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Screening the yield potential of some bread and durum wheat under new valley conditions using some statistical procedures

Mokhtar M. M. Gab Alla [1] and Eman M. A. Hussein[2]

Address:

[1]Wheat Research Department, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt

[2]Central Laboratory for Design and Statistical Analysis Research, Agricultural Research Center, Giza, Egypt

*Corresponding author: ***Eman M. Hussein.*** email: *eman.m.a.hussein@arc.sci.eg*

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ABSTRACT

Heat stress is a significant challenge for agriculture in dry and semi-arid regions. This study investigates the effects of temperature on the yields of eighteen wheat genotypes (ten bread wheat and eight durum wheat) grown in New Valley, Egypt, during the 2021/2022 and 2022/2023 growing seasons using a randomized complete block design (RCBD). We examined the relationship between yield and traits influencing yield under heat stress through simple correlation, and partial and path coefficient analysis. Key characteristics for selecting high-yielding wheat genotypes include the number of spikes per square meter (NS/m²), the number of kernels per spike (NK/S), and the 1000-kernel weight (TKW). The analytical hierarchical process (AHP) identified weight coefficients of 0.744 for NS/m², 0.135 for NK/S, and 0.121 for TKW. Breeding criteria focus on increasing NS/m² while minimizing NK/S and TKW to select heat-resistant varieties in three scenarios. Notably, the genotypes Misr 2, Misr 4, Sakha 95 (bread wheat), Beniswef 7, Beniswef 8, and Sohag 4 (durum wheat) showed comparable heat tolerance in both growing seasons. These findings can aid plant breeders in developing cultivars better suited for warmer, arid conditions.

Keywords: New Valley, Bread Wheat, Durum Wheat, The analytic hierarchy process (AHP), partial correlation analysis and path analysis.

INTRODUCTION

The rising demand for wheat is primarily attributed to the growth in population, income, and the adversities of climate change, such as increased temperature and reduced precipitation. Likewise, the scarcity of land and water, along with sub-optimal temperature and precipitation levels, causes heat and water stress to the wheat plants (Alborghetti, 2023). Egypt consumes around 20.6 million tonnes of wheat annually, relying heavily on imports to meet its needs, as domestic production covers less than half of this amount (USDA, 2024). One of the primary causes of yield losses in wheat is abiotic stresses such as high temperature, and drought rather than biotic stresses (Ahmad *et al.,* 2022; Coast *et al.,* 2022; Darwish *et al.,* 2024).

The Intergovernmental Panel on Climate Change (IPCC) scenario analysis indicates that the reduction in precipitation and increase in temperature will further worsen the damage to wheat productivity. However, the increase in demand is projected to affect future import dependency. This, in turn, will increase the uncertainty of regional food security in (Algeria, Egypt, Morocco, and Tunisia) (Alborghetti, 2023).

The genus Triticum contains the majority of wheat species. Durum wheat (*Triticum durum L.*) and bread wheat (*Triticum aestivum L.*) make up more than 80 % of the global crop productivity (Ali *et al.,* 2019). Heat stress can significantly harm the growth, quality, and yield of crops. Rising temperature has been proven to be a major cause of global yield losses (Chandio *et al.,* 2023; Deng *et al.,* 2023). Wheat plants are especially vulnerable to heat stress during sensitive periods of growth, such as anthesis, grain filling, and reproduction. Heat stress can also indirectly affect metabolic plant growth. Studies have shown that when the temperature is increased from 15-20°C to 40-45°C, wheat productivity can decrease by 23 % on the third day after anthesis (Majeed *et al.,* 2023). In the coming years, agriculture will be significantly affected by various precipitation patterns such as intensity, volume, and distribution changes. Additionally, the amount of atmospheric water vapour, the water content of the soil, and higher temperatures will also play a crucial role, leading to increased evapotranspiration. All of these factors combined will on agriculture and it is important to be aware of them. These factors will contribute to higher water demand due to extreme temperatures and precipitation (Gabr, 2023). Climate change will have significant and far-reaching impacts on the Middle East and North Africa (MENA) (Alotaibi *et al.,* 2023). One way to address the impacts of climate change on agriculture is to enhance the capacity of agricultural systems to adapt and reduce their exposure and vulnerability to climate change (IPCC, 2023).

In response to the present situation, the government of Egypt has initiated the National Climate Change Strategy (NCCS). The main objective of this strategy is to consolidate all the aspects of climate change into a single document that can be used as a reference to facilitate the transition towards a climate-resilient economy. The program aims to enhance adaptive capacity and resilience to climate change and mitigate its negative impacts (Ibrahim, 2023). To better adapt wheat production to warming, it is crucial to identify genotypes that confer heat tolerance and are easy to phenotype, so they can be incorporated into breeding programs (Coast *et al.,* 2022 and Chandio *et al.,* 2023).

Developing strategies for the indirect selection of multi-trait genotypes in grains is possible by understanding the relations between yield components. Linear correlation analysis is a commonly used technique in wheat research to determine the strength and direction of relationships among different traits. However, the correlation between a pair of traits may be affected by the presence of another trait. In such cases, partial correlation analysis can be more appropriate as it allows the effects of another trait to be removed (Trivisiol *et al.,* 2024). Maximizing efficiency in genotype selection is achieved by understanding linear relations between wheat traits by development cycle. Path analysis is a statistical method used to understand the relationship between different variables and how they affect a dependent variable, such as crop yield. By analyzing the correlation coefficients between these variables, researchers can determine the direct and indirect effects independent variables have on the dependent variable. This knowledge can be useful in developing a selection process for multiple traits, allowing for direct and indirect selection of different component variables (Patial *et al.,* 2023).

Multi-criteria decision-making (MCDM) methods are effective and dependable techniques for policy-making and identifying the most suitable solutions. These approaches influence various factors, each of which has a different level of importance when comparing alternatives. Nevertheless, the outcomes obtained from MCDM methods depend on the algorithm and criteria utilized (Boix-Cots *et al.,* 2022; Mirpanahi *et al.,* 2023) where there are many MCDM methods, including the analytic hierarchy process (AHP). Biswas *et al.,* (2024) mentioned that the deliberate selection of MCDM methods, particularly the AHP, demonstrates a conscious decision to address the intricacies involved in agricultural decision-making. AHP is renowned for its ability to handle complex decision-making scenarios that involve multiple criteria and options. So, the objective of this study includes the following:

1- Assess the yields of eighteen wheat genotypes, consisting of ten bread wheat and eight durum wheat, and examine how temperature affects them in the New Valley Governorate.
2- Identifying traits that can directly and indirectly affect wheat yields. Wheat breeders can use these traits to develop and improve wheat varieties to withstand heat stress and drought environments for the next generations.
3- Focused and enhanced on genotypes capable of providing stable yields and having higher heat tolerance by ranking genotypes under this investigation which can help improve wheat production in future.
4- Our screening approach includes partial correlation coefficients, path analysis, and the AHP as an effective selection criterion for wheat production under New Valley conditions. We hope the resulting information can help select appropriate genotypes and plan new hybridizations to cultivate resistance to heat and drought stress.

MATERIALS AND METHODS

1.1- Experimental design and plant materials:

The experiment aimed to investigate grain yield productivity in eighteen wheat genotypes, including ten bread wheat and eight durum wheat. Table (1) lists the names and pedigrees of the studied wheat cultivars, grown under New Valley conditions on November 7^{th} and 10^{th} during the winter seasons of 2021-2022 and 2022-2023. The research farm at Elfarafra is located at Longitude 27.8923 and Latitude 27.0628. A randomized complete block design (RCBD) was used, consisting of four replicate arrangements. It was planted with an amount of grain equal to 400 grain/m^2 using the drill method. The plot area (4.2 m^2) consisted of guarded six rows, 3.5 m long and 20 cm apart. Plants were randomly selected from each plot to measure morphological studied characteristics. Irrigation was conducted using a surface irrigation system, applied fully between eight and nine times at different growth stages. It was observed that the electrical conductivity (EC) of the water was ≤ 0.55 Decisiemens per meter (dS/m^{-1}). The soil structure is sandy loam, with a pH of 7.8 and an EC of 0.86 dS/m^{-1}.

1.2- Plant morphological data:

The data were collected appropriately, covering various agronomic and yield components:

1. Number of Days to Heading (DH): Number of days from sowing to the emergence of approximately 50% of the spikes/plot.
2. Number of Days to Maturity (DM): The number of days from sowing to approximately 50% of the peduncles in the plot turned to yellow colour.
3. Grain Filling Period (GFP): Number of days from anthesis to physiological maturity.
4. Grain Filling Rate (GFR) in g m^{-2} $days^{-1}$, equal to yield per feddan by GFP.
5. Plant Height (PH) is measured in centimetres (cm) from the soil surface to the top of the spike, excluding the own.
6. Growing Degree days (GDD): The GDD was calculated according to (Gomez and Richards, 1997), in which GDD $=\Sigma[(Tmax_i + Tmin_i)/2 - T_b]$ where T max_i and T min_i are the maximum and minimum daily air temperature on an i_{th} day and T_b is the base temperature below which the rate of development is assumed to be zero.
7. Number of Spikes/m^2 (NS/m^2): were calculated by counting all spikes per square meter.
8. Number of Kernels/Spike (NK/S): Average number of grains in ten randomly chosen spikes
9. A random sample of 1000 grains was taken from each sub-plot, hand-counted, and weighed to determine the 1000-kernel Weight (TKW) in grams.
10. Grain Yield (GY): Data were collected from six guarded rows per plot and converted to ard/fed. After threshing, yields were recorded and converted to Ardab/fed (1 Ardab = 150 kg at 14.5% moisture, 1 feddan = 4200 m²).

Table 1. The name and pedigree, of the studied eighteen wheat genotypes, including ten bread wheat and eight durum wheat

