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Combining Ability Analysis, Estimation of Heterosis and Some Genetic Parameters Using Half Diallel Cross in Bread wheat (Triticum aestivum L)

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Abstract:
This research was conducted at the Agricultural Scientific Research Center in Idlib during the 2022–2023 and 2023–2024 growing seasons. The study aimed to evaluate heterosis relative to the mid-parent (MP) and better-parent (BP), and to assess general and specific combining abilities (GCA and SCA) for several traits, including: number and weight of grains in the main spike, thousand-kernel weight, grain yield per plant, and grain crude protein content (%). A comparison of the trait means among the parental lines revealed sufficient variability across most traits, qualifying them for use in breeding and hybridization programs. This was evident in the hybrids derived from half-diallel crosses, which showed notable differences in most studied traits. Analysis of variance for combining ability indicated that (δ^2GCA < δ^2SCA) for traits such as number and weight of grains in the main spike, grain yield per plant, and grain crude protein content—suggesting a predominance of non-additive genetic effects. However, for thousand-kernel weight, the relationship (δ^2SCA = δ^2GCA) indicated the involvement of both additive and non-additive gene actions.
Several parental lines exhibited significant and favorable general combining ability effects for grain yield and its components, qualifying them for inclusion in wheat breeding programs due to their potential to transmit desirable traits to their progeny. Notably, cultivars Wafiya, Douma 4, and Golan 2 demonstrated such potential.
Moreover, high and significant heterosis values relative to MP and BP were observed in several hybrids for various traits. These hybrids also showed desirable specific combining ability effects, typically resulting from at least one parent with favorable GCA, including: Douma 4× Golan 2, Odessa × Douma 4, Jihan 99 × Douma 4, Golan 2× Sham 12, Wafiya × Sham 12, and Odessa × Jihan 99. These hybrids are promising candidates for further selection in segregating generations and may serve as a basis for the development of high-yielding and protein-rich soft wheat lines.
Keywords: *Heterosis – Combining Ability – Gene Action – Soft Wheat*

1. INTRODUCTION:

Wheat is an annual grass belonging to the family Poaceae and the genus Triticum, comprising around 27 wild and cultivated species (Shewry, 2009). Wheat (Triticum spp.) is a staple food crop, cultivated on more than 17% of arable land and providing over one-fifth of the daily caloric intake globally (FAO, 2017).
Rajaram (2005) noted that by 2025, a 40% increase in wheat production will be required to meet global demand due to rapid population growth. Therefore, there is an urgent need to improve wheat genotypes with high yield potential. This requires exploring the maximum genetic potential within available wheat (Alsalmo et al., 2025).
Accordingly, the primary goal of wheat breeding programs worldwide is to develop high-yielding cultivars (Ehdaie and Waines, 1989).
Achieving this goal requires detailed information on the genetic control of yield-related traits, which can be obtained through statistical and genetic analyses, including diallel, half-diallel, and generation mean analyses. Estimating combining ability plays a key role in evaluating the breeding value of parental lines for hybrid development (Unay, 2004).
Half-diallel crossing is one of the most effective methods for comparing genetic performance across different genotypes and estimating genetic parameters in both pure lines and self-pollinated commercial cultivars. It is also essential for evaluating heterosis and determining the underlying gene action controlling the traits of interest (Antonio et al., 1997).

Introgression, selection, and hybridization are among the most commonly used methods for improving self-pollinated crops (Chahal & Gosal, 2002). Therefore, careful selection of parental lines is crucial, taking into account their genetic origin, agronomic traits, and combining abilities (Azzam et al., 2009).
Evaluating hybrids in early generations of self-pollinated crops is also important, as their stability and superiority reflect their true genetic potential. This allows breeders to select promising genotypes for further advancement in subsequent segregating generations (Atta Allah et al., 2023; Leffel and Hanson, 1961).

2. Research Rationale

Due to rapid population growth and limited arable land, there is a pressing need to improve grain yield of local wheat genotypes through vertical (intensive) expansion. This can be achieved by exploiting the maximum genetic potential for key traits within the existing wheat germplasm.

3. Objectives

- To develop F1 hybrids of soft wheat through a half-diallel crossing method.
- To identify superior hybrids with significant heterosis and specific combining ability.
- To determine the best parental lines with high general combining ability.
- To investigate the type of gene action controlling the inheritance of the studied traits.

4. REVIEW OF LITERATURE

a. Heterosis

Heterosis is the phenomenon where hybrid individuals outperform their parents in terms of size, growth rate, fertility, and resistance to pests and diseases (Belhis, 2014; Sabouh et al., 2010).
Keeble and Pellew (1910) attributed heterosis to the combined effect of favorable dominant alleles inherited from both parents. It is defined as the increase in growth, size, and yield of F1 hybrids over the mid-parent or better-parent, and is common in both cross-pollinated and self-pollinated crops.
A study by Bilgin et al. (2022) reported heterosis across several hybrids and traits: plant height (-12.71 to 8.23%), spike length (-15.46 to 8.36%), grain number per spike (-16.62 to 24.80%), grain weight (-23.61 to 36.50%), harvest index (-17.13 to 8.84%), grain yield (-44.26 to 15.83%), and thousand-kernel weight (-17.61 to 8.38%).
Al-Abd Al-Wahid et al. (2024) also recorded significant mid-parent and better-parent heterosis for hybrids such as Douma 4 × Jawaher 14, Jawaher 14× ACSAD 1252, Sham 6× Douma 64453, and Sham 6× ACSAD 1149. These hybrids are valuable for selection in subsequent segregating generations aimed at developing superior wheat lines.

b. Combining Ability

Griffing (1956) partitioned total variance into general combining ability (σ^2GCA) for parents and specific combining ability (σ^2SCA) for hybrids (Yan and Hunt, 2002). The concepts of GCA and SCA were first introduced by Sprague and Tatum (1942).
A study by Khoury et al. (2023) on soft wheat hybrids showed that additive gene action predominated for most traits (spike length, grains per plant, thousand-kernel weight, and grain yield per plant), except for thousand-kernel weight, which was mainly controlled by non-additive gene action. Several parents showed significant GCA effects for yield traits, including lines L-68467, L-1300, and L-68017.
Hybrids such as L-1300 × L-68467 and L-68017 × L-68467 demonstrated favorable SCA effects, making them promising candidates for selection in future segregating generations.
In another study by Abdo and Al-Khaled (2024) on soft wheat, analysis of variance showed that δ^2GCA > δ^2SCA for traits such as days to emergence, heading date, grain-filling period, plant height, main spike peduncle length, and harvest index—indicating the dominance of additive gene effects. Conversely, δ^2SCA > δ^2GCA for traits such as days to maturity, awn length of the main spike, number of productive tillers, number and weight of grains, thousand-kernel weight, biological yield, grain yield per plant, and crude protein content—suggesting non-additive gene action. Traits like spike length and number of spikelets per spike exhibited dominance degrees near one, indicating contributions from both additive and non-additive effects.

5. MATERIALS AND METHODS:

5.1. Plant Material (Genetic Material):

The plant material consisted of several pure genetic lines of soft wheat, including the Syrian local varieties: Sham 12, Golan 2, and Douma 4(They were provided by the General Authority for Agricultural Research (GAR) and belong to local varieties approved by the Syrian Variety Approval Committee (SVAC)), in addition to Turkish varieties: Jihan 99, Wafiya, and Odessa (Source General Directorate of Turkish Agricultural Projects).

5.2. Research Site:

The field experiments were conducted during the 2022–2023 and 2023–2024 agricultural seasons at the Agricultural Scientific Research Center in Idlib (Kafr Yahmul Research Station) Located 17 km north of Idlib city in the first stabilisation zone. The average rainfall (in mm) for the 2023–2024 season is presented in Table 1.

Table 1. Rainfall data at the research site during the 2023–2024 season (mm):

October	November	December	January	February	March	April	May	Total
35	34.5	62.5	155	51.5	76	27	30	471.5

The experimental site soil is classified as reddish clay loam, medium-textured, with low organic matter content and an alkaline pH. Table 2 presents the soil's mineral composition based on laboratory analysis conducted by the Faculty of Agricultural Engineering at Idlib University.

Table 2. Soil analysis results of the experimental site:

Parameter	Nitrogen (ppm)	Soil rating	Potassium (ppm)	Soil rating	Phosphorus (ppm)	Soil rating	pH	Soil texture
Value	3.88	Very Poor	243	Medium	4.8	Poor	7.85	Alkaline

. First Season (2022–2023):

During this season, the six parent lines were planted in three successive sowing dates, spaced ten days apart. Half-diallel hybridization was carried out among them according to the design shown in Table 3.

Table 3. Half-diallel mating design:

Parents	P_1	P_2	P_3	P_4	P_5	P_6
P_1		$P_2 \times P_1$	$P_3 \times P_1$	$P_4 \times P_1$	$P_5 \times P_1$	$P_6 \times P_1$
P_2	*		$P_3 \times P_2$	$P_4 \times P_2$	$P_5 \times P_2$	$P_6 \times P_2$
P_3	*	*		$P_4 \times P_3$	$P_5 \times P_3$	$P_6 \times P_3$
P_4	*	*	*		$P_5 \times P_4$	$P_6 \times P_4$
P_5	*	*	*	*		$P_6 \times P_5$
P_6	*	*	*	*	*	

. Second Season (2023–2024):

In this season, both the parent lines and F1 generation hybrids were planted, with three replicates per genotype. All necessary measurements for the studied traits were recorded at the appropriate time, using ten randomly selected plants from each experimental plot.

5.3. Genetic Indicators Studied:

5.3.1. Heterosis:

Heterosis was estimated as a percentage using the following formulas:(Lamkey and Edwards, 1999)

Heterosis relative to the mid-parent (HMP):

$HMP = [(MF_1 - MP) / MP] \times 100$

$MP = (MP_1 + MP_2)/2$

$MF_1 = F_1/n$

Where:

- MF_1: Mean of the F1 generation
- MP: Mid-parent value
- F_1: Total of F1 individuals
- n: Number of F_1 plants
- MP_1, MP_2: Means of parent 1 and parent 2 respectively

Heterosis relative to the better parent (HBP):

$HBP = [(MF_1 - HP) / HP] \times 100$

Where:

- HBP: Heterosis relative to the better parent
- BP: Mean of the better parent
- MF_1: Mean of the F_1 generation

5.3.2. General and Specific Combining Ability (GCA and SCA):

GCA and SCA were evaluated using Method II, Model I of Griffing's (1956) diallel analysis. The ratio of variance components (σ^2SCA / σ^2GCA) was calculated to assess the nature of gene action controlling the traits. The formulas used were:

$$\sigma^2_{GCA} = (Ms_{gca} - Ms_e) / (P + 2)$$

σ^2SCA= MsSCA – Mse

Where:

σ^2_{GCA} : Estimated variance due to general combining ability
σ^2SCA : Estimated variance due to specific combining ability
MS_{GCA}, MS_{SCA} : Mean squares for GCA and SCA respectively
MSe: Error mean square
P: Number of parental lines

The ratio (σ2SCA/σ2GCA), which is a measure of the genetic behaviour of the trait in question, is a ratio that determines the contribution of each of the genetic effects to the inheritance of the studied traits.

If σ2SCA/σ2GCA >1, this indicates the dominance of the cumulative genetic effect in the inheritance of these traits.

(σ^2SCA/σ^2GCA) <1 indicates that the non-additive genetic effect dominates the inheritance of this trait.

When (σ2SCA/σ2GCA) = 1, this indicates that both the cumulative and non-cumulative genetic effects contribute equally to the inheritance of this trait.

5.3.3. Degree of dominance:

This is a measure of the average dominance of all the genes controlling the trait in one parent over the genes that exist in the other parent, and it can be calculated in several ways, the most important of which is the Mather method (Mather, 1949), which is the method used in this study. The following formula is used: $a = \sqrt{VD/VA}$

Dominance Degree, where:
VA: Variation in the cumulative genetic effect, and
VD: Variation in the dominant genetic effect.

If: 1=a, this indicates that the trait is subject to both the cumulative and non-cumulative genetic effects, and represents complete dominance.

If 1<a, the trait is subject to the non-additive genetic effect (dominance and superiority).

If 1 > a, the trait is subject to the cumulative genetic effect and represents partial dominance.

If a is greater than +1 or less than -1, it is superdominance.

5.4. Experimental Design and Statistical Analysis:

The experiment was arranged in a randomized complete block design (RCBD). Variance analysis was performed using the Genstat-12 statistical software. Means were compared using the Least Significant Difference (LSD) test at a significance level of 0.05 for agronomic traits and 0.01 for quality traits (e.g., protein content). Diallel analysis was also conducted to evaluate general and specific combining abilities (GCA and SCA).

5.5. Studied Traits and Characteristics:

5.5.1. Agronomic Traits (Grain Yield and Components):

1. Number of grains per main spike: Mean number of grains from 10 randomly selected main spikes per plot
2. Weight of grains per main spike: Mean weight from 10 randomly selected main spikes per plot
3. Thousand-kernel weight (g): Average of three measurements from each plot
4. Grain yield per plant (g): Yield calculated from 10 randomly selected plants per plot

5.5.2. Grain Quality and Processing Characteristics:

1. Crude protein content (%) of grains

6. RESULTS AND DISCUSSION

Table (4): Mean Values of Studied Traits for Soft Wheat Parents and Their Half-Diallel Hybrids

Genotypes	Number of Grains per Main Spike	Grain Weight per Main Spike (g)	Thousand Grain Weight (g)	Grain Yield per Plant (g)
Sham12	57.33^{d}	1.30^{e}	38.00^{c}	29.40^{ab}
Golan2	91.33^{b}	3.19^{cd}	33.00^{d}	25.60^{abc}
Duma4	99.67^{ab}	3.65^{bc}	38.00^{c}	32.77^{a}

Jehan99	72.00c	2.65d	36.00cd	24.14bc
Wafia	107.00a	5.85a	51.33a	33.41a
Odessa	100.00ab	4.51b	45.00b	19.96c
General average	87.90	3.53	40.22	27.5
LSD 0.05	12.85	0.88	2.712	8.47
Golan2 x Sham12	89.67 a	2.75 abc	34.00 g	34.09abcd
Duma4 x Sham12	79.00 ab	3.50 ab	45.00abcd	38.61abc
Jehan99xSham12	87.00 a	4.05 a	44.00bcde	30.74cd
Wafia x Sham12	59.00 abc	2.81 abc	50.00a	27.28cde
Odessa x Sham12	13.33 d	0.25 d	19.09h	11.83fg
Duma4x Golan2	89.00 a	4.11 a	41.33cdef	45.80a
Jehan99x Golan2	87.00 a	2.95 abc	38.00fg	23.68def
Wafia x Golan2	71.28 ab	2.81 abc	39.82def	29.32cd
Odessa x Golan2	74.93 ab	3.01 abc	39.32efg	30.10cd
Jehan99x Duma4	88.67 a	4.16 a	39.33efg	32.18bcd
Wafia x Duma4	47.33 bcd	2.11 abcd	48.00ab	26.16de
Odessa x Duma4	47.67 bc	2.04 abcd	45.00abcd	27.00cde
Wafia x Jehan99	33.67 cd	1.55 bcd	48.00ab	16.23efg
Odessa x Jehan99	26.00 cd	0.89 cd	46.00abc	11.02g
Odessa x Wafia	79.00 ab	3.53 ab	49.33ab	42.89ab
General average	64.8	2.70	41.75	28.46
LSD 0.05	17.76	1.127	2.771	6.259

Similar letters have no significant differences between them

Table (5): Sources and Components of Variance for Traits of Soft Wheat Parents and Their Half-Diallel Hybrids

Source of Variance	Number of Grains per Main Spike	Grain Weight per Main Spike (g)	Thousand Grain Weight (g)	Grain Yield per Plant (g)
Rep Lines ms	182.39	0.71	0.22	56.04
Lines ms	1109.16**	7.35**	135.69**	82.91*
Errero (Lines) ms	49.92	0.23	2.22	21.70
CV%	8.0	13.7	3.7	16.9
Rep Crosses ms	1.90	0.08	3.561	52.49
Crosses ms	1942.00**	4.03**	182.362**	306.01**
Error (Crosses) ms	112.70	0.45	2.744	14.00
CV%	16.4	24.9	4.0	13.1
MS(GCA)	1459.990	3.893	284.031	322.924
MS(SCA)	2151.156	5.498	122.756	206.317
MS (Error (GCA, SCA))	98.777	0.403	2.500	19.130
Variance Components				
σ^2GCA	170.152	0.436	35.192	33.190
σ^2SCA	2052.379	5.095	120.256	474.053
σ^2GCA/σ^2SCA	0.083	0.086	0.293	0.070
VA	340.303	0.872	70.383	66.379
VD	2052.379	5.095	120.256	474.053
A	2.456	2.417	1.307	2.672

*significant differences, ** Highly significant

Table (6): Heterosis Values for Traits of Parents and Their Half-Diallel Hybrids

Hybrids	Number of Grains per Main Spike		Grain Weight per Main Spike (g)		Thousand Grain Weight (g)		Grain Yield per Plant (g)	
	HMP	HBP	HMP	HBP	HMP	HBP	HMP	HBP

Golan2 x Sham12	20.63*	-1.82	22.55**	-13.78**	-4.23**	-10.53**	23.98**	15.95**
Duma4 x Sham12	0.64	-20.74*	41.41**	-4.11**	18.42**	18.42**	24.19**	17.81**
Jehan99x Sham12	34.54**	20.83*	105.41**	53.15**	18.92**	15.79**	14.82**	4.55
Wafia x Sham12	-28.19**	-44.86**	-21.34**	-51.94**	11.94**	-2.59*	-13.14**	-18.36**
Odessa x Sham12	-83.05**	-86.67**	-91.28**	-94.39**	-53.99**	-57.57**	-52.05**	-59.76**
Duma4x Golan2	-6.81	-10.70	20.12**	12.60**	16.43**	8.77**	56.93**	39.75**
Jehan99x Golan2	6.53	-4.74	1.14*	-7.52**	10.14**	5.56**	-4.77	-7.47*
Wafia x Golan2	-28.13**	-33.39**	-37.96**	-52.05**	-5.56**	-22.42**	-0.62	-12.24**
Odessa x Golan2	-21.68**	-25.07**	-21.98**	-33.39**	0.82	-12.62**	32.16**	17.60**
Jehan99x Duma4	3.30	-11.04	32.24**	14.06**	6.31**	3.70*	13.09**	-1.80
Wafia x Duma4	-54.19**	-55.76**	-55.66**	-64.01**	7.47**	-6.49**	-20.94**	-21.70**
Odessa x Duma4	-52.25**	-52.33**	-49.94**	-54.73**	8.43**	0.00	2.41	-17.62**
Wafia x Jehan99	-62.38**	-68.54**	-63.45**	-73.46**	9.93**	-6.49**	-43.61**	-51.44**
Odessa x Jehan99	-69.77**	-74.00**	-75.05**	-80.21**	13.58**	2.22	-50.02**	-54.36**
Odessa x Wafia	-23.67**	-26.17**	-31.83**	-39.64**	2.43*	9.63**	60.73**	28.36**

*significant differences, ** Highly significant

Table (7): General Combining Ability (GCA) Effects for Studied Traits of Parental Genotypes

Genotypes	Number of Grains per Main Spike	Grain Weight per Main Spike (g)	Thousand Grain Weight (g)	Grain Yield per Plant (g)
Sham12	-7.16*	-0.57**	-2.64**	0.49
Golan2	11.82**	0.18	-3.84	2.10*
Duma4	6.38*	0.33*	0.68	4.74**
Jehan99	-4.20	-0.21	-0.23	-4.41**
Wafia	0.54	0.49**	6.08	1.41
Odessa	-7.38*	-0.23	-0.06	-4.33**
SE	1.85	0.12	0.30	0.82

*significant differences, ** Highly significant

Table (8): Specific Combining Ability (SCA) Effects for Studied Traits of Hybrids

Hybrids	Number of Grains per Main Spike	Grain Weight per Main Spike (g)	Thousand Grain Weight (g)	Grain Yield per Plant (g)
Golan2 x Sham12	13.58*	0.21	-0.84	3.30
Duma4 x Sham12	8.36	0.80*	5.64	5.18*
Jehan99x Sham12	26.94	1. 90	5.56	6.45*
Wafia x Sham12	-5.80	-0.04	5.24	-2.83
Odessa x Sham12	-43.54	-1.88	-19.53	-12.53
Duma4x Golan2	-0.63	0.66	3.18**	10.76**
Jehan99x Golan2	7.96	0.04	0.76	-2.21
Wafia x Golan2	-12.51*	-0.80*	-3.73**	-2.39
Odessa x Golan2	-0.94	0.11	1.90*	4.13
Jehan99x Duma4	15.07**	1.10**	-2.43**	3.65
Wafia x Duma4	-31.01	-1.66**	-0.08	-8.19**
Odessa x Duma4	-22.76**	-1.00**	3.06**	-1.61
Wafia x Jehan99	-34.09	-1.67**	0.84	-8.98**
Odessa x Jehan99	-33.84	-1.61**	4.97	-8.44**
Odessa x Wafia	14.42*	0.33	2.00*	17.61
SE	5.09	0.32	0.81	2.24

*significant differences, ** Highly significant

6.1. Number of Grains per Main Spike:

The number of grains in the main spikelet is one of the three important components that directly affect the grain yield, which It is affected by the plant's genetic makeup as well as environmental factors that influence the increase in the number of grains in the spikes (Kadum, et al.)., 2019).

- **Variance Analysis and Mean Comparisons**: Highly significant differences were observed among the parents and their resulting hybrids. The highest mean value for the number of grains per main spike (107.00) was recorded for the Wafia genotype (Table 4), outperforming other genotypes, followed by Odessa and Douma4. This indicates that introduced genotypes with dense spikes produce a higher number of grains per spike, contributing to the transfer of this trait to some hybrids. Conversely, Sham12 exhibited the lowest number of grains per main spike (57.33). The hybrids Golan2 × Sham12, Douma4 × Golan2, Jihan99 × Golan2, and Jihan99 × Sham12 showed the highest grain numbers, while the hybrid Odessa × Sham12 had the lowest.
- **Heterosis**: Table 6 shows that the hybrid Jihan99 × Sham12 exhibited a highly significant and desirable positive heterosis of 34.54**, followed by Golan2 × Sham12 with a significant and desirable positive heterosis of 20.63*. Three hybrids displayed positive but non-significant heterosis, while ten hybrids showed undesirable negative heterosis, both significant and non-significant. Relative to the better parent, only one hybrid, Jihan99 × Sham12, exhibited a significant and desirable positive heterosis of 20.83*, while the remaining 12 hybrids showed undesirable negative heterosis, both significant and non-significant.
- **Combining Ability**: Table 5 results indicate non-significant variance for both general and specific combining abilities. The ratio of general to specific combining ability variance (σ^2GCA/σ^2SCA) was 0.083, less than one, indicating the dominance of non-additive gene action in the inheritance of this trait, confirmed by a degree of dominance greater than one (2.456). Table 7 shows that Golan2 had a highly significant and desirable positive general combining ability (GCA) of 11.82**, followed by Douma4 with a significant and desirable positive GCA of 6.38*. Other genotypes exhibited undesirable negative GCA, both significant and non-significant, except for Wafia, which had a non-significant positive GCA. For specific combining ability (SCA) effects (Table 8), the hybrid Douma4 × Jihan99 exhibited the highest significant positive SCA (15.07**), resulting from parents with one positive and one negative GCA (additive × non-additive). This was followed by Sham12 × Golan2 and Wafia × Odessa, with significant positive SCA effects of 13.58* and 14.42*, respectively, both resulting from parents with one positive and one negative GCA (non-additive × additive).

6.2. Grain Weight per Main Spike:

The **Grain Weight per Main Spike**, especially the main spike, is one of the most important components of the main spike yield (Mahmoud, 2011; Balhiss, 2014).

- **Variance Analysis and Mean Comparisons**: Statistical analysis revealed highly significant differences among parents for this trait (Table 4). Wafia recorded the highest grain weight per main spike, followed by Odessa, Douma4, and Golan2, while Sham12 had the lowest. The parental behavior was clearly reflected in hybrid performance, with Jihan99 × Douma4 showing the highest grain weight, followed by Golan2 × Douma4 and Jihan99 × Sham12.
- **Heterosis**: Table 6 indicates heterosis relative to mid-parent ranging from -91.28** to 105.41**. Five hybrids exhibited highly significant and desirable positive heterosis: Jihan99 × Sham12 (105.41**), Douma4 × Sham12 (41.41**), Jihan99 × Douma4 (32.24**), Golan2 × Sham12 (22.55**), and Douma4 × Golan2 (20.12**). For better-parent heterosis, values ranged from -94.39** to 53.15**, with three hybrids showing highly significant and desirable positive heterosis: Jihan99 × Sham12 (53.15**), Jihan99 × Douma4 (14.06**), and Douma4 × Golan2 (12.60**). Other hybrids exhibited undesirable negative heterosis.
- **Combining Ability**: Table 5 shows non-significant variance for both GCA and SCA, with a σ^2GCA/σ^2SCA ratio of 0.086, indicating the dominance of non-additive gene action, confirmed by a degree of dominance greater than one (2.417). Table 7 indicates that Wafia had the highest significant positive GCA (0.49**), followed by Douma4 with a significant positive GCA. For SCA effects (Table 8), Jihan99 × Douma4 exhibited the highest significant positive SCA (1.10**), resulting from parents with one positive and one negative GCA (non-additive × additive), followed by Douma4 × Sham12 with a significant positive SCA of 0.80*, resulting from parents with one positive and one negative GCA (non-additive × additive). Other hybrids showed both significant and non-significant positive and negative SCA effects.

6.3. Thousand Grain Weight (g)

This trait is important for yield improvement, especially when associated with increased grain size. This is consistent with what was found (Diane, 2016; Saada and Lawand, 2016; Sheikhmos et al., 2013).

- **Variance Analysis and Mean Comparisons**: Variance analysis (Table 5) revealed highly significant differences among parents for this trait. Wafia, Odessa, Douma4, and Sham12 recorded the highest thousand grain weights, while Golan2 had the lowest. Among hybrids, Odessa × Wafia, Wafia × Sham12, Wafia × Douma4, and Wafia × Jihan99 showed the highest mean values, while Sham12 × Odessa had the lowest.

- **Heterosis**: Table 6 shows that ten hybrids exhibited highly significant and desirable positive heterosis relative to mid-parent, except for Odessa × Wafia, which showed significant but desirable positive heterosis. Jihan99 × Sham12 achieved the highest heterosis (18.92**), followed by Douma4 × Sham12 (18.42**). For better-parent heterosis, six hybrids showed highly significant and desirable positive heterosis: Douma4 × Sham12 (18.42**), Jihan99 × Sham12 (15.79**), Odessa × Wafia (9.63**), Douma4 × Golan2 (8.77**), and Jihan99 × Golan2 (5.56**). Seven hybrids exhibited undesirable negative heterosis, both significant and non-significant.
- **Combining Ability**: Table 10 indicates non-significant variance for both GCA and SCA, with a σ^2GCA/σ^2SCA ratio of 0.293, confirming the dominance of non-additive gene action. Table 7 shows that Wafia had the highest non-significant positive GCA (6.08), followed by Douma4 (0.68). Other genotypes had non-significant negative GCA, except Sham12, which had a highly significant negative GCA. Table 8 shows that Douma4 × Golan2 and Odessa × Douma4 had highly significant positive SCA (3.18** and 3.06**), resulting from parents with one positive and one negative GCA (additive × non-additive). Odessa × Wafia and Odessa × Golan2 also showed significant positive SCA (2.00* and 1.90*), while other hybrids had non-significant negative SCA.

6.4. Grain Yield per Plant (g)

This trait is the culmination of all components of productivity, and is influenced by complex physiological and developmental traits across growth stages, similar to what was found by (Qabili et al., 2013).

- **Variance Analysis and Mean Comparisons**: Genotype variance was significant for this trait (Table 5). Wafia and Douma4 outperformed other genotypes, while Odessa had the lowest grain yield per plant. Highly significant variance was observed among hybrids, with Odessa × Jihan99 showing the lowest yield (Table 4).
- **Heterosis**: Table 6 shows that Odessa × Wafia exhibited the highest significant and desirable positive heterosis relative to mid-parent (60.73**), followed by Douma4 × Golan2 (56.93**). Five hybrids showed highly significant and desirable positive heterosis. For better-parent heterosis, six hybrids exhibited significant and non-significant desirable positive heterosis, with Douma4 × Golan2 achieving the highest (39.75**), followed by Odessa × Wafia (28.36**). The remaining nine hybrids showed undesirable negative heterosis, both significant and non-significant.
- **Combining Ability**: Table 5 indicates a σ^2GCA/σ^2SCA ratio of 0.203, confirming the dominance of non-additive gene action, supported by a degree of dominance greater than one (1.570). Table 7 shows that Douma4 had the highest significant positive GCA (4.74**), followed by Golan2 (2.10*) and Wafia and Sham12 with non-significant positive GCA. Odessa and Jihan99 had highly significant negative GCA. Table 8 shows that Douma4× Golan2 had the highest significant positive SCA (10.76**), resulting from parents with positive GCA (additive × additive). Jihan99 × Sham12 and Douma4 × Sham12 also showed significant positive SCA (6.45* and 5.18*), while eight hybrids had significant and non-significant negative SCA.

Table (9): Mean Values and Combining Ability for Grain Crude Protein Content (%) in Parents and Their Half-Diallel Hybrids

Genotypes	Grain Crude Protein Content (%)	
	Means	Combining Ability
Sham12	14.35 ab	-0.30**
Golan2	11.75 c	-0.53**
Duma4	15.10 a	-0.00145
Jehan99	12.32 c	0.06
Wafia	13.66 b	1.00
Odessa	14.01 b	-0.23*
General average	13.532	S. E=0.06
LSD $_{0.05}$	0.4806	
Golan2 x Sham12	13.34ef	0.04
Duma4 x Sham12	11.74hi	-2.09
Jehan99x Sham12	12.24gh	-1.65

Wafia x Sham12	19.36[a]	4.53
Odessa x Sham12	11.11[i]	-2.48
Duma4x Golan2	15.38[c]	1.78
Jehan99x Golan2	14.83[cd]	1.17
Wafia x Golan2	13.92[de]	-0.69**
Odessa x Golan2	13.71[e]	0.34
Jehan99x Duma4	12.61[fgh]	-1.58
Wafia x Duma4	15.06[c]	-0.06
Odessa x Duma4	13.89[de]	-0.0009
Wafia x Jehan99	18.01[b]	2.82
Odessa x Jehan99	17.05[b]	3.10
Odessa x Wafia	13.23[efg]	-1.66
General average	14.365	S.E =0.16
LSD $_{0.05}$	0.5438	

*significant differences, ** Highly significant. Similar letters have no significant differences between them

Table (10): Heterosis Values for Grain Crude Protein Content (%) in Hybrids

Hybrids	**Grain Crude Protein Content (%)**	
	HMP	HBP
Golan2 x Sham12	2.21**	-7.04**
Duma4 x Sham12	-20.29**	-22.26**
Jehan99x Sham12	-8.25**	-14.73**
Wafia x Sham12	38.25**	34.91**
Odessa x Sham12	-21.66**	-22.58**
Duma4x Golan2	14.59**	1.90**
Jehan99x Golan2	23.19**	20.34**
Wafia x Golan2	9.53**	1.90**
Odessa x Golan2	6.38**	-2.20**
Jehan99x Duma4	-8.02**	-16.47**
Wafia x Duma4	4.78**	-0.22
Odessa x Duma4	-4.57**	-7.99**
Wafia x Jehan99	38.65**	31.88**
Odessa x Jehan99	29.48**	21.67**
Odessa x Wafia	-4.37**	-5.59**

*significant differences, ** Highly significant

Table (11): Sources and Components of Variance for Grain Crude Protein Content (%)

Source of Variance	Grain Crude Protein Content (%)
Rep Lines $_{ms}$	0.132
Lines $_{ms}$	4.793**
Errero $_{(Lines)\ ms}$	0.070
CV%	2.0
Rep Crosses $_{ms}$	0.136
Crosses $_{ms}$	16.179**
Error $_{(Crosses)\ ms}$	0.106
CV%	2.3
$MS_{(GCA)}$	6.849**
$MS_{(SCA)}$	15.009**
MS (Error $_{(GCA,\ SCA)}$)	0.099
Variance Components	
σ^2_{GCA}	0.844
σ^2_{SCA}	14.910
$\sigma^2_{GCA}/\sigma^2_{SCA}$	0.057
VA	1.687
VD	14.910

a	2.972

*significant differences, ** Highly significant

6.5. Grain Crude Protein Content (%)

- **Variance Analysis and Mean Comparisons**: Table 11 indicates highly significant differences among parents for grain crude protein content. Douma4 recorded the highest value (15.10 %), followed by Sham12 and Odessa, while Golan2 had the lowest (11.75%). This was reflected in the hybrids, which showed highly significant variance. The hybrid Wafia × Sham12 had the highest value for this trait (19.36 %) (Table 9).
- **Heterosis**: Nine hybrids exhibited highly significant and desirable positive heterosis relative to mid-parent (HMP), with Wafia × Jihan99 showing the highest (38.65**), followed by Wafia × Sham12 (38.25**) and Odessa × Jihan99 (29.48**). The remaining hybrids had undesirable negative heterosis (Table 10). Relative to the better parent (HBP), six hybrids showed highly significant and desirable positive heterosis, ranging from 1.90** to 34.91**, with Wafia × Sham12 being the best.
- **Combining Ability**: Table 11 shows that the σ^2GCA/σ^2SCA ratio was less than one (0.057), indicating the dominance of non-additive gene action in the inheritance of this trait, confirmed by a degree of dominance greater than one (2.972). Table 9 indicates that Wafia had a desirable but non-significant positive general combining ability (GCA) (1.00), followed by Jihan99, also with non-significant positive GCA. Other genotypes exhibited undesirable negative GCA, both significant and non-significant. For specific combining ability (SCA), Odessa × Golan2, resulting from parents with negative GCA (non-additive × non-additive), had significant positive SCA. Seven hybrids showed non-significant positive SCA ranging from 0.04 to 4.53, with Wafia × Sham12, resulting from parents with one negative and one positive GCA (non-additive × additive), being the best. Other hybrids had undesirable negative SCA (Table 9).

7. CONCLUSIONS

1. Non-additive gene action dominated the inheritance of the studied traits, as the σ^2GCA/σ^2SCA ratio was less than one and the degree of dominance was greater than one, except for thousand grain weight, where both additive and non-additive gene actions contributed, with a σ^2GCA/σ^2SCA ratio less than one and a degree of dominance approximately equal to one.
2. The study identified several parental genotypes with significant and desirable general combining ability (GCA) for the studied traits, which, when crossed with similar genotypes, can achieve substantial genetic progress in resulting hybrids. Notable among these are the local genotype Douma4 for all traits except grain crude protein content, the introduced genotype Wafia for grain weight per spike, and the local genotype Golan2 for the number of grains per spike and grain yield per plant.
3. Most hybrids with significant and desirable heterosis also exhibited significant and desirable specific combining ability (SCA), making them suitable for further study in segregating generations. These include Douma4 × Golan2, with significant heterosis and SCA for thousand grain weight; Odessa × Douma4, with significant heterosis and SCA for thousand grain weight; and Jihan99 × Douma4, with significant heterosis and SCA for grain weight per main spike, with one parent having high GCA.
4. The hybrid Golan2 × Sham12 exhibited significant heterosis and SCA, with one parent having high GCA for the number of grains per main spike.
5. The hybrid Wafia × Sham12 showed significant SCA and heterosis for grain crude protein content.
6. The hybrid Douma4 × Golan2 outperformed others with significant heterosis for grain weight per main spike, thousand grain weight, grain yield per plant, and grain crude protein content.
7. The hybrid Odessa × Jihan99 exhibited significant heterosis for thousand grain weight and grain crude protein content.

8. Recommendations

1. Incorporate the local parental genotypes Golan2 and Douma4, and the introduced Turkish genotype Wafia, into breeding programs aimed at improving soft wheat yield due to their significant and desirable GCA.
2. Continue studying the hybrids Douma4 × Golan2, Odessa × Douma4, Jihan99 × Douma4, Golan2×, Wafia × Sham12, and Odessa × Jihan99 by examining their genetic behavior in segregating generations (six populations) to develop promising lines with significant and desirable SCA.
3. Investigate the genetic behavior of the studied genotypes and their populations at the molecular level.

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