.

Biological material

The biological material used in the study consisted of commercial sunflower hybrids and inbred lines originating from both commercial sources and a gene bank.

In order to obtain inbred lines through self-fertilization, the commercial hybrids *Suria* and *Andrada* (Ciproma) were used. Self-fertilization was carried out over several generations with the aim of increasing homozygosity and stabilizing genetic traits.

Development of inbred lines

Two breeding approaches were applied to develop inbred lines:

1. Self-fertilization method

This method involved repeated self-pollination of the selected hybrids (*Suria* and *Andrada*) across successive generations to achieve genetic stabilization and a high degree of homozygosity.

2. Hybridization followed by selfing

The second method consisted of crossing fertility restorer (Rf) inbred lines followed by self-fertilization in subsequent generations. The following combinations were performed:

- CONFSCCL-R6 (female parent, emasculated) × RHA-480 (pollen donor);
- RF-3023 (female parent, emasculated) × RHA-478 (pollen donor).

The parental lines used in these crosses were obtained from the Gene Bank of the United States of America and are recognized for their genetic value in sunflower breeding programs.

Controlled pollination and line stabilization

Controlled pollination was performed manually by emasculating the female parental lines

(CONFSCCL-R6 and RF-3023) and applying pollen from the donor lines to obtain F₁ hybrids. The resulting biological material was subsequently subjected to repeated self-fertilization in order to fix traits and obtain stable inbred lines.

Obtained inbred lines

Following the application of the breeding methods, several inbred lines with high genetic potential were developed:

- LC-853 (derived from hybrid *Suria*);
- LC-861 (derived from hybrid *Andrada*);
- LC-623 (from CONFSCCL-R6 × RHA-480);
- LC-635 (from RF-3023 × RHA-478).

Hybridization scheme

The obtained inbred lines were used as male parental forms in hybridization schemes. These were crossed with three cytoplasmic male sterile (CMS) tester lines:

- LC-492-A;
- LC-411-A;
- LC-485-A.

These CMS lines served as female parents for the production of experimental hybrids.

Experimental hybrids

As a result of the crosses, the following hybrids were obtained:

- HS-56/24 = LC-492-A × LC-853;
- HS-76/24 = LC-411-A × LC-861;
- HS-13/24 = LC-492-A × LC-623;
- HS-32/24 = LC-485-A × LC-635.

These hybrids were further evaluated for combining ability and heterosis expression.

Traits evaluated and statistical analysis

A set of key agronomic traits was evaluated in order to assess the performance of the parental lines and their corresponding hybrids. The analyzed traits included plant height (cm), stem diameter (cm), number of leaves per plant, head diameter (cm), seed weight per head (g), number of seeds per head, thousand kernel weight (TKW, g), hectoliter mass (Mh), seed yield (kg/ha), oil content (%), and oil yield per hectare (kg/ha).

The recorded data were used to evaluate the expression of heterosis in the studied hybrid combinations. Heterosis was estimated by comparing hybrid performance with both parental lines, considering mid-parent values and better-parent values as reference points.

Descriptive statistical analysis was applied to characterize the variability of the studied traits. In addition, an analysis of variance (ANOVA) was performed in order to evaluate the significance of differences between genotypes. The significance of differences was assessed at the level of $p < 0.05$.

The analysis focused on highlighting the magnitude of heterosis for yield-related traits, as well as the contribution of parental lines to hybrid performance. Special attention was given to seed yield and oil yield per hectare, as these represent the most important economic traits in sunflower cultivation.

RESULTS AND DISCUSSIONS

Analysis of hybrid HS-56/24

For hybrid HS-56/24, all evaluated traits showed superior values compared to both parental lines, indicating a strong expression of heterosis, according to Table 1.

The most relevant trait, seed yield, recorded a value of 3914 kg/ha, significantly higher than both parental lines (1579 kg/ha and 351 kg/ha). The analysis of variance (ANOVA) indicated that these differences were statistically significant ($p < 0.05$).

Table 1. Agronomic traits of parental lines and F1 hybrid (HS-56/24)

Trait	LC-492-A (♀)	LC-853 (♂)	F1 (HS-56/24)
Plant height (cm)	107	126	157
Stem diameter (cm)	1.5	1.7	2.5
Number of leaves	18	17	20
Head diameter (cm)	17.5	11	22.9
Seed weight per head (g)	39.98	8.18	105.6
Number of seeds per head	951	780	1528
Thousand kernel weight (g)	42	26.2	65.8
Hectoliter mass (Mh)	40.9	31.5	44.3
Seed yield (kg/ha)	1579	351	3914
Oil content (%)	49.55	37.91	46.04
Oil yield (kg/ha)	792	133	1803

The calculated mid-parent heterosis reached +305.6%, while better-parent heterosis was +147.8%, indicating a very strong heterotic effect for productivity. Similar trends have been

reported in previous studies, where significant positive heterosis for seed yield and yield-related traits was observed in sunflower hybrids (Abdel-Rahem et al., 2021).

The superior performance of this hybrid was also reflected in key yield components such as head diameter, seed number, and seed weight per head, which are known to be strongly influenced by heterosis, as reported in the literature.

Analysis of hybrid HS-76/24

Hybrid HS-76/24 showed strong vegetative development and high productivity, exceeding both parental lines for most traits, according to Table 2.

Seed yield reached 4007 kg/ha, compared to 1657 kg/ha and 376 kg/ha in the parental lines. The analysis of variance (ANOVA) confirmed that the differences between the hybrid and its parental lines were statistically significant ($p < 0.05$).

The calculated mid-parent heterosis was +294.2%, while better-parent heterosis reached +141.7%.

This hybrid also recorded the highest plant height and number of leaves, indicating strong vegetative vigor, which contributed to increased yield potential. These findings are in agreement with previous studies, which highlighted that vegetative traits such as plant height and leaf number are positively correlated with hybrid performance (Kaya et al., 2009).

Table 2. Agronomic traits of parental lines and F1 hybrid (HS-76/24)

Trait	LC-411-A (♀)	LC-861 (♂)	F1 (HS-76/24)
Plant height (cm)	104	112	160
Stem diameter (cm)	2,1	1,7	2,2
Number of leaves	16	17	26
Head diameter (cm)	18	12.5	24.7
Seed weight per head (g)	36.26	8.77	80.8
Number of seeds per head	603	1076	1554
Thousand kernel weight (g)	60.1	20	52
Hectoliter mass (Mh)	34.5	41.4	40.8
Seed yield (kg/ha)	1657	376	4007
Oil content (%)	48.8	44.35	46.04
Oil yield (kg/ha)	808	167	1844.8

Analysis of hybrid HS-13/24

Hybrid HS-13/24 exhibited a balanced performance across all traits, with particularly strong results for reproductive characteristics, according to Table 3.

Seed yield reached 3963 kg/ha, compared to 1599 kg/ha and 742 kg/ha in the parental lines. Statistical analysis (ANOVA) revealed significant differences among genotypes for this trait ($p < 0.05$).

The calculated mid-parent heterosis was +238.6%, while better-parent heterosis was +147.9%.

This hybrid also showed the highest oil yield per hectare (1863 kg/ha), indicating its strong economic potential. Similar observations have been reported in the literature, where moderate heterosis for oil content combined with high seed yield leads to significant increases in oil production per unit area (Ebrahimi et al., 2021).

Table 3. Agronomic traits of parental lines and F1 hybrid (HS-13/24)

Trait	LC-492-A (♀)	LC-623 (♂)	F1 (HS-13/24)
Plant height (cm)	107	110	125
Stem diameter (cm)	1.5	1	2.3
Number of leaves	18	17	24
Head diameter (cm)	17.5	9.5	24.6
Seed weight per head (g)	39.98	18.57	115.7
Number of seeds per head	951	719	1987
Thousand kernel weight (g)	42	25.8	58.2
Hectoliter mass (Mh)	40.9	48.6	44.5
Seed yield (kg/ha)	1599	742	3963
Oil content (%)	49.55	17.62	47
Oil yield (kg/ha)	792	353	1863

Analysis of hybrid HS-32/24

Hybrid HS-32/24 showed the highest overall performance among all studied hybrids, according to Table 4.

Seed yield reached 4203 kg/ha, compared to 2755 kg/ha and 843 kg/ha in the parental lines. The analysis of variance (ANOVA) indicated that these differences were statistically significant ($p < 0.05$).

The calculated mid-parent heterosis was +133.6%, while better-parent heterosis was +52.6%.

Although heterosis percentages were lower compared to other hybrids, the absolute yield

was the highest, indicating superior genetic potential. This supports previous findings that high-performing parental lines may lead to lower heterosis values but higher absolute productivity (Melchinger, 1999).

Table 4. Agronomic traits of parental lines and F1 hybrid (HS-32/24)

Trait	LC-485-A (♀)	LC-635 (♂)	F1 (HS-32/24)
Plant height (cm)	120	125	145
Stem diameter (cm)	1.6	1.5	2.3
Number of leaves	22	18	26
Head diameter (cm)	19.5	10.5	25
Seed weight per head (g)	68.4	21.9	120.6
Number of seeds per head	1108	1004	2057
Thousand kernel weight (g)	61.7	21	59.8
Hectoliter mass (Mh)	44.6	54	44
Seed yield (kg/ha)	2755	843	4203
Oil content (%)	48.89	41.43	44
Oil yield (kg/ha)	1347	349	1850

Comparative analysis of hybrids

A comparative evaluation of the four hybrids highlights important differences in heterosis expression depending on the genetic background of parental lines, according to Figure 1.

The statistical analysis confirmed significant variability among hybrid combinations ($p < 0.05$), highlighting the influence of genetic background on heterosis expression.

Hybrids HS-56/24 and HS-76/24 showed the highest heterosis values, suggesting a strong genetic divergence between parental lines. In contrast, HS-32/24, although having the highest yield, showed lower heterosis percentages, indicating a closer genetic relationship between its parental lines.

Hybrid HS-13/24 demonstrated a balanced performance, combining high yield with the highest oil production, making it particularly valuable from an economic perspective.

These results are consistent with previous research indicating that heterosis expression varies significantly among hybrid combinations depending on the combining ability of parental genotypes (Skoric et al., 2007).

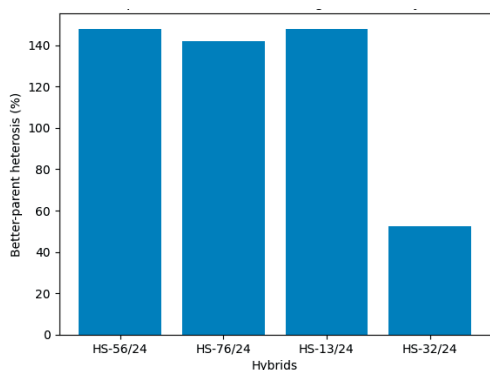


Figure 1. Comparison of heterosis (better-parent %) among sunflower hybrids

Influence of breeding method

The results clearly indicate that the breeding method significantly influenced the expression of heterosis.

Hybrids derived from crosses between genetically distant parental lines showed higher heterosis values, confirming that genetic divergence is a key factor in hybrid performance. Similar conclusions have been reported in sunflower breeding studies, where parental diversity was identified as a major determinant of heterosis expression (Hochholdinger & Hoecker, 2007).

In contrast, hybrids obtained from less divergent parental material showed lower heterosis, even if absolute productivity remained high.

These findings emphasize the importance of selecting appropriate breeding strategies and parental combinations in order to maximize hybrid performance and improve sunflower productivity.

CONCLUSIONS

The present study highlighted the significant role of genetic background and breeding strategy in the expression of heterosis in sunflower hybrids.

The experimental results demonstrated that all analyzed hybrids outperformed their parental lines for the majority of evaluated traits, particularly for seed yield and yield components, confirming the efficiency of hybrid breeding in sunflower.

The highest heterosis values were recorded in hybrids HS-56/24 and HS-76/24, indicating that crosses between genetically divergent parental

lines lead to a strong heterotic response. These findings confirm that genetic distance between parental genotypes is a key factor influencing hybrid performance.

Hybrid HS-32/24, although exhibiting the highest absolute seed yield, showed lower heterosis values, suggesting that high-performing parental lines may reduce the magnitude of heterosis while still ensuring superior productivity. This result emphasizes the importance of distinguishing between heterosis expression and absolute performance. Hybrid HS-13/24 showed a balanced performance, combining high seed yield with the highest oil yield per hectare, highlighting its potential for both agronomic and economic efficiency.

Statistical analysis (ANOVA) confirmed the existence of significant differences among hybrids ($p < 0.05$), validating that the observed variations are genetically determined and not due to random environmental factors.

Overall, the results demonstrate that the choice of breeding method and parental combinations plays a crucial role in maximizing hybrid performance. The use of genetically diverse parental lines is recommended when the objective is to enhance heterosis, while the use of elite parental material may ensure high absolute productivity.

These findings contribute to the optimization of sunflower breeding programs by providing practical insights into the relationship between genetic background, heterosis expression, and yield performance.

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