Cultivar Bread Wheat	Cross Name/ Pedigree
Misr 1	OASIS/SKAUZ//4*BCN/3/2*PASTOR CMSS00Y01881T-050M-030Y-030M-030WGY-33M-0Y-0S
Misr 2	SKAUZ/BAV92, CMSS96M03611S-1M-010SY-010M-010SY-8M-0Y-0S
Misr 3	ATTILA*2/PBW65*2/KACHU CMSS06Y00582T-099TOPM-099Y-099ZTM-099Y-099M-10WGY-0B-0EGY
Misr 4	NS732/HER/3/PRL/ SARA// TSI/VEE 5/6/FRET 2/5/WHEAR/SOKOLL CM SA09Y007125-050Y- 050ZTM-0NJ-099NJ-0B-0EG.
Sakha 95	PASTOR // SITE / MO /3/ CHEN / AEGILOPS SQUARROSA (TAUS) // BCN /4/ WBLL1.CMA01Y00158S-040POY-040M-030ZTM-040SY-26M-0Y-0SY-0S.
Sids 14	BOW"S"/VEE"S"//BOW" S"/TSI/3/BANI SEWEF 1, SD293-1SD-2SD-4SD-0SD
Giza 171	SAKHA 93/GEMMEIZA 9 S.6-1GZ-4GZ-1GZ-2GZ-0S
Noubariua 1	FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ*2/5/BOW/URES//2*WEAVER/3/CROC_1/AE.SQUARROSA (213)//PGO CGSS05B00144T-099TOPY-099M-099NJ-099NJ-7WGY-0B-5Y-0B-0NUB
Shandweel1	SITE/MO/4/NAC/TH.AC//3*PVN/3/MIRLO/BUC CMSS93B00567S-72Y-010M-010Y-010M-3Y-0M-0HTY-0SH
Sids 12	BUC//7C/ALD/5/MAYA74/ON//1160.147/3/BB/GLL/4/CHAT"S"/6/MAYA/VUL//CMH74A.630/4*SX, SD7096-4SD-1SD-1SD-0SD
Durum Wheat	Cross Name/ Pedigree
Benisweif 1	Jo”s”/AA”s”//FG”s”. CD 9799-126M-1M-SY-0M-0SD.
Benisweif 4	AINZEN1. ICD88-II20-ABL-0TR-1BR-0TR-6AP-0AP-0SD.
Benisweif 5	Dipper-2/Bushen-3. CDSS92B128-1M-0Y-0M-0Y-3B-0Y-0SD.
Benisweif 6	Boomer-21/Busca-3. CDSS95-Y001185-8Y-0M-0Y-0B-1Y-0B-0SD.
Benisweif 7	CBC509CHILE//SOOTY_9/RASCON_37/9/USDA595/3/D67.3/ ABI//CRA/4/ALO/5/HUI/YAV_1/6/ARDENTE/7/HUI/YAV7 9/8/POD_9. CDSS02-Y01233T-0T0PB-0Y-0M-26Y-0Y-0S
Benisweif 8	SOOTY_9/RASCON_37//STORLOM/5/TOSKA_2 6/RASCON_37//SNITAN/4/ARMENT//SRN_3/N IGRIS_4/3/CANELO_9.1/6/RISSA/GAN//POHO_ 1/3/PLATA_3//CREX/ALLA*2/4/ARMENT//SRN _3//NIGRIS_4/3/CANELO_9.1 CDSS07Y00575T-099Y099M-13Y-1M-04Y-0B-0EG
Sohag 4	Ajaia-I6//Hora/Jro/3/Ga/4/Zar/S/Suok-7/6/Stot//Altar84/Aid. CDSSB007785-0T0PY-0M-0Y-129Y-0M-0Y-IB-0SH.
Sohag 5	TRN//21563/AA/3/BD2080/4/BD2339/5/Rascon37//Tarro2//Ras con3/6/Auk/Gull//Green. CDSS00B00364T-0T0PB-0B=2Y-0M-0Y-1B-0Y-0SH.

Source: According to the data of the Wheat Research Section, FCRI = Field Crops Research Institute, ARC (Agriculture Research Center), Giza, Egypt

1-3- Weather data of new valley, governorate, Egypt:

Mean values and change rate of metrological data during the two growing seasons of 2021/2022 and 2022/2023 are presented in (Tables 2 a, and b). These data were obtained from the Central Laboratory for Agricultural

Climate (CLAC), Agriculture Research Center as Maximum Temperature (C°), Minimum Temperature (C°), Relative Humidity % (RH), Rain: Precipitation (mm day $^{-1}$), Wind Speed (m/s) (WS), and Dew/Frost Point (C°) (Dew).

Table 2a. Mean values and change rate of metrological data during the two growing seasons of 2021-2022 and 2022-2023.

Date	Maximum Temperature (C°)		Change Rate %	Minimum Temperature (C°)		Change Rate %	Relative Humidity %		Change Rate %
	Season 1	Season 2		Season 1	Season 2		Season 1	Season 2	
08-Nov	26.4	23.9	⇩ 9.5	13.9	12.1	⇩ 12.4	51.4	54.6	⇧ -6.3
18-Nov	24.6	23.7	⇩ 3.8	11.5	10.7	⇩ 7.2	42.2	44.4	⇧ -5.2
28-Nov	22.5	22.2	⇩ 1.5	9.8	10.3	⇧ -4.4	44.9	53.3	⇧ -18.9
08-Dec	18.7	24.4	⇧ -30.4	7.7	10.7	⇧ -39.2	53.0	42.9	⇩ 19.1
18-Dec	16.4	20.0	⇧ -21.9	4.5	9.2	⇧ -102.9	64.2	66.6	⇧ -3.7
28-Dec	18.2	18.8	⇧ -3.6	7.1	7.2	⇧ -1.6	63.3	69.3	⇧ -9.6
07-Jan	18.4	18.0	⇩ 2.3	4.9	6.4	⇧ -30.3	48.3	60.4	⇧ -25.0
17-Jan	14.4	19.4	⇧ -34.4	2.6	5.9	⇧ -128.8	60.9	53.5	⇩ 12.1
27-Jan	15.8	20.0	⇧ -26.8	2.9	6.5	⇧ -123.6	59.7	45.8	⇩ 23.2
06-Feb	18.3	17.1	⇩ 6.3	4.2	5.2	⇧ -22.0	54.6	51.8	⇩ 5.2
16-Feb	18.9	18.5	⇩ 2.1	6.5	4.9	⇩ 24.5	56.6	58.9	⇧ -4.2
26-Feb	23.5	28.4	⇧ -21.0	8.9	10.5	⇧ -17.3	36.7	25.5	⇩ 30.5
08-Mar	19.5	25.2	⇧ -29.2	6.6	9.9	⇧ -50.9	46.8	34.8	⇩ 25.6
18-Mar	19.7	24.7	⇧ -25.6	5.0	10.8	⇧ -116.7	43.7	41.4	⇩ 5.2
28-Mar	32.5	25.8	⇩ 20.6	13.4	9.9	⇩ 25.6	19.7	31.3	⇧ -59.1
07-Apr	31.0	28.8	⇩ 7.3	13.9	13.8	⇩ 1.0	26.7	25.1	⇩ 6.0
17-Apr	31.6	32.1	⇧ -1.5	15.7	16.0	⇧ -1.7	23.0	22.3	⇩ 3.1
27-Apr	33.6	31.4	⇩ 6.7	18.0	15.9	⇩ 11.9	22.8	24.5	⇧ -7.5
07-May	32.4	31.2	⇩ 3.6	18.4	16.4	⇩ 11.1	25.6	30.0	⇧ -17.1
17-May	33.0	35.0	⇧ -6.3	17.2	19.5	⇧ -13.4	22.2	20.9	⇩ 6.1
27-May	37.9	34.3	⇩ 9.4	21.2	21.0	⇩ 1.1	19.9	26.0	⇧ -30.9
Change Rate Average%			⇧ -6.1			⇧ -26.6			⇧ -2.4

⇧ : Increase and ⇩ : Decrease

1- 4 Statistical analysis:

Before running an analysis of variance (ANOVA), we utilized the Shapiro-Wilk test (Shapiro & Wilk, 1965) to assess the normal distribution of the variables and the (Levene test 1960) was used to examine the equality of error variances. Where the data did not satisfy the assumptions of homogeneity of individual error variances, we analyzed each season separately using ANOVA following the appropriate experimental design RCBD (Fig. 1).

The mean comparison was run using the least significant difference test (LSD) to identify significant differences at the 0.05 probability level. Additionally, for each season, an orthogonal contrast comparing bread wheat cultivars versus the set of durum wheat ones was used.

Simple correlation coefficients between grain yield and six independent variables were computed according to (Gomez and Gomez, 1984). Partial correlation was employed to isolate the specific effects of each character. This method allows us to assess the impact of multiple variables on dependent variables (Y) while considering the relationships between the independent variables (DH, DM, PH, NS/m^2, NK/S and TKW).

Before running path-coefficient analysis, the yield and yield trait data were logarithmically transformed to fulfil the additivity assumption. This transformation enabled the conversion of the multiplicative model of grain yield into an additive model by taking natural algorithms. Subsequently, path analysis was conducted for partitioning correlation coefficients and examining the direct and indirect effects of traits on grain yield **(**Dewey and Lu, 1959). So, the contribution of each character to yield could be estimated. Consequently, estimate the traits of most impacts on improving the production. The three main yield components were then used to select elite genotypes using the AHP (Fig. 1).

Table 2b. Mean values and change rate of metrological data during the two growing seasons of 2021-2022 and 2022-2023.

Date	Precipitation (mm day -1)		Wind Speed (m/s)		Change Rate %	Dew/Frost Point (C°)		Change Rate %
	Season 1	Season 2	Season 1	Season 2		Season 1	Season 2	
08-Nov	0.0	0.0	2.0	3.0	⬆ -48.4	8.2	7.8	⬇ 5.0
18-Nov	0.1	0.0	2.1	2.2	⬆ -4.4	3.2	3.1	⬇ 2.8
28-Nov	0.0	0.0	2.8	2.1	⬇ 23	1.9	5.2	⬆ -165.0
08-Dec	0.0	0.0	2.2	1.9	⬇ 14.9	2.3	2.8	⬆ -19.0
18-Dec	0.0	0.2	2.6	3.0	⬆ -16.7	2.7	7.2	⬆ -172.3
28-Dec	0.1	0.0	2.8	2.8	⬆ -0.6	4.5	5.9	⬆ -31.6
07-Jan	0.0	0.2	3.1	2.3	⬇ 25.1	-1.1	3.3	⬇ 399.2
17-Jan	0.1	0.0	2.6	2.0	⬇ 23.1	-0.1	1.5	⬇ 1767.4
27-Jan	0.0	0.0	3.4	2.8	⬇ 17	0.4	-0.5	⬇ 221.2
06-Feb	0.0	0.2	2.3	3.1	⬆ -32.9	0.5	0.0	⬇ 95.1
16-Feb	0.1	0.0	3.2	2.9	⬇ 10.1	2.8	2.5	⬇ 9.3
26-Feb	0.0	0.0	2.7	2.6	⬇ 4.8	-0.7	-3.8	⬆ -463.4
08-Mar	0.0	0.0	3.7	2.8	⬇ 26.3	0.5	0.1	⬇ 79.0
18-Mar	0.2	1.0	3.3	3.3	⬇ 1.7	-1.3	2.3	⬇ 278.4
28-Mar	0.0	0.0	2.0	2.7	⬆ -37.7	-5.0	-1.1	⬇ 78.9
07-Apr	0.0	0.0	3.0	3.0	⬇ 0.8	-0.7	-2.0	⬆ -199.1
17-Apr	0.0	0.0	3.1	2.6	⬇ 17.2	-1.1	-0.7	⬇ 39.2
27-Apr	0.0	0.0	3.5	3.0	⬇ 16.1	0.4	0.9	⬆ -142.0
07-May	0.0	0.0	3.5	3.3	⬇ 5.7	3.3	3.7	⬆ -10.6
17-May	0.0	0.0	3.1	3.1	⬇ 0.9	0.5	1.7	⬆ -263.9
27-May	0.0	0.1	2.9	2.8	⬇ 3.6	2.4	5.4	⬆ -126.8
Change Rate Average %					⬇ 2.4			⬇ 65.8

⬆ : Increase and ⬇ : Decrease

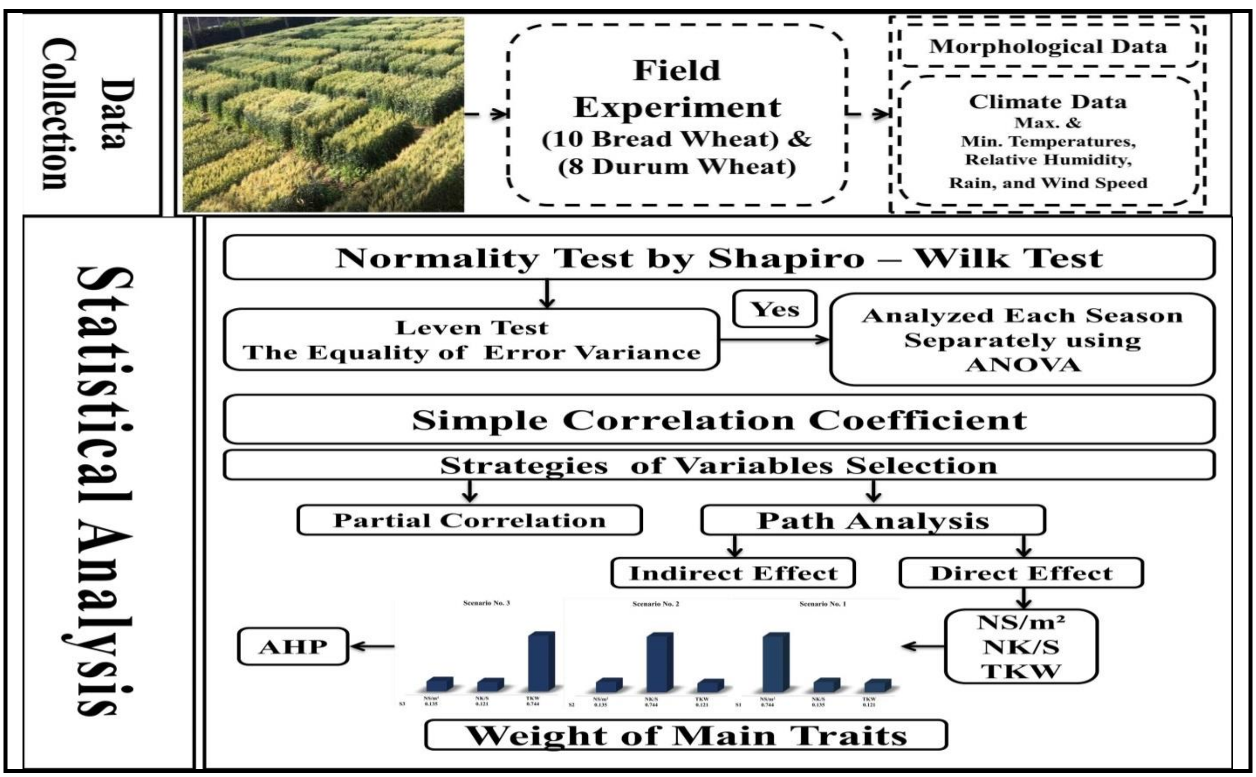

Fig. 1. Flowchart showing the appropriate steps of statistical analysis.

According to the AHP method (Saaty, 2008), a pair-wise comparison based on the purpose of the study and expertise knowledge from long-term observation was applied to the selected traits. Thus, each parameter was assigned a relative importance value ranging from 1 to 9 to create the AHP matrix, as shown in (Table 3). To select high-yield options, a hierarchical framework model was built, considering the interrelationship and subordinate levels of the relevant factors through various levels of aggregation and combination. Goal hierarchy provided a detailed evaluation of bread and durum wheat cultivars, ranking them in conditions of yield potential. The hierarchy was based on three primary criteria or scenarios (S) that focused on yield traits: (NS/m²), (NK/S), and the (TKW) in grams. These scenarios are labelled as (S1), (S2), and (S3).

In the first scenario (S1), the NS/m² was deemed significantly more important, receiving very strong importance, compared to the NK/S. The TKW was also considered essential. In the second scenario (S2), the NK/S was prioritized over the other traits. In the third scenario (S3), the TKW was regarded as more important, also receiving very strong importance, compared to the NS/m² and the NK/S, both of which were considered essential. The judgment matrix was constructed by calculating the weights of the factors, determining the maximum eigenvalue (λ_max), and finding the corresponding eigenvectors. Consistency was assessed using the Consistency Ratio (CR) relative to the Consistency Index (CI), with CR values under 0.1 indicating a reasonable level of consistency (Saaty, 2008).

Table 3. Scale for making the pair-wise comparison matrix

Intensity of importance	Definition
1	Equal importance
3	Moderate importance of one over the other
5	Essential or Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values between the two adjacent

Source: Saaty (2008)

RESULTS

3.1- Weather data:

Weather data for each season is presented in (Tables 2a and b), including average maximum and minimum temperatures (C), (RH) (%), precipitation (mm/day $^{-1}$), wind speed (m/s), dew/frost point, and change rate %. Throughout the first growing season (2021-2022), the coldest months in terms of average monthly maximum and minimum temperatures were December, January, and the first ten days of February (Table 2a).

The average maximum and minimum temperatures were recorded during the second growing season (2022 - 2023) (Table 2a) indicating that the maximum temperatures increased by 6.1%, and minimum temperatures by 26.6 % compared to the first season. It was noted that the second season was warmer than the first growing season (Table 2a). During the first growing season (2021 - 2022), the RH ranged from 19.89 % to 64.19 %. In the second season (2022 - 2023), it increased to a minimum of 20.89% and a maximum of 69.31% (Table 2a). The RH increased by 2.4% in the second season compared to the first. In the second season, the wind speed decreased by 2.4% compared to the first season. The dew point also decreased by 65.8% in the second season compared to the first. These results are presented in Table 2b. Additionally, the precipitation (mm/day $^{-1}$) was ineffective through two consecutive growing seasons.

3-2 Analysis of variance:

The Shpiro-Wilk test revealed that all variables had a normal distribution. Each season was analyzed separately after conducting a significant homogeneity test. The ANOVA results indicated a highly significant difference among cultivars in all traits in each season; with p-values < 0.05 (Table 4). The values of the coefficient of variation for all traits were statistically accepted (CV lower than 15) which indicated the validity of the ANOVA model during the two growing seasons. Orthogonal comparisons, between the set of bread wheat vs. the set of durum wheat cultivars in the first season, revealed significant differences among them regarding GFP, PH, NS/m², NK/S, TKW and GDD. Similarly, in the second season, there were significant differences among them regarding (DH), GFP, PH, NK/S, TKW and GDD (Table 4).

Table 4. Analysis of variance for morphological characters and orthogonal contrast of bread vs. durum wheat during the two growing seasons of 2021-2022 and 2022-2023

Source of variation	d.f.	Mean square									
		DH	DM	GFP	GFR	PH	NS/ m²	NK/S	TKW	GY	GDD
1st Season											
Replication	3	2.56	5.94	16.09*	5.75	45.72*	1989.57	34.58	68.8	5.43	222.6
Cultivar	17	58.7**	18.0**	23.2**	250.6**	136.9**	8788.7**	44.9**	42.7**	25.9**	4735.7**
bread vs. durum	1	14.5	2.8	32.71*	134.3	832.7**	11408**	114.5**	85.2*	1.5	2255.9**
		(1.65)#	0.9	8.3	3.2	35.8	7.7	15.0	11.7	0.4	2255.9
Residul	51	3.4	3.0	5.7	46.9	15.8	1564.7	15.4	13.2	5.2	317.5
Coeff. of variation (CV)		**2.0**	**1.2**	**4.7**	**11.0**	**3.7**	**11.3**	**8.4**	**7.5**	**10.7**	**1.6**
2nd Season											
Replication	3	5.1	7.0	6.7	89.8	75.9**	3789.5	25.1	2.2	9.6	807.4
Cultivar	17	31.2**	19.6**	24**	131.9**	144.5**	6703.3**	79.6**	25.9**	12.9**	4953.0**
bread vs. durum	1	136.9**	6.0	85.6**	1.9	210.1**	1782	513.9**	75.5**	6.9	21615.3**
		25.8	1.8	21.0	0.1	8.6	1.7	38.0	17.0	3.1	21615.3
Residul	51	3.1	2.8	4.8	36.0	12.9	1443.9	21.1	9.5	4.1	486.2
Coeff. of variation (CV)		**2.1**	**1.2**	**3.9**	**11.1**	**3.4**	**11.3**	**11.1**	**5.8**	**10.0**	**1.9**

In parentheses indicates the ratio between the contrast sum of squares and the cultivar sum of squares.
* and **: Significant and highly significant (P) 0.05 and 0.01 priority levels, respectively.

3-3 Mean performance of agronomic traits and grain yields:

The mean performance of earliness characters was summarized in (Table 5 and Fig. 2). Results showed that the latest heading cultivars with the longest DH were recorded by Misr 2, Sids 14, and Misr 4 (96.3, 95.0, and 93.0 days, respectively) from the bread wheat group in the first season, while, their corresponding DM recordings (146.5, 143.75, and 143.5 days, respectively). During the second season, the wheat plants recorded shorter days to heading and maturity for bread & durum wheat cultivars. In the second season, the days to heading decreased by 11.3 % for the bread wheat group and by 7.4 % for the durum wheat group compared to the first season. Meanwhile, days to maturity decreased by 2.3 % for both bread and durum wheat groups (Table 5). Further, the lowest grain-filling period was recorded by Nubaria 1, Shandaweel 1 and BeniSweif 6 (durum wheat) (48.25 days), while the highest GFP was recorded by Sids 12, Sohg 5 and BeniSweif 5(durum wheat) (57.75, 53.5 and 52.75 days, respectively) at the first season. Giza 171 and Misr 3 (bread wheat) showed the highest GFP (62.25 and 61.25) compared to other tested cultivars in the second season. It's important to note that the GFP increased by 14.4 % for bread wheat and 7.1% for durum wheat in the second season compared to the first. Misr 2 recorded the highest grain-filling rates (71.80) in the first season, while Misr 4 was the highest one (71.80) in the second season compared to other tested cultivars (Table 5 and Fig. 2).

In the 2nd season, bread wheat cultivars showed a 15.0 % reduction in grain-filling rates, while durum cultivars exhibited the lowest reduction percentage (9.65 %) compared to the first season (Table 5).

Growing seasons of 2021-2022 and 2022-2023:

In addition, Misr 2 produced the tallest plants (116.25 and 115.0 cm). While Sids 12 and Sakha 95 produced the shortest plants (94.4 and 98.1 cm) in two seasons. Variation between the eighteen wheat cultivars indicated significantly different performances for growing degree days (Table 6 and Fig. 3).

The mean comparison for each group (bread wheat and durum) showed significant differences in growing degree days, where the bread wheat group registered the highest growing degree days in the first season. In the second season, the durum wheat group registered the highest growing degree days. Moreover, Sids 12 had the lowest GDD which matured after the accumulation of the smallest thermal units (1034.70 and 1062.60, respectively) compared to other tested cultivars in both seasons. Contrariwise, Misr 2 had the highest GDD which matured after the accumulation of the largest thermal units (1194.90 and 1197.90, respectively) in both seasons compared to other tested cultivars (Table 6 and Fig. 3).

Table 5. Mean values of earliness characters for eighteen wheat cultivars during the two growing seasons of 2021-2022 and 2022-2023.

Wheat Cultivar	Days to Heading			Days to Maturity			Grain Filling Period			Grain Filling Ratio		
	S 1	S 2	C.R. %	S 1	S 2	C.R. %	S 1	S 2	C.R. %	S 1	S 2	C.R. %
Misr 1	**90.8**	**80.0**	**▼ 11.8**	**140.5**	**139.5**	**▼ 0.7**	**49.8**	**59.5**	**▲ -19.6**	**64.6**	**50.6**	**▼ 21.6**
Misr 2	**96.3**	**84.8**	**▼ 11.9**	**146.5**	**143.5**	**▼ 2.0**	**50.3**	**58.8**	**▲ -16.9**	**71.8**	**58.8**	**▼ 18.1**
Misr 3	**91.3**	**79.3**	**▼ 13.2**	**142.5**	**140.5**	**▼ 1.4**	**51.3**	**61.3**	**▲ -19.5**	**65.1**	**52.2**	**▼ 19.8**
Misr 4	**93.0**	**82.3**	**▼ 11.6**	**143.5**	**137.0**	**▼ 4.5**	**50.5**	**54.8**	**▲ -8.4**	**68.9**	**64.1**	**▼ 7.0**
Sakha 95	**89.5**	**79.8**	**▼ 10.9**	**140.0**	**135.0**	**▼ 3.6**	**50.5**	**55.3**	**▲ -9.4**	**67.7**	**57.8**	**▼ 14.7**
Sids 14	**95.0**	**83.5**	**▼ 12.1**	**143.8**	**138.5**	**▼ 3.7**	**48.8**	**55.0**	**▲ -12.8**	**66.1**	**58.9**	**▼ 10.9**
Giza 171	**91.3**	**78.5**	**▼ 14.0**	**141.5**	**140.8**	**▼ 0.5**	**50.3**	**62.3**	**▲ -23.9**	**56.9**	**46.0**	**▼ 19.3**
Nubaria 1	**93.0**	**81.0**	**▼ 12.9**	**141.3**	**138.3**	**▼ 2.1**	**48.3**	**57.3**	**▲ -18.7**	**68.8**	**49.8**	**▼ 27.7**
Shandweel 1	**93.3**	**84.3**	**▼ 9.7**	**141.5**	**138.5**	**▼ 2.1**	**48.3**	**54.3**	**▲ -12.4**	**58.4**	**57.6**	**▼ 1.3**
Sids 12	**78.3**	**74.0**	**▼ 5.4**	**136.0**	**133.0**	**▼ 2.2**	**57.8**	**59.0**	**▲ -2.2**	**49.6**	**44.8**	**▼ 9.7**
Average	**91.2**	**80.8**	**▼ 11.4**	**141.7**	**138.5**	**▼ 2.3**	**50.6**	**57.8**	**▲ -14.4**	**63.8**	**54.1**	**▼ 15.0**
Benisweif 1	**90.3**	**84.5**	**▼ 6.4**	**141.3**	**138.3**	**▼ 2.1**	**51.0**	**53.8**	**▲ -5.4**	**61.5**	**57.2**	**▼ 7.0**
Benisweif 4	**88.0**	**82.0**	**▼ 6.8**	**142.0**	**139.0**	**▼ 2.1**	**54.0**	**57.0**	**▲ -5.6**	**58.6**	**50.6**	**▼ 13.7**
Benisweif 5	**88.8**	**82.3**	**▼ 7.3**	**141.5**	**138.5**	**▼ 2.1**	**52.8**	**56.3**	**▲ -6.6**	**66.7**	**55.6**	**▼ 16.7**
Benisweif 6	**93.8**	**84.3**	**▼ 10.1**	**142.0**	**139.0**	**▼ 2.1**	**48.3**	**54.8**	**▲ -13.5**	**54.7**	**56.3**	**▲ -2.9**
Benisweif 7	**91.5**	**83.8**	**▼ 8.5**	**144.5**	**139.3**	**▼ 3.6**	**53.0**	**55.5**	**▲ -4.7**	**70.6**	**62.3**	**▼ 11.6**
Benisweif 8	**90.8**	**84.0**	**▼ 7.4**	**142.0**	**139.0**	**▼ 2.1**	**51.3**	**55.0**	**▲ -7.3**	**68.8**	**57.9**	**▼ 15.7**
Sohg 4	**89.8**	**83.3**	**▼ 7.2**	**141.3**	**139.3**	**▼ 1.4**	**51.5**	**56.0**	**▲ -8.7**	**65.5**	**48.7**	**▼ 25.8**
Sohg 5	**88.8**	**84.0**	**▼ 5.4**	**142.3**	**140.0**	**▼ 1.6**	**53.5**	**56.0**	**▲ -4.7**	**41.9**	**46.3**	**▲ -10.5**
Average	**90.2**	**83.5**	**▼ 7.4**	**142.1**	**139.1**	**▼ 2.1**	**51.9**	**55.6**	**▲ -7.1**	**61.0**	**54.4**	**▼ 9.6**
P Value	**<.001**	**<.001**		**<.001**	**<.001**		**<.001**			**<.001**	**<.001**	
LSD 0.05	**2.62**	**2.48**		**2.44**	**2.57**		**3.36**	**3.1**		**9.69**	**8.48**	

S1: 1st season, S2: 2nd Season, C.R.%: Change Rate Average, LSD: Least Significant Difference, ▲: Increase and ▼ : Decrease, (P Values): < 0.05.

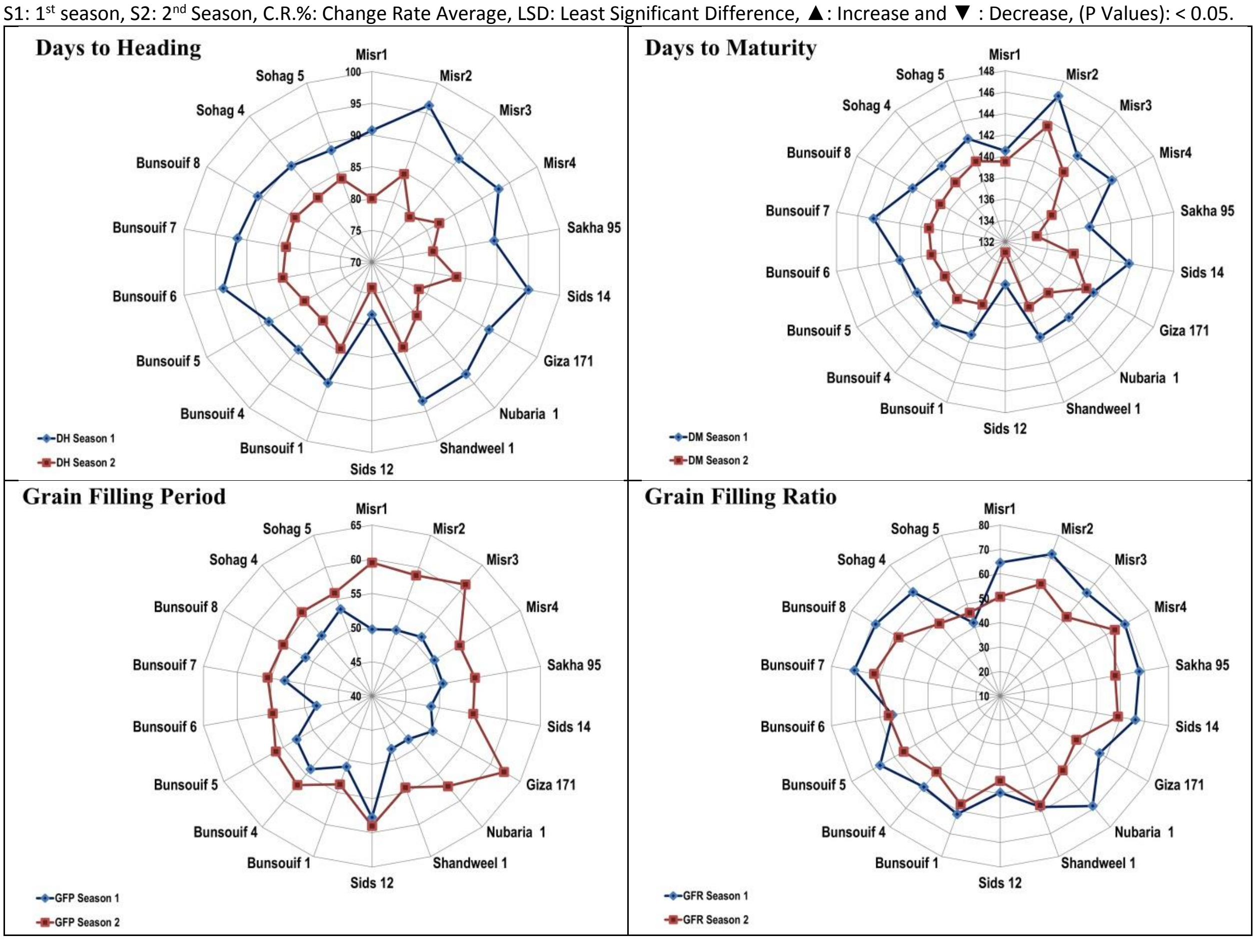

Fig. 2. Radar charts comparing mean values of earliness characters for eighteen wheat cultivars during the two

Table 6. Mean values of plant height and growing degree days for eighteen wheat cultivars during the two growing seasons of 2021-2022 and 2022-2023.

Wheat Cultivars	Plant Height (PH)		Change Rate %	Growing Degree Days (GDD)		Change Rate %
	Season 1	Season 2		Season 1	Season 2	
Misr 1	101.3	95.0	▼ 6.2	1140.2	1139.4	▼ 0.1
Misr 2	116.3	115.0	▼ 1.1	1194.9	1197.9	▲ -0.3
Misr 3	105.0	102.5	▼ 2.4	1144.7	1129.3	▼ 1.3
Misr 4	111.3	107.5	▼ 3.4	1163.2	1167.5	▲ -0.4
Sakha 95	115.0	110.0	▼ 4.3	1128.5	1135.6	▲ -0.6
Sids 14	113.8	112.5	▼ 1.1	1182.8	1182.7	▼ 0.0
Giza 171	112.5	110.0	▼ 2.2	1146.3	1119.3	▼ 2.4
Nubaria 1	107.5	107.5	▼ 0.0	1162.6	1152.3	▼ 0.9
Shandweel 1	110.0	107.5	▼ 2.3	1164.9	1191.5	▲ -2.3
Sids 12	102.5	95.0	▼ 7.3	1034.7	1062.6	▲ -2.7
Average	109.5	106.3	▼ 3.0	1146.3	1147.8	▲ -0.2
Benisweif 1	105.0	100.0	▼ 4.8	1134.7	1195.5	▲ -5.4
Benisweif 4	108.8	111.3	▲ -2.3	1115.3	1163.7	▲ -4.3
Benisweif 5	107.5	106.3	▼ 1.2	1121.3	1166.7	▲ -4.0
Benisweif 6	96.3	96.3	▼ 0.0	1169.9	1191.9	▲ -1.9
Benisweif 7	102.5	101.3	▼ 1.2	1147.1	1186.9	▲ -3.5
Benisweif 8	101.3	103.8	▲ -2.5	1139.4	1188.8	▲ -4.3
Sohg 4	98.8	100.0	▲ -1.3	1130.5	1179.3	▲ -4.3
Sohg 5	101.3	103.8	▲ -2.5	1121.8	1188.7	▲ -6.0
Average	102.7	102.6	▲ -0.2	1135.0	1182.7	▲ -4.2
P Value	<.001	<.001		<.001	<.001	
$LSD_{0.05}$	5.62	5.09		25.3	31.3	

S1: 1st season, S2: 2nd Season, C.R.%: Change Rate Average, LSD: Least Significant Difference, ▲: Increase and ▼ : Decrease, (P Values): < 0.05

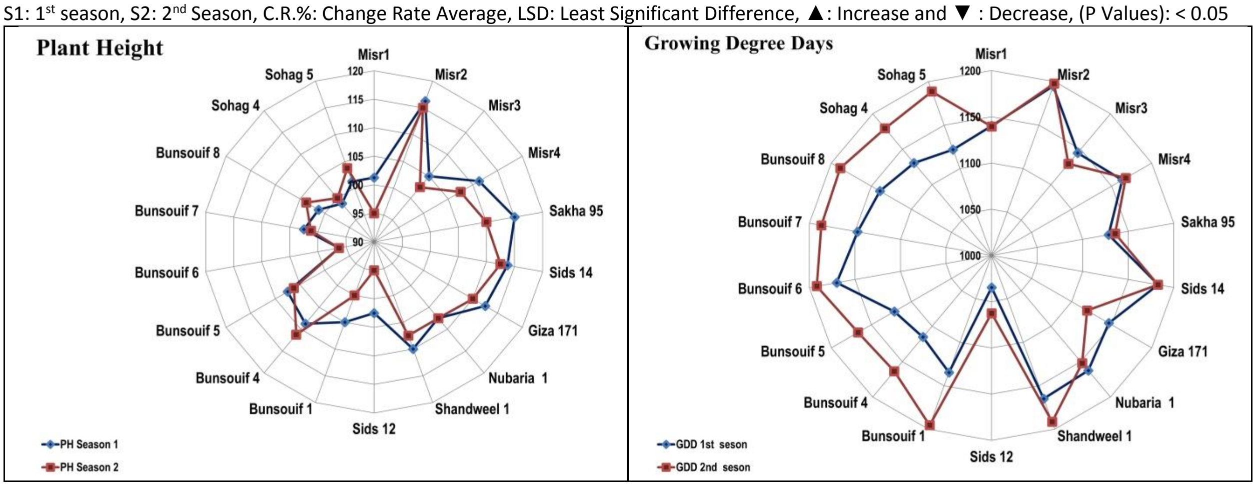

Fig. 3. Radar charts comparing mean values of plant height and growing degree days for eighteen wheat cultivars during the two growing seasons of 2021-2022 and 2022-2023.

The mean values for grain yield and related traits (NS/m^2, NK/S and TKW) were presented in (Table 7 and Fig 4). Highly significant cultivars effects ($p < 0.05$) were observed for these traits. In the bread wheat group, the NS/m^2 decreased by 8.9 % from the first season to the second season, compared to the durum wheat group. The lowest reduction in NS/m^2 was noted for the cultivars Misr 2 (0.2%), Misr 4 (2%), and Nubaria 1 (5.6 %) from the bread wheat group (Table 7 & Fig. 6). On the contrary, Benisweif 4, Benisweif 6, Sohg 4 and Sohg 5 showed an increase in the number of spike/m^2 by rate (6.2 %, 33.7 %, 3 %, and 15 %) respectively in the second season from the durum wheat group.

In the second season, the NK/S decreased for most cultivars, except for Cultivar Shandweel 1, which saw an increase of 6.4 (Table 7). In the first season, Cultivar Sids 12 had the highest NK/S or spikes at (55.1), while in the second season, Shandweel 1 recorded (47.9), both from the bread wheat group. On the other hand, cultivars Benisweif 8 and Benisweif 1 (48.30 and 47.05) respectively, have the highest NK/S in the first season from the durum group. It is worth mentioning that Benisweif 5 (42.6) and Benisweif 8 (45.5) had the highest in the second season (Table 7 and Fig. 4).

The performance of TKW is illustrated in (Fig. 4 and Table 7). Both bread wheat and durum genotypes exhibited significant variability in TKW. Over two growing seasons, Sids 12 and Giza 171 recorded the highest TKW values in the two seasons, measuring (50.7 g, 55.7 g, 49.3 g and 57.8 g), respectively. High TKW was noted in Benisweif 4, and Sohg 4 (54.1g and 53.7 g respectively, in the first season from the durum wheat group, while Benisweif 6 (57.3 g) and Benisweif 4(56.8 g) were the heaviest ones in the second growing season. The TKW increased by 11.3% for bread wheat and 11% for durum wheat in the second season compared to the first one (Table 7). Considerable differences were found among the 18 wheat cultivars regarding grain yield. The means of grain yield in the two growing seasons ranged from 14.9 for Shog 5 to 24.9 for Benisweif 7 Ardb/Fadan (Table 7).

As shown in Figure 4, When looking at all GY and its main components in the two growing seasons it is clear that cultivars Misr 2 (24.1) and Misr 4 (23.0) had the highest yields, from the bread wheat group while the cultivars Benisweif 7 (24.9), Benisweif 8 and Benisweif 5 (23.5) had the highest yields from the durum wheat group.

It is important to note that productivity decreased from the first season to the second season for both wheat groups (bread wheat and durum wheat). However, several varieties recorded an increase in productivity such as Misr 4 (1.3 %), Sids 14 (0.6 %), Giza 171 (0.2 %), and Shendweel 1 (10.9 %) in the bread wheat group. Additionally, Benisweif 6 experienced a 16.7% increase, while Sohg 5 increased by 15.3 % (Table 7).On the other hand, cultivar Sohg 5 exhibited the lowest GY overall cultivars in both growing seasons (Table 7 & Fig. 4).

3-4 Correlation coefficients analysis:

To address multicollinearity issues, we excluded attributes derived from mathematical calculations, such as the GFP, GFR, and GDD. GY is taken as the dependent variable, while the independent variables include DH, DM, PH, NS/m², NK/S, and TKW. Correlation coefficients between selected pairs of the studied traits across the two seasons were computed and graphically illustrated in (Fig. 5). The data distribution for each variable is displayed on the diagonal of the matrix. Below the diagonal, scatter plots that include a fitted line between each two studied traits. Additionally, the correlation values and their significance levels represented by stars, are shown above the diagonal.

Under experimental conditions, DH exhibited a highly significant and positive correlation with DM (r = 0.80***) and NS/m² (r = 0.56*). Conversely, it showed no significant correlation with PH, and GY and a significant negative correlation with NK/S (r = - 0.46*) and TKW (r = - 0.41*) (Fig. 5).

Fig. (5) showed that DM has a significant positive correlation with NS/m² (r = 0.52*) and significant negative correlation with NK/S(r = - 0.42*) and TKW (r = - 0.41*) and a non-significant positive correlation with PH, and GY.

Plant Height recorded no significant correlation with NS/m², NK/S, GY and TKW. There was a significant negative correlation between the NS/m² and TKW(r = - 0.47*).

On the other hand, GY showed a strong significant positive association with NS/m² (r = 0.81***), while it had a nonsignificant correlation with DH, DM, PH, and NK/S. In contrast, GY exhibited no significant negative correlation with TKW, with a coefficient of (r = - 0.17) (Fig. 5).

3-5 Strategies of variable selection:

The selection process included the following steps: (1) selecting variables with the highest absolute correlation to dependent variables after partial correlation and identifying those with the maximum R^2 values (Table 8). (2) to understand the actual effects of a character on the GY, we can estimate both direct and indirect impacts through path analysis (Table 9). (3) The AHP was utilized to develop a decision model that examined three key variables related to wheat production using partial correlation and path coefficients.

Three scenarios were considered: the first focused on selecting and breeding for the NS/m², the second for the NK/S, and the third for the TKW. These evaluations were conducted during the first and second growing seasons, as illustrated in (Fig. 8 and Tables 10 &11).

3-5-1 Partial correlation:

The partial correlation coefficients ranged from 0.241 (for DH versus GY) to 0.864 (for NSm^2 versus GY), as indicated in Table 8. GY showed a significant positive correlation with NSm^2 (0.864), NK/S (0.709), and TKW (0.627), with relative contributions of 74.65 %, 50.27 %, and 39.31 %, respectively (Table 8).

Table 7. Mean values of grain yield and its main components for eighteen wheat cultivars during the two growing seasons of 2021-2022 and 2022-2023.

Wheat Cultivars	Number of Spikes/m²				Number of Kernels/Spikes				1000 Kernel Weight				Grain Yield			
	S 1	S 2	C.R. %		S 1	S 2	C.R. %		S 1	S 2	C.R. %		S 1	S 2	C.R. %	
Misr 1	366.8	323.7	▼	11.7	49.4	40.3	▼	18.3	47.9	54.3	▲	-13.4	21.4	20.1	▼	6.5
Misr 2	429.0	425.2	▼	0.9	47.2	42.7	▼	9.5	42.5	48.4	▲	-13.9	24.1	23.0	▼	4.4
Misr 3	405.0	354.9	▼	12.4	42.3	41.2	▼	2.7	45.9	52.2	▲	-13.7	22.3	21.3	▼	4.3
Misr 4	378.5	370.9	▼	2.0	48.3	42.8	▼	11.5	49	52.6	▲	-7.5	23.0	23.3	▲	-1.3
Sakha 95	388.3	365.2	▼	5.9	46.8	43.6	▼	6.9	48.2	53.1	▲	-9.9	22.8	21.3	▼	6.5
Sids 14	387.0	322.1	▼	16.8	43.1	41.9	▼	2.8	47.6	52.5	▲	-10.2	21.5	21.6	▲	-0.6
Giza 171	293.0	250.4	▼	14.5	50.7	47.1	▼	7.1	49.3	57.8	▲	-17.1	19.0	19.1	▲	-0.2
Nubaria 1	356.3	336.2	▼	5.6	49.5	45.2	▼	8.6	46.6	51.0	▲	-9.4	22.2	18.9	▼	14.7
Shandweel 1	338.5	302.4	▼	10.7	45.1	47.9	▲	-6.4	46.8	50.3	▲	-7.7	18.8	20.8	▲	-10.9
Sids 12	285.8	261.2	▼	8.6	55.1	47.2	▼	14.3	50.7	55.7	▲	-9.9	19.1	17.6	▼	7.8
Average	362.8	331.2	▼	8.9	47.8	44.0	▼	7.5	47.5	52.8	▲	-11.3	21.4	20.7	▼	3.1
Benisweif 1	345.5	332.5	▼	3.8	47.1	39.2	▼	17.1	45.4	55.9	▲	-23.2	20.9	20.5	▼	1.7
Benisweif 4	298.3	316.7	▲	-6.2	46.2	39.6	▼	14.2	54.1	56.8	▲	-4.8	21.1	19.3	▼	8.9
Benisweif 5	356.5	323.7	▼	9.2	45.5	42.6	▼	6.2	52.7	55	▲	-4.4	23.5	20.8	▼	11.6
Benisweif 6	277.3	370.8	▲	-33.7	46.6	33.3	▼	28.5	51.1	57.3	▲	-12.1	17.6	20.5	▲	-16.7
Benisweif 7	403.0	354.2	▼	12.1	43.6	41.0	▼	5.8	50.6	53.3	▲	-5.3	24.9	23.0	▼	7.9
Benisweif 8	376.8	336.5	▼	10.7	48.1	45.5	▼	5.2	45.2	54.2	▲	-19.7	23.5	21.2	▼	9.7
Sohg 4	362.8	373.7	▲	-3.0	42.1	33.4	▼	20.7	53.7	55.1	▲	-2.7	22.5	18.1	▼	19.5
Sohg 5	279.8	321.8	▲	-15.0	42.5	34.3	▼	19.2	44.3	51.2	▲	-15.5	14.9	17.2	▲	-15.3
Average	337.5	341.2	▲	-2.8	45.2	38.6	▼	14.6	49.6	54.9	▲	-11.0	21.1	20.1	▼	3.4
P Value	<.001	<.001			0.002	<.001			<.001	0.003			<.001	<.001		
LSD 0.05	55.94	53.74			5.56	6.5			5.13	4.37			3.22	2.88		

S1: 1st season, S2: 2nd Season, C.R.%: Change Rate Average, LSD: Least Significant Difference,(P Values): < 0.05.

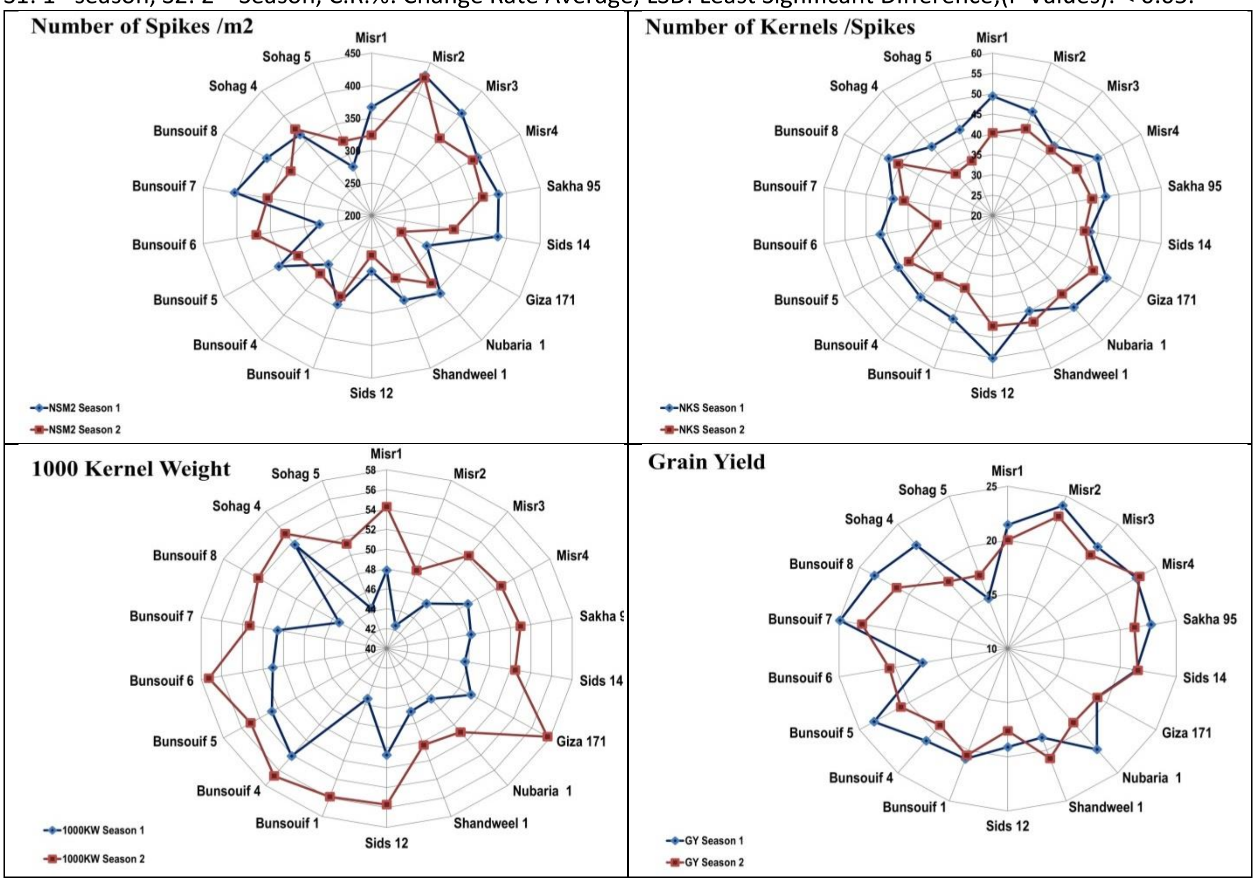

Fig. 4. Radar charts comparing mean values of grain yield and its main components for eighteen wheat cultivars during the two growing seasons of 2021-2022 and 2022-2023.

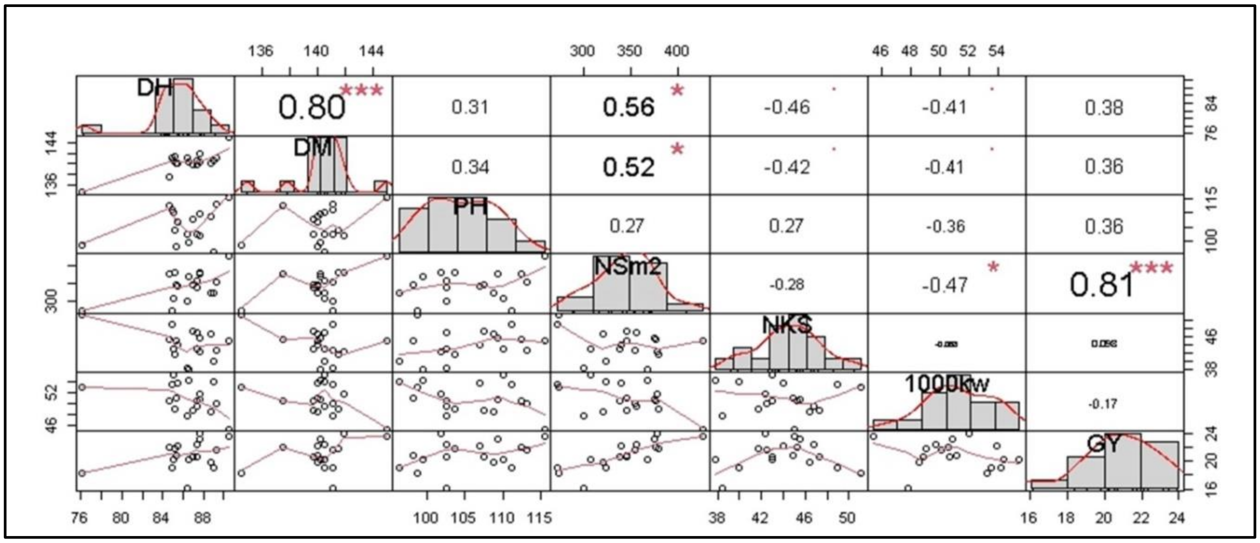

Fig. 5. Correlation matrix among, DH: Days to heading, DM: Days to maturity, PH: Plant Height (cm), NS/m^2: Number of spikes /m^2, NK/S: Number of kernels/spikes, TKW: 1000 kernel weight (gram) and GY: Grain Yield (ard/fed).

The magnitude of the correlation between the two traits NK/S, TKW and GY increased according to partial correlation compared to the person correlation coefficient. DH, DM, and PH exhibited nonsignificant positive partial correlation with GY with correlation coefficients being 0.241, 0.187, and 0.005, respectively and they had small relative contributions as shown in (Table 8).

Table 8. Partial Correlation matrix between GY and other traits across the two growing seasons

Variables	Partial Corr. Coeff.	Partial R^2 %	P-value
Days to heading (DH)	0.241	5.81	0.89
Days to maturity (DM)	0.187	3.50	0.314
Plant Height (PH)	0.005	0.00	0.981
Number of spikes /m^2 (NSm^2)	0.864	74.65	0.000
Number of kernels/spikes (NK/S)	0.709	50.27	0.000
1000 kernel weight (TKW)	0.627	39.31	0.000

3-5-2 Path coefficient analysis:

To understand the actual effects of a character on the GY, the direct and indirect effects were analyzed using path analysis (Table 9). The data were transformed to meet the assumption of additivity through a logarithmic transformation. Underlined numbers indicate positive direct effects (boldface). Values in the off-diagonal columns represent indirect effects on grain yield.

The association of various plant characteristics with traits of major interest and economic importance, such as grain yield, results from their direct and indirect effects.

Path analysis separates correlation coefficients into direct and indirect effects, which simple correlation estimates of yield and other traits may not capture. Results of Path coefficient analysis revealed that NS/m^2 had the highest positive direct effect on GY (0.998) followed by NK/S (0.647) and TKW (0.546) (Table 9). The NS/m², NK/S and TKW were the main factors affecting yield during the growth period (Table 9). NS/m² had the largest impact, contributing 37.14 %, while NK/S and TKW contributed 13.43 % and 9.57%, respectively, totalling 94.11 % of the yield variance.

It is important to note that the relationship among the three characteristics is an indirect inverse relationship, as illustrated in (Table 9). Specifically, as the NS/m² increases, the NK/S and the TKW decrease. Conversely, when NK/S rises, the NS/m² and the TKW tend to decrease. Additionally, when the TKW increases, there is a decline in the NS/m² and the NK/S. This phenomenon is known as a competitive relationship.

Table 9. Estimates of direct and indirect effects of grain yield components across two seasons.

Main yield determinants	Correlation coefficient			
	Log NS/m²	Log NK/S	Log TKW	Log GY
Log NS/m²	**1**	**-0.214**	**-0.388***	**0.726****
Log NK/S		**1**	**-0.432***	**0.181**
Log TKW			**1**	**- 0.151**
	Partitioning correlation coefficient via path analysis			
Log NS/m²	0.998	-0.139	-0.212	0.726
Log NK/S	-0.230	0.647	-0.236	0.181
Log TKW	-0.418	-0.280	0.546	-0.151
Relative importance (RI %)				
Log NS/m²	37.14	9.56	14.63	∑ (RI %) = 94.11
Log NK/S		13.43	9.79	
Log TKW			9.57	

Log: logarithmic transformation, NS/m²:Number of spikes /m², NK/S: Number of kernels/spikes, TKW: 1000 kernel weight (gram) and GY: Grain Yield (ard/fed).

3-5-3 Ranking the genotypes in three scenarios during the first and second seasons via the analytic hierarchy process (AHP):

3-5-3-a Prioritization of the weight for main tratis:

The first step in developing the analytic hierarchy process (AHP), after defining the parameters affecting wheat production, was to determine their weights. The three main traits were thoroughly compared. The weights were determined (Fig. 6) based on the scores assigned according to the study's purpose and expert knowledge, following the Satty scoring chart (Table 3).

The NS/m² trait had the highest weight in the decision matrix at 0.774, followed by NK/S at 0.135, and TKW at 0.121 in the first scenario. The decision matrix scenario two indicates that the maximum weight for NK/S is 0.744, followed by the number of spikes / m² at 0.135, and TKW at 0.121. In the third scenario, TKW received the highest weight of 0.774, followed by NS/m² at 0.135 and NK/S at 0.121. As shown in Figure 6, one criterion maximizing NS/m² is targeted for breeding, while the other two are minimized. These criteria include the number of kernels per spike (NK/S) and the weight of 1000 kernels (TKW).

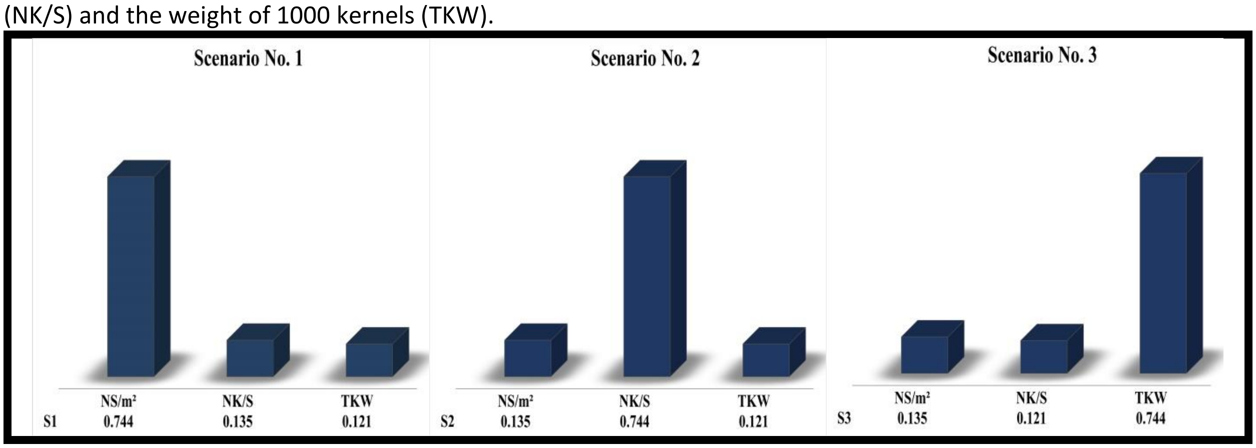

Fig. 6. The weight given by the three main yield components under the three proposed scenarios 1, 2, and 3.

3-5-3-b Ranking the genotypes using the analytic hierarchy process (AHP) first season:

In the second step, the selected traits for evaluation of the tested cultivars were subjected. Based on their relative importance, the analytic hierarchy process (AHP) matrix was designed. AHP revealed that grain yield varied across three scenarios based on genotypes across two seasons. The GY, NS/m², NK/S, and the TKW are presented in Tables 10 and 11. These tables display results from the first and second seasons, along with the ranking of genotypes. Additionally, the values derived from scores obtained through AHP weights across three scenarios are included. The ranking ascended from 1 to 18, with lower ranks having higher yield potential. The selection process was conducted at a 50% election rate, as illustrated by the arrows (Tables 10 and 11).

According to the first scenario, in the first season of the study, the genotypes were ranked as follows: for the bread wheat group, the highest scores were given to Misr 2, Misr 3, Sakha 95, Misr 4, Sids 14, and Misr 1. For the durum wheat group, the top-ranked genotypes included Benisweif 7, Benisweif 8, and Sohg 4.

The second scenario shows that Sids 12, Misr 1, Nubaria 1, Giza 171, Misr 4, Misr 2, and Sakha 95 achieved the highest scores in the bread wheat group. Additionally, Bunesouif 1 and Bunesouif 8 topped the rankings in the durum wheat group (Table 10).

In contrast, the third scenario recorded a greater variety of durum wheat that achieved higher ranks than bread wheat. This result may be attributed to the TKW for the durum wheat is higher than the bread wheat weight.

Accordingly, Sids 12, Misr 4, Sakha 95, and Misr 1 recorded higher scores for bread wheat, while Sohg 4, Benisweif 5, Benisweif 4, Benisweif 7, and Benisweif 6 recorded higher scores from the durum wheat group.

Notably, the two varieties, Sohag 5(durum wheat) and Shendweel 1(bread wheat) received a lower ranking than the other varieties in all three scenarios (Table 10).

Table 10. Means of NS/m^2, NK/S, TKW, GY and values of the scores among three scenarios in the first season

Geno.	NS/m^2		NK/S		TKW		GY		S_1		S_2		S_3	
	mean	R	mean	R	mean	R	mean	R	mean	R	mean	R	mean	R
Misr 1	366.8	↑ 8	49.4	↑ 4	47.9	↓ 10	21.4	↓ 11	218.3	↑ 8	64.4	↑ 2	63.2	↑ 9
Misr 2	429.0	↑ 1	47.2	↑ 7	42.4	↓ 18	24.1	↑ 2	240.3	↑ 1	62.7	↑ 7	58.7	↓ 17
Misr 3	405.0	↑ 2	42.3	↓ 17	45.9	↓ 14	22.3	↑ 8	229.0	↑ 3	57.9	↓ 17	60.9	↓ 13
Misr 4	378.5	↑ 6	48.3	↑ 5	49.0	↑ 8	23.0	↑ 5	223.4	↑ 5	63.8	↑ 5	64.3	↑ 6
Sakha 95	388.3	↑ 4	46.8	↑ 9	48.2	↑ 9	22.7	↑ 6	226.3	↑ 4	62.4	↑ 8	63.6	↑ 7
Sids 14	387.0	↑ 5	43.1	↓ 15	47.6	↓ 11	21.5	↓ 10	222.9	↑ 6	58.6	↓ 15	62.3	↓ 11
Giza 171	293.0	↓ 15	50.7	↑ 2	49.3	↑ 7	19.0	↓ 15	186.0	↓ 15	64.0	↑ 4	62.8	↓ 10
Nubaria 1	356.3	↓ 11	49.5	↑ 3	46.6	↓ 13	22.2	↑ 9	213.0	↓ 11	64.0	↑ 3	61.7	↓ 12
Shandweel 1	338.5	↓ 13	45.0	↓ 13	46.7	↓ 12	18.8	↓ 16	202.5	↓ 13	59.3	↓ 14	60.7	↓ 14
Sids 12	285.8	↓ 16	55.1	↑ 1	50.7	↑ 5	19.1	↓ 14	185.3	↓ 16	68.0	↑ 1	64.6	↑ 5
Benisweif 1	345.5	↓ 12	47.1	↑ 8	45.4	↓ 15	20.8	↓ 13	206.1	↓ 12	61.2	↑ 9	59.9	↓ 16
Benisweif 4	298.3	↓ 14	46.2	↓ 11	54.1	↑ 1	21.1	↓ 12	188.3	↓ 14	60.5	↓ 11	66.8	↑ 3
Benisweif 5	356.5	↓ 10	45.5	↓ 12	52.7	↑ 3	23.5	↑ 3	213.8	↓ 10	61.0	↓ 10	66.9	↑ 2
Benisweif 6	277.3	↓ 18	46.6	↓ 10	51.0	↑ 4	17.6	↓ 17	177.3	↓ 17	59.9	↓ 12	63.4	↑ 8
Benisweif 7	403.0	↑ 3	43.6	↓ 14	50.6	↑ 6	24.9	↑ 1	231.8	↑ 2	59.8	↓ 13	65.7	↑ 4
Benisweif 8	376.8	↑ 7	48.0	↑ 6	45.2	↓ 16	23.5	↑ 4	220.4	↑ 7	62.9	↑ 6	60.6	↓ 15
Sohg 4	362.8	↑ 9	42.1	↓ 18	53.7	↑ 2	22.5	↑ 7	214.9	↑ 9	57.9	↓ 16	67.4	↑ 1
Sohg 5	279.8	↓ 17	42.5	↓ 16	44.3	↓ 17	14.9	↓ 18	173.3	↓ 18	55.0	↓ 18	56.5	↓ 18
Mini	277.3		42.1		42.4		14.9		173.3		55.0		56.5	
Maxi	429.0		55.1		54.1		24.9		240.3		68.0		67.4	

NS/m^2: Number of Spikes /m^2, NK/S: Number of Kernels/Spikes, TKW: Weight of 1000 Kernels, R: Rank of genotypes, GY: Grain Yield, S1: first scenario, S2: second scenario and S3: third scenario, ↑: Increase and ↓: Decrease

3-5-3-c Ranking the genotypes using the analytic hierarchy process (AHP) second season:

The rankings for genotypes in the three scenarios are shown in (Table 11) for the second season. The ranking results are different under various scenarios in the second season. Additionally, shaded arrows mark the genotypes that are ranked in the top or bottom nine-order positions across all scenarios. When maximizing NS/m^2 for breeding (Scenario 1), Misr 2 irrespective of its low TKW(ranked as the last one) emerges as the highest producer regarding GY via NS/m^2, followed by Misr 4, Sakha 95, and Nubaria 1 from the bread wheat group. Concerning, the durum wheat group it shows that Sohg 4, Benisweif 6, Benisweif 7, and Benisweif 8 as the next most appealing and tolerant genotypes. Conversely, Giza 171, Sids 12, and Shandweel 1 are identified as the least tolerant genotypes (Table 11).

In the second scenario which aims to maximize the NK/S in breeding programs, improved score values were achieved for several bread wheat varieties, including Shandweel 1, Sids 12, Giza 171, Nubaria 1, Sakha 95, and Misr 2. Meanwhile, the durum wheat varieties Benisweif 8 and Benisweif 5 attained the highest score.

The results of the third scenario showed that the bread wheat genotypes Giza 171, Sids 12, and Sakha 95 received the highest scores. In contrast, the durum wheat genotypes Benisweif 6, Benisweif 4, Benisweif 1, Benisweif 8, and Shog 4 achieved the highest scores.

Table 11. Means of NS/m^2, NK/S, TKW, GY and values of the scores among three scenarios in the second season

Geno.	NS/m^2		NK/S		TKW		GY		S_1		S_2		S_3	
	mean	R	mean	R	mean	R	mean	R	mean	R	mean	R	mean	R
Misr 1	323.7	↓ 12	40.3	↓ 13	54.3	↑ 8	20.0	↓ 12	196.5	↓ 12	55.3	↓ 13	66.6	↓ 12
Misr 2	425.2	↑ 1	42.7	↑ 8	48.4	↓ 18	23.0	↑ 2	239.3	↑ 1	59.1	↑ 7	63.8	↓ 16
Misr 3	354.9	↑ 6	41.2	↓ 11	52.2	↓ 14	21.3	↑ 5	210.1	↑ 7	56.6	↓ 11	65.6	↓ 13
Misr 4	370.8	↑ 3	42.8	↑ 7	52.6	↓ 12	23.3	↑ 1	218.3	↑ 2	58.6	↑ 8	66.7	↓ 10
Sakha 95	365.2	↑ 5	43.6	↑ 6	53.0	↓ 11	21.3	↑ 6	216.6	↑ 3	59.4	↑ 6	67.1	↑ 9
Sids 14	322.1	↓ 13	41.9	↓ 10	52.5	↓ 13	21.6	↑ 4	196.0	↓ 13	56.6	↓ 10	65.1	↓ 14
Giza 171	250.4	↓ 18	47.1	↑ 3	57.7	↑ 1	19.1	↓ 14	167.0	↓ 18	60.4	↑ 4	68.6	↑ 2
Nubaria 1	336.2	↑ 9	45.2	↑ 5	51.0	↓ 16	18.9	↓ 15	203.7	↑ 9	60.0	↑ 5	64.7	↓ 15
Shandweel 1	302.4	↓ 16	47.9	↑ 1	50.3	↓ 17	20.8	↑ 8	189.5	↓ 16	61.7	↑ 1	63.7	↓ 17
Sids 12	261.2	↓ 17	47.2	↑ 2	55.7	↑ 5	17.6	↓ 17	171.7	↓ 17	60.6	↑ 3	67.2	↑ 7
Benisweif 1	332.5	↓ 10	39.0	↓ 15	55.9	↑ 4	20.5	↓ 11	200.3	↓ 10	54.3	↓ 15	68.0	↑ 4
Benisweif 4	316.7	↓ 15	39.6	↓ 14	56.7	↑ 3	19.3	↓ 13	193.9	↓ 14	54.7	↓ 14	68.4	↑ 3
Benisweif 5	323.7	↓ 11	42.6	↑ 9	55.0	↑ 7	20.8	↑ 9	198.3	↓ 11	57.7	↑ 9	67.7	↑ 6
Benisweif 6	370.8	↑ 4	33.3	↓ 18	57.2	↑ 2	20.5	↓ 10	213.3	↑ 5	49.2	↓ 16	68.9	↑ 1
Benisweif 7	354.2	↑ 7	41.0	↓ 12	53.3	↓ 10	23.0	↑ 3	210.2	↑ 6	56.6	↓ 12	66.6	↓ 11
Benisweif 8	336.5	↑ 8	45.5	↑ 4	54.2	↑ 9	21.2	↑ 7	205.5	↑ 8	60.8	↑ 2	67.8	↑ 5
Sohg 4	373.7	↑ 2	33.4	↓ 17	55.1	↑ 6	18.1	↓ 16	213.6	↑ 4	49.1	↓ 17	67.1	↑ 8
Sohg 5	321.8	↓ 14	34.3	↓ 16	51.2	↓ 15	17.2	↓ 18	190.1	↓ 15	48.7	↓ 18	62.4	↓ 18
Mini	250.4		33.3		48.4		17.2		167.0		48.7		62.4	
Maxi	425.2		47.9		57.7		23.3		239.3		61.7		68.9	

NS/m^2: Number of Spikes /m^2, NK/S: Number of Kernels/Spikes, TKW: Weight of 1000 Kernels, R: Rank of genotypes, GY: Grain Yield, M: mean S_1: first scenario, S_2: second scenario and S_3: third scenario, ↑ : Increase and ↓ : Decrease

DISCUSSION

Microclimate agricultural productivity factors are air temperature, wind speed and direction, soil moisture, soil temperature, radiation distribution, soil acidity, and CO_2 level, by restricting these factors, crop production quality and output an increased **(**Majumder *et al.,* 2024). In southern Egypt, wheat is typically sown with the arrival of winter, specifically during the first two weeks of November. Air temperature significantly affects wheat production, with an optimal growth range of 16–26 °C (Sharma *et al.,* 2022; Gamal *et al.,* 2024).

The occurrences of heat stress during the wheat growing season have increased in the second season compared to the first one in the current study. The impact of warmer seasons on wheat production is a critical factor in climate change. As global temperatures continue to rise, longer and more intense warm seasons directly affect the growth cycle of wheat. Higher temperatures can cause the growing season to start earlier, speeding up the reproductive process and affecting the growth stages and production cycles. Additionally, warm seasons can lead to increased evaporation, causing dryness and creating water supply challenges for wheat cultivation (Yanagi, 2024).

Water vapours are measured, by RH but it is always relative to the temperature of the air. The humidity is closely linked to rainfall, wind, and temperature. Nevertheless, it is the primary factor that plays a significant role in crop production. It directly influences the water relations of plants and indirectly affects leaf growth, photosynthesis, pollination, the occurrence of diseases, and finally economic yield. High humidity at grain filling reduces crop yields. It is always safe to have a moderate RH of above 40%, for almost all crops (Ahmad *et al.,* 2023). Furthermore, high humidity reduces the irrigation water demand of crops as the evapotranspiration losses from crops are affected by atmospheric moisture. Also, very high RH increases the heat load of plants.

The primary objective of this study was to assess the yield and its components and their interrelationships under new-valley conditions.

Dagar *et al.,* (2022); Janni *et al.,* (2024) reported that combining drought and heatwaves leads to a production loss of cereals, including wheat, estimated at -11.3 %. In this study, the main effect of temperature (Tables 4, 5, and

6) indicated the overall response of wheat production to high-temperature stress across various bread and durum wheat genotypes. The variation observed in all traits across 18 genotypes indicates significant heterogeneity among the evaluated genotypes, which will facilitate breeding efforts. Heat stress and increased thermal time accelerated crop development, shortening the generative phase from DM by 11% for bread wheat and 7.4% for durum wheat (Table 4). Higher air temperatures also led to earlier grain maturity. In this regard, (Pang *et al.,* 2024; Salama *et al.,* 2024) found that exposure of bread wheat to high temperatures significantly accelerates heading and physiological maturity, thereby shortening the grain filling period. Our findings confirmed that all genotypes were significantly impacted by high-temperature stress conditions, leading to a reduction in heading and maturity dates. Notable variability was observed among wheat genotypes in their ability to withstand heat stress. There was significant variability in the responses observed for all the measured parameters. Despite the difference in testing years, the heat stresses experienced by both bread and durum wheat reduced GY on average. Heat stress reduced yield-attributing parameters like PH, NK/Sm^2, and NK/S. This reduction contributed to an average decline in GY. Furthermore, heat stress affects plant reproduction by reducing pollen viability, decreasing fertilisation and resulting in fewer NK/S. High temperatures during grain filling can shorten this period, minimize grain size (TKW), and alter the starch and protein composition, impacting yield and quality. Wheat crops growing in hot, stressful environments usually complete their life cycle earlier than in more favourable conditions. Genotypes that reach the heading and flowering stages earlier are preferred. These findings are harmonic with those of (Lamba *et al.,* 2023; Bhandari and Poudel 2024; Maity *et al.,* 2024; Pang *et al.,* 2024), for bread wheat, (Chaouachi *et al.,* 2024; Groli, *et al.,* 2024) for durum wheat. The breeder should be aware of the nature of associations among traits. Efforts to boost GY wheat by increasing grain size (TKW) have faced challenges due to a negative relationship with grain numbers, such as the NS/m² and NK/S. Despite extensive research on grain numbers (GN) and grain weight (GW), the genetic basis of this trade-off is still unclear, posing a significant barrier to improving GY in wheat (Taranto *et al.,* 2023).

A system consists of essential components, and understanding their interactions is key to ensuring efficiency and effectiveness. Efficient and effective selection criteria based on various morphological, physiological, and biochemical traits should be used to screen genotypes for heat tolerance in wheat. Scatter plots and Pearson's correlation coefficients help illustrate the relationships between trait pairs and reveal linear associations (Trivisiol *et al.,* 2024). The correlation coefficient is a key statistical tool for selecting high-yielding genotypes by assessing relationships among traits. However, a simple correlation does not adequately reveal each trait's contribution to yield (Kumar *et al.,* 2024). The correlation coefficient has limitations for data analysis and classification because it only reflects the linear association and direction between datasets, without accounting for the influence of other variables. Yield is typically viewed as a polygenic trait, controlled by various other traits or components. Therefore, selecting solely based on correlation analysis might overlook indirect factors which may create misleading results (Patial *et al.,* 2023).

The concept of the partial correlation coefficient was introduced to address this limitation. Partial correlation analysis helps determine the true relationship between two datasets by controlling for the effects of other variables that might influence the correlation coefficient. This statistical method allows researchers to examine the relationship between two specific variables while filtering out the impact of additional variables (Ma *et al.,* 2022; Ejegwa *et al.,* 2023; Mao *et al.,* 2024). Our findings align with those of (Sabhyata *et al.*, 2024; Trivisiol *et al,* 2024), who observed that an increase in the number of spikes per square meter (NS/m²), the NK/S, and the TKW all contributed to higher grain yields in wheat. This suggests that high-yield-performing wheat genotypes can be identified indirectly by focusing on NS/m², NK/S, and TKW.

Correlation coefficients alone do not provide sufficient information for breeders. Therefore, path coefficients, which are recognized as standard partial regression coefficients, help to distinguish between the direct and indirect effects on the components of correlation coefficients. This method demonstrates the effect of a feature on yield and other features, making it essential to reveal the selection criteria (Karaman *et al.,* 2024). The path coefficient analysis provided a different perspective than the simple correlation analysis of the traits being studied.

Path coefficient analysis has become a valuable tool in breeding programs, helping to clarify the direct and indirect contributions of various traits to the economic yield of crop plants. Focusing on the selection of these traits can enable breeders to achieve desirable correlated responses that lead to higher productivity (Saini *et al.,* 2024). The path coefficient analysis helps study the magnitude of each effect, providing a clearer understanding of the complexities involved in the selection process (Okuyama *et al.,* 2020). It is used to establish precise relationships between cause and effect, identifying the direct, indirect, and total causal effects. The results indicated that NS/m^2 exerted the highest effects on grain yield, followed by NK/S and TKW. This suggests a direct relationship between these characteristics and grain yield. Hence, selection through these traits would result in a substantial positive effect on grain yield. These factors can be directly selected to improve yield. Additionally, they positively contribute to grain yield. These traits can be distinguished for the best-performing genotypes under heat stress conditions. To assess the suitability of bread and durum wheat genotypes for higher productivity and tolerance under heat stress conditions, the AHP ranked them based on three scenarios derived from the previously mentioned results. The AHP is used in various fields. Numerous studies have been conducted on its applications. Specifically, the AHP method effectively identifies purpose-oriented priorities and significant criteria, particularly in breeding research (Karaman *et al.,* 2024). AHP involves constructing and solving multiple criteria decision-making and planning problems. The goal is to assist decision-makers facing these challenges. Assume that K options must be assessed before selecting the best one. AHP is a multi-criteria decision-making method that uses pairwise comparisons. It relies on expert judgment to establish priority scales, emphasizing that individuals' experience and knowledge are as valuable in decision-making as the data they utilize **(**Biswas *et al.,* 2024; Makar *et al.,* 2024**).** The study finds that the (AHP) and the mean performance are highly consistent in Tables 10 & 11. The wheat genotypes, both bread and durum, with high comprehensive scores in the AHP are very adaptable, stable, and high-yielding, consistent with their performance in the field.

CONCLUSIONS

Heat stress affects wheat crops during germination and reproduction, prompting Egypt to develop heat-tolerant genotypes to boost production. ANOVA results indicate that Misr 2 and Misr 4 had the highest bread wheat yields, while Benisweif 5, 7, and 8 excelled in durum wheat. Selecting wheat genotypes with higher GY can be done indirectly using the NS/m^2, NK/S, and TKW. Eighteen genotypes of bread and durum wheat were evaluated using the AHP under heat stress conditions across three scenarios. In the high-production scenario for NS/m^2 the top genotypes include Misr 2, Misr 3, Sakha 95, Misr 4, Sids 14, and Misr 1 in bread wheat. For durum wheat, the highest-ranked were Benisweif 7, 8, and Sohg 4 in the first season. In the scenario measuring NK/S, leading bread wheat varieties were Sids 12, Misr 1, Nubaria 1, Giza 171, and Sakha 95, with Benisweif 1 and 8 topping the durum group. In terms of TKW, Sids 12, Misr 4, Sakha 95, and Misr 1 excelled in bread wheat, while Sohg 4 and Benisweif 5, 4, 7, and 6 performed well in durum wheat. In the second growing season, Misr 2 led in bread wheat, followed by Misr 4 and Sakha 95, while Sohg 4 and Benisweif 6, 7, and 8 were the top durum genotypes. The highest scores for NK/S were achieved by Shandweel 1, Sids 12, Giza 171, Nubaria 1, Sakha 95, and Misr 2 in bread wheat, and Benisweif 8 and 5 in durum. The third scenario saw Giza 171, Sids 12, and Sakha 95 top the bread wheat scores, while Benisweif 6, 4, 1, 8, and Sohg 4 excelled in durum wheat. Genotypes showing heat stress tolerance may be valuable for breeding in arid conditions. Farmers in Egypt's New Valley Governorate should consider cultivating these heat-tolerant varieties.

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فحص إمكانات إنتاجية بعض أصناف قمح الخبز و المكرونه تحت ظروف محافظة الوادي الجديد بإستخدام بعض الإجراءات الإحصائيه

مختار مراجع مختار جاب الله[1]– إيمان محمود احمد حسين[2]

1قسم بحوث القمح – معهد بحوث المحاصيل الحقلية - مركز البحوث الزراعية.
2المعمل المركزي لبحوث التصميم والتحليل الإحصائي– مركز البحوث الزراعية.
بريد الباحث المراسل: eman.m.a.hussein@arc.sci.eg

يشكل الإجهاد الحراري تحديًا كبيرًا للزراعة في المناطق الجافة وشبه الجافة. تبحث هذه الدراسة في تأثير درجات الحرارة على إنتاجية ثمانية عشر صنفا من القمح (عشرة أنواع من قمح الخبز وثمانية أنواع من قمح المكرونه) مزروعة في الوادي الجديد بمصر خلال موسمي 2021-2022 و2022-2023 باستخدام تصميم القطاعات الكاملة العشوائية. تم فحص العلاقة بين المحصول والصفات المؤثرة علي المحصول تحت الإجهاد الحراري من خلال دراسة الإرتباط البسيط والجزئي و كذلك تحليل معامل المسار. تشمل الخصائص الرئيسية لإختيار أصناف القمح عالية المحصول عدد السنابل لكل متر مربع (NS/m^2)، وعدد الحبوب لكل سنبلة (NK/S)، ووزن 1000 حبة (TKW).

حددت العملية الهرمية التحليلية (AHP) معاملات الوزن 0.744 لـ NS/m^2 و 0.135 لـ NK/S و 0.121 لـ TKW. تركز معايير التربية على زيادة NS/m^2 مع تقليل NK/S و TKW لاختيار الأصناف المقاومة للحرارة في ثلاث سيناريوهات مختلفة. من الجدير بالذكر أن الأصناف مصر 2 و مصر4 و سخا 95 (قمح الخبز) و بني سويف 7 و بني سويف 8 و سوهاج 4 (قمح مكرونة) أظهