Original Article

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Multivariate analysis for the development of an ideotype of ornamental sunflower (*Helianthus annuus* L.) in the autumn season

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Abstract

The development of an ideotype of ornamental sunflower (*Helianthus annuus* L.) in autumn has a strategic value because few flowers are available in autumn. This study was conducted to assess the genetic diversity and elite lines that perform better in the autumn season. The target ideotype for autumn production was predefined as a compact-to-medium plant stature, multiple heads per plant, a medium-to-large head diameter, a sturdy stem, and early flowering, and genotypes were subsequently screened against these criteria. To fill this gap, 28 multi-headed genotypes that are genetically different were evaluated under semi-controlled conditions of pot culture in a completely randomized design (CRD) with three replications at the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan. Data were recorded on different parameters such as: Plant height, Stem diameter, Head diameter, Number of heads per plant, Number of leaves and leaf width. Analysis of variance (ANOVA) revealed highly significant variation for all the recorded traits, which substantially shows that there is high genetic variability in the germplasm. Correlation analysis revealed that vegetative traits were strongly and positively correlated with each other, whereas head diameter demonstrated negative correlations with most parameters, which provided evidence of a resource allocation trade-off between vegetative vigor and floral display. Principal component analysis accounted for 53.3 percent of overall variance in the first two components and hierarchical cluster analysis, validated by silhouette analysis, organized the genotypes into two separate phenotypic groups, with Cluster I having homogeneous ideotype-proximate materials and Cluster II having divergent genotypes that could be candidates to provide new combination of traits. The ornamental sunflower ideotype was a medium to small plant height, multiple heads per plant, medium to large diameter of the head, strong stem, and early flowering. Direct selection with genotypes similar to this ideotype is suggested, and divergent members of a cluster are to be utilized as parents in hybridization programs to obtain better ornamental sunflower varieties. As this study was based on pot-grown plants evaluated for morphological and phenological traits only, field validation and assessment of additional ornamental attributes such as flower color, ray floret characteristics and vase life are recommended before commercial deployment.

Keywords: Ornamental Sunflower, Autumn Ideotype, Multivariate Analysis, Genetic Diversity, Cluster Analysis, Principal Component Analysis

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Introduction

Sunflower (*Helianthus annuus* L.) is one of the widely cultivated crops, an important source of oilseeds, and also used as an ornamental plant with conspicuous inflorescences, a wide range of ray floret colors, and a versatile plant structure that enables it to be used both in gardens and in containers, and as cut flowers (1). Ornamental production is mainly based on visual characteristics, including the petal color, size and shape of the head, the height of the plant, and its branching intensity, which have shown great variability in the production of ideotypes of ornamental plants adapted to various ornamental uses (2). An ideotype concept, which describes as an ideal or model plant to be used in particular environments and applications, provides a systematic guide to the enhancement of ornamental sunflowers. Ideotypes in sunflower have been measured in the agronomic characteristics of plant height, capitulum area, maturity, yield, and oil content under specified environmental conditions (3).

Approaches based on ideotypes have also been used in the domestication and neo-domestication of annual and perennial Helianthus, in which possible combinations of branching architecture, capitulum morphology and flowering time are designed to balance domesticated types of shoots with perennial or stress-adaptive phenotypes (4). Such studies establish the fact that ideotypes can be described in quantifiable terms as morphological and phenological combinations and subjected to quantitative genetic and multivariate analyses. (5).

Such ideotypes are empirically defined by genetic diversity and trait relation (6). Many studies on sunflower germplasm have indicated high variation of major morphological characteristics, such as plant height, stem diameter, leaf number, head diameter, and flowering time, and have employed analysis of variance, cluster analysis and principal component analysis to cluster genotypes and to provide promising parents in breeding (7). Parallel multivariate studies of ornamental sunflower have revealed that branching, head size and flowering characteristics are significant sources of decorative value and can be used to define ideotypes of cut, garden or pot production (8).

Ideotype design is another aspect that is added by seasonal adaptation. As a spring-grown rainfed crop, sunflower is also sensitive to temperature and water regime during flowering and flowering time has a strong impact on yield formation and overall performance (9). The changes to other sowing windows and other cropping systems such as low-input and more ecological systems should alter the trait combinations demanded by future sunflower ideotypes not only to yield, but also to ecosystem services and diversified end uses (10). In the case of decorative sunflowers, the timing of production during the fall is strategically valuable due to the scarcity of flowers during this time. Still, lower temperatures and changed photoperiodism may interfere with vegetative development, head development, and flowering timings.

Published studies of ornamental variability and of genetic diversity of sunflower show the extent of germplasm available and the utility of multivariate techniques (ANOVA, clustering, correlation and principal components) in defining better genotypes and in measuring trait associations (11, 7). It is on this basis that the current research will (i) define morphological diversity in ornamental sunflower, (ii) come up with an ideotype of ornamental sunflower that fits the autumn production conditions and (iii) to identify promising genotypes with desired ornamental characters and also adapted performance under such conditions.

Materials and Methods

The experiment was carried out in the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan. Faisalabad has a semi-arid climate with very hot summer temperatures of 45–50°C in May and cold, dry winters with temperatures of 4.0°C in January (Figure 1). This experiment was conducted in a semi-controlled pot culture with the aim that the soil conditions, moisture level, and the plant placement would remain uniform. Pots measuring 30 cm diameter × 35 cm height were filled with a mixed composition of sandy-loam soil, sand and farmyard manure. The main objective was to evaluate the morphological and agronomic traits of multiheaded sunflower (*Helianthus annuus* L.) genotypes and to identify superior ornamental characteristics along with potential for small-scale seed production.

In this experiment, twenty-eight genetically diverse multiheaded sunflower genotypes were evaluated in pots in a completely randomized design (CRD) with three replications, resulting in a total of eighty-four pots. Four seeds per genotype were sown in each pot and after germination, thinning was carried out at the first true-leaf stage to retain two healthy plants per pot. Uniform agronomic practices were followed throughout the season, including regular watering, manual weeding, and appropriate pest and disease control measures as needed. Two plants per genotype were randomly selected and data was recorded. The recorded parameters included the number of flowers per plant, head diameter (cm), number of leaves per plant, leaf width (cm), plant height (cm) measured from ground to head base, and stem diameter (cm) measured from the bottom of the plants.

The recorded data were subjected to ANOVA. After that, a correlation analysis was conducted to determine the relationship between traits. Standardized trait values were subjected to principal component analysis (PCA) to identify the key contributors to variability among genotypes, and scree plots were used to determine the number of significant components. The cluster analysis was carried out using the Euclidean distance and Ward linkage to cluster genotypes according to their profiles of multivariate traits. Cluster stability and the appropriate number of clusters (k = 2) were validated using average silhouette width analysis. The morphological and phenological ideotype criteria evaluated in this study (compact stature, multiple heads, medium-to-large head size, sturdy stem and early flowering) were adopted a priori from previously reported ornamental and agronomic sunflower ideotype frameworks; ornamental attributes not measured here (flower/ray floret colour, flowering duration, uniformity, branching pattern and post-harvest vase life) fall outside the scope of the present pot-based screening and are noted as a limitation in the Discussion. All the analyses and visualizations were conducted under the R program.

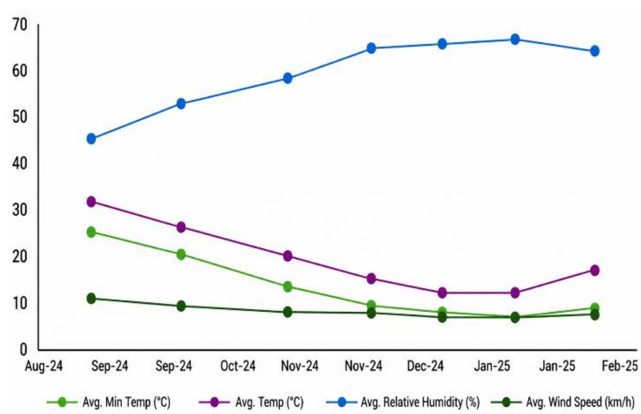

Figure 1. Weather conditions of autumn season 2024-25

Results

The Analysis of Variance (ANOVA) for ornamental traits of *Helianthus annuus* evaluated during the autumn season is presented in Table 1. The results revealed highly significant differences among genotypes for all the characteristics studied carried out, including plant height, days to flowering, head diameter, leaf length and width and number of heads per plant. The significant mean squares indicate substantial genetic variability among the evaluated genotypes. This variability provides a strong foundation for effective selection and ideotype development of an ornamental sunflower suited to autumn cultivation. Overall, the findings confirm that the available germplasm has considerable potential to develop a compact, uniform, early-flowering, and visually attractive ornamental sunflower with improved decorative quality and extended post-harvest longevity.

Analysis of variance revealed highly significant ($P \leq 0.01$) differences among the 28 sunflower genotypes for all traits studied, confirming substantial genetic variability in the screened germplasm, and mean comparison using Tukey's HSD test grouped the genotypes into distinct statistical classes for each trait (Figure 2); leaf length ranged from 6.80 (L13) to 20.03 cm (L11), with L11 significantly superior, while leaf width followed a similar trend, being highest in L11 (12.47 cm) and lowest in L2 (4.50 cm); number of heads per plant, a key trait for multi-headed types, varied from 3.57 to 16.33, with L27 forming a distinct top group, whereas stem diameter ranged narrowly (3.00–5.87 cm), with L27 and L26 statistically superior; number of leaves per plant was highest in L1 (35.00) and lowest in L5 (15.50), and plant height ranged from 97.33 (L23) to 163.67 cm (L11), with L11, L10 and L2 forming the tallest group; days to flowering, important for autumn adaptability, ranged from 55.63 (L20) to 70.93 (L25), with L20, L28 and L11 flowering earliest, while head size varied from 2.40 (L28) to 8.87 cm (L8), with L8 significantly superior; overall, L11, L27 and L8 consistently performed best across traits, whereas L20, L28 and L13 showed early flowering and compact plant type, making them suitable for autumn cultivation.

Pearson correlation analysis among morphological traits (Figure 3) was performed to identify trait associations relevant to the development of an ideal ornamental plant type (ideotype) for the autumn season. A strong positive correlation was observed between leaf length (LL) and leaf width (LW) (r = 0.68), followed by moderately positive associations between LW and number of heads (NOH) (r = 0.61), NOH and stem diameter (SD) (r = 0.56), LL and NOH (r = 0.50), and LW and SD (r = 0.46), indicating that genotypes with better vegetative growth also tended to produce more heads on thicker stems, a desirable combination for multi-headed ornamental types. LL showed a further positive association with SD (r = 0.30), while plant height (PH) exhibited weak positive correlations with SD (r = 0.25), number of leaves (NOL) (r = 0.25) and LL (r = 0.19), suggesting that moderate increases in vegetative traits contribute to a compact, well-proportioned plant architecture suited for ornamental display. In contrast, head size (HS), a key ornamental quality trait, showed consistent negative correlations with NOH (r = -0.44), LL (r = -0.41), LW (r = -0.18) and SD (r = -0.17), revealing a trade-off between the number of heads and the size of individual heads that must be balanced when selecting an ideotype. Days to flowering (DTF), a critical trait for autumn-season adaptability, was negatively correlated with PH (r = -0.31), LL (r = -0.21) and NOH (r = -0.19), indicating that early-flowering genotypes, favorable for autumn cultivation, tend to be shorter with fewer heads, while its association with HS (r = 0.01) and SD (r = 0.02) was negligible.

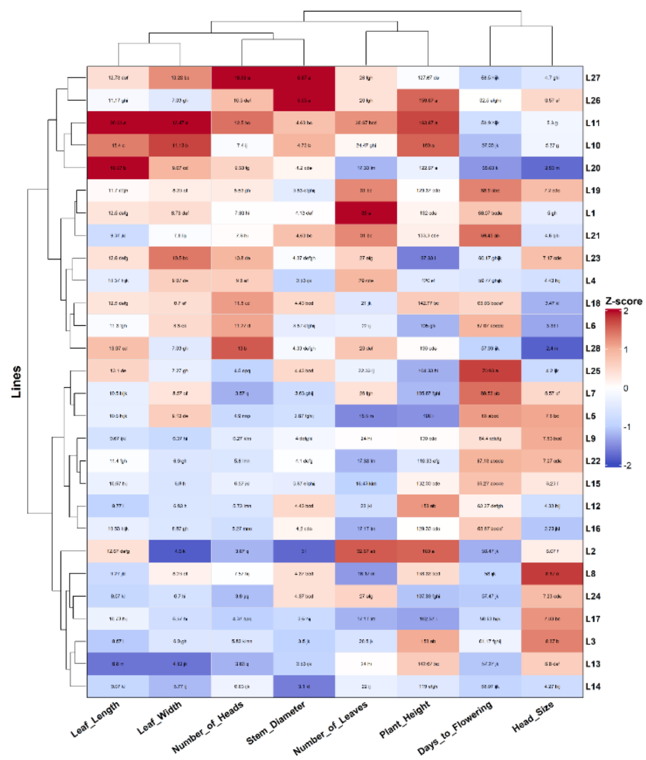

Figure 2. Hierarchical heat map of sunflower lines with Tukey's HSD grouping

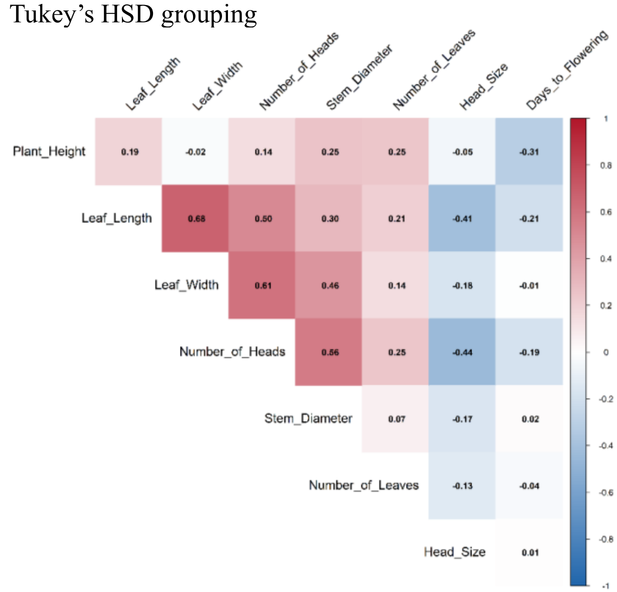

Figure 3. Pearson correlation matrix among morphological traits

Table 1. Mean squares and F-values from analysis of variance for plant height (PH), leaf length (LL), leaf width (LW), stem diameter (SD), number of leaves (NoL), head diameter (HD) and days to flowering (DTF) in 28 ornamental sunflower genotypes. **Significant at $P \leq 0.01$ (F-critical, df 27,56 = 2.03).

SOV	DF	PH	LL	LW	SD	NoL	HD	DTF
Lines	27	1181.98**	23.775**	10.0897**	1.18851**	89.3663**	9.517**	68.36**
Error	56	21.97	0.231	0.0862	0.02274	0.8762	0.054	2.284
Total	83							
F-value (Lines/Error)		53.80**	102.92**	117.05**	52.27**	101.99**	176.24**	29.93**

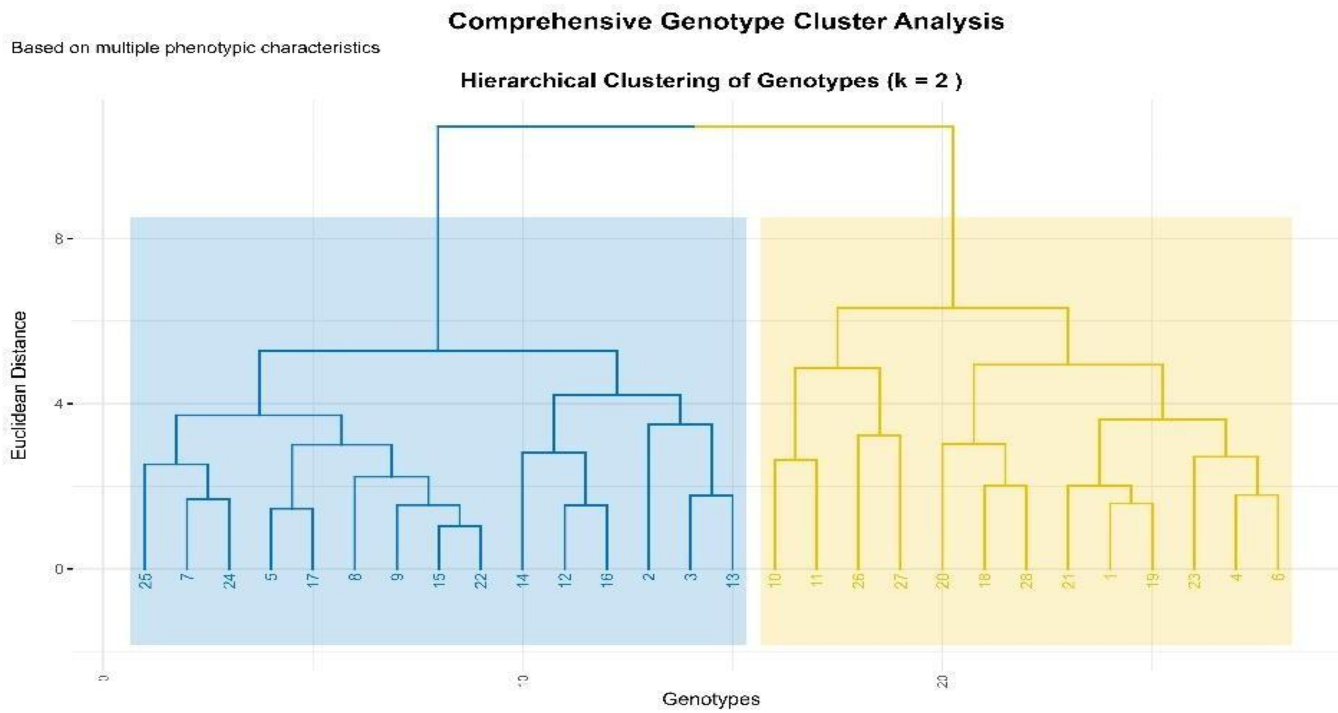

Figure 4. Hierarchical Clustering of 28 Sunflower Genotypes Based on Phenotypic Traits

These correlation patterns suggest that an ideal ornamental sunflower ideotype for the autumn season should combine early flowering, moderate plant height, an optimal number of heads, and reasonably large head size, and that simultaneous improvement of these traits requires careful selection to manage the observed trade-offs, particularly between head number and head size.

Hierarchical cluster analysis based on multiple phenotypic characteristics grouped the 28 screened sunflower genotypes into two major clusters (k = 2) at a Euclidean distance of approximately 9.0, reflecting the overall genetic divergence within the germplasm evaluated for ideotype development (Figure 4). Cluster I comprised 15 genotypes (L25, L7, L24, L5, L17, L8, L9, L15, L22, L14, L12, L16, L2, L3 and L13), which further separated into two sub-clusters at a distance of about 5.0, while Cluster II included 13 genotypes (L10, L11, L26, L27, L20, L18, L28, L21, L1, L19, L23, L4 and L6), similarly divided into two sub-groups at a comparable distance. The clear separation of genotypes into two distinct clusters indicates the presence of considerable phenotypic diversity among the accessions, with genotypes within each cluster sharing greater similarity for the morphological traits studied. This clustering pattern provides a useful basis for parental selection in breeding programs, as genotypes from divergent clusters, such as those consistently identified as superior performers (e.g., L11, L27, L20 in Cluster II and L25, L2 in Cluster I), may be crossed to combine complementary traits, such as early flowering, optimum head number, and desirable head size, toward the development of an improved ornamental sunflower ideotype suited for the autumn season.

Principal component analysis was used to classify the 28 sunflower genotypes into distinct ideotype groups based on their overall phenotypic profile, showing that PC1 and PC2 together accounted for 53.3% of the total variance (36.67% and 16.64%, respectively), providing an adequate basis for visualizing genotype grouping in two-dimensional space. PC1 was most strongly loaded by leaf length, leaf width and number of heads (vegetative-vigor axis), while PC2 was most strongly loaded by head diameter and days to flowering (floral-architecture axis) — please supply the exact loading/eigenvector values from the R output; based on the distribution of genotypes along these axes, four broad ideotype categories were identified (Figure 5): the "Multi-headed Vegetative" group, occupying the central region, comprised L1, L10, L11, L14, L16, L21, L23 and L25, characterized by strong vegetative growth combined with higher head number; the "Vigorous Ornamental" group, positioned toward the negative PC1 axis, included L2, L3, L13, L19 and L20, representing genotypes with pronounced vegetative vigor; the "Compact Late-flowering" group, on the positive PC1 side, consisted of L4, L7, L8, L15, L18, L24, L26 and L28, reflecting delayed flowering with relatively compact stature; and the "Large-headed Ornamental" group, extending further along the positive PC1 and negative PC2 directions, included L5, L6, L9, L12, L17, L22 and L27, representing genotypes with the largest head size, with a few genotypes (e.g., L4, L27, L19) falling within overlapping regions indicating intermediate phenotypes between neighboring ideotypes; this classification confirmed that no single genotype combined all desirable traits simultaneously, reinforcing the trade-off between vegetative vigor, head number, head size and flowering time observed in the correlation and biplot analyses, and suggesting that genotypes from the "Compact Late-flowering" and "Large-headed Ornamental" groups, such as L17, L28 and L6, could serve as promising base material for developing an early-flowering, moderately compact, large-headed ideotype for autumn-season ornamental sunflower cultivation, potentially through hybridization with vigorous types such as L20 or L13 to improve overall plant architecture.

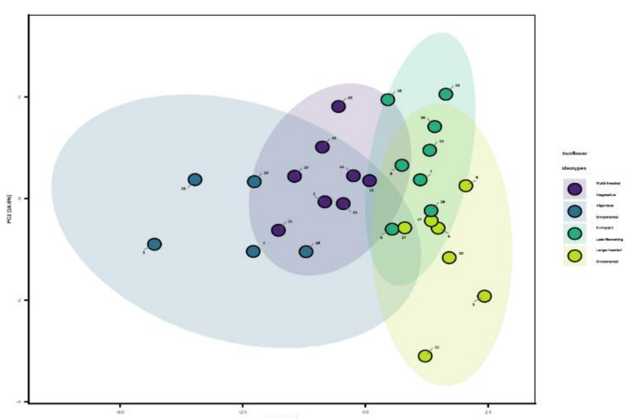

Figure 5. Principal component analysis (PCA) of 28 sunflower genotypes based on multiple phenotypic characteristics.

Discussion

The highly significant genotypic differences detected by ANOVA for plant height, days to flowering, head diameter, leaf dimensions and number of heads per plant demonstrate the presence of broad genetic variability in the autumn grown ornamental sunflower panel, in line with recent reports in both ornamental and agronomic sunflower germplasm (13, 14). Similar magnitudes of variation and significant mean squares have been observed for plant height, head diameter, flowering time and head number, with high genotypic and phenotypic coefficients of variation and generally high heritability, indicating that much of the variability is genetically controlled and only weakly influenced by the environment (15, 16). High heritability coupled with substantial genetic advance for plant stature, branching and head traits reported in ornamental and multiflower types suggests predominantly additive gene action, supporting the effectiveness of direct phenotypic selection for compactness, branching pattern and inflorescence size in ideotype breeding (17). The significant variability in days to flowering is particularly important for autumn cultivation, as recent studies have shown large genetic control of flowering time and its close association with yield and adaptation in both wild and cultivated sunflower (18). Likewise, variation in head size and number of heads per plant is consistent with contemporary findings that these traits are major contributors not only to yield but also to marketability and consumer preference in ornamental forms (19, 20). The combination of wide variability across all measured ornamental traits and the precedent of successful exploitation of similar variation in other sunflower breeding programs strongly supports the conclusion that the evaluated germplasm constitutes a valuable resource for developing compact, uniform, early flowering ornamental sunflower ideotypes with enhanced decorative quality and extended post-harvest longevity tailored to the autumn season (16, 21)

The correlation analysis among six morphological traits in ornamental sunflower indicates that vegetative growth attributes are closely interrelated, whereas head size tends to vary in the opposite direction, suggesting a trade-off between vegetative vigor and floral display. Positive relationships between leaf width, number of heads, and stem diameter, and moderate positive relationships between number of leaves and plant height indicate that more vigorous plants are likely to be thicker, leafier, and have more heads, which is corroborated by the results that productivity traits in sunflower have a positive relationship with plant height, number of leaves, and stem diameter (22, 23). The lack of correlation between plant height and leaf width may indicate that canopy expansion and vertical growth is partially independent and hence breeders can control plant height without always changing leaf width (24). Conversely, the correlation between head size and most vegetative characteristics was always negative (with the number of heads and leaf width showing the most significant association), which is in line with literature on the fact that relationships between head diameter and other characteristics or yield may change with genetic background and environment (and may switch to either positive or negative) (25, 26). This relationship can be explained as a resource allocation trade-off, with investment in bigger individual heads possibly being offset by vegetative growth or the number of heads as in trade-offs observed between head diameter, seed number and the gross yield structure in various sunflower germplasm (26). The fact that correlation coefficients are in agreement with the linear trends that are apparent in the scatter plots, as well as the fact that the distributions of the various traits are almost normal, suggests that such associations are statistically consistent; confirming whether they reflect a genuine physiological trade-off would require direct measurement of resource allocation, which was beyond the scope of this study. The findings, when taken together, point to the fact that ideotype design should be able to compromise between vegetative vigour and head architecture and should lean towards the combinations of moderate head size and vegetative support which is adequate to ensure both ornamental and plant strength (27).

The outcome of the clustering processes is that the 28 ornamental sunflower genotypes are in two major, although not entirely discrete, phenotypic groups. The Ward dendrogram with k = 2, as indicated by silhouette analysis, indicates that this partitioning gives a good balance between cluster homogeneity and cluster separation which is consistent with recent multivariate analysis in sunflower where 25 major clusters commonly absorb most of the exploitable diversity (28, 29). Cluster I contains more genotypes with relatively small within group distances, suggesting a more phenotypically uniform pool that could serve as a source of stable, ideotype like materials, whereas Cluster II holds fewer but more divergent genotypes, echoing findings where subgroups with greater internal variation are preferred as donors of novel alleles for key traits (14). The predominance of positive silhouette widths, especially in Cluster II, confirms that most genotypes are well assigned, but the lower or near zero values for some Cluster I entries and the slight overlap between ellipses in the PCA biplot point to a degree of continuity rather than strict boundaries between phenotypic classes, a pattern also reported in larger sunflower panels where clustering is not perfectly concordant with genetic or geographic origin (30-32). The first two principal components explaining 53.3% (PC1 = 36.7%, PC2 = 16.6%) of the variance is comparable to other sunflower studies where PC1–PC2 captured 47–65% of total variation and effectively separated genotypes along major agro morphological axes (33, 34). The clear separation of the two clusters mainly along Dim1 suggests that a limited set of correlated traits underlies the major phenotypic contrast, which could be exploited for constructing heterotic groups and for targeted parent choice to maximize ornamental trait divergence while maintaining sufficient overlap to permit transgressive segregation in subsequent generations (35).

It should be noted that the genotypes evaluated here (n = 28) were screened as multi-headed types under semi-controlled pot conditions with three replications; this sample size and container-based environment, while adequate for an initial diversity screen, may not fully represent genotype performance, plant vigor, or head architecture under open-field commercial ornamental production, and multi-location/multi-season field trials are recommended before the identified genotypes are advanced as parents or released as ideotype candidates. Similarly, because the present evaluation was restricted to vegetative and floral-architecture traits (plant height, stem diameter, head diameter, number of heads, leaf number and width, and days to flowering), it does not capture other determinants of ornamental value such as ray floret and disc colour, flowering duration and uniformity, branching pattern, or post-harvest vase life; these traits should be incorporated in future evaluations to build a more complete ornamental ideotype. Furthermore, autumn-specific environmental responses that determine ornamental persistence under fall conditions, such as temperature response, flowering stability under shortening photoperiod, and post-anthesis longevity, were not directly measured; days to flowering was used here only as a proxy for autumn adaptability, and this inference should be treated as preliminary until validated against direct environmental-response data. The correlation-based trade-off between vegetative vigor and head size discussed above is likewise a statistical association only; no physiological measurements (e.g., photosynthate partitioning, assimilate allocation) were collected in this study, and the resource-allocation explanation should therefore be regarded as a plausible working hypothesis rather than a demonstrated mechanism. Consequently, the direct-selection and hybridization strategies proposed below should be read as breeding hypotheses to be tested, rather than as recommendations validated across environments.

Conclusion

As the current research proves, the 28 ornamental sunflower genotypes under evaluation possess significant genetic diversity in all the major morphological and phenological characteristics, which forms a strong base to breed using ideotypes to suit production in the autumn season. On the basis of mean performance and multivariate groupings observed, genotypes L11, L27 and L8 were the most consistent top performers across traits and are proposed as the primary direct-selection candidates, while L20, L28 and L13 are highlighted for early flowering and compact habit suited to autumn timing; these should be regarded as breeding hypotheses pending field-level confirmation rather than as validated elite releases.

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Authors' Contribution Statements: AS and HR planned and conduct experiment. AS and MAZ write a manuscript on it. WH conducted a statistical analysis on R and ZN Proofread it.

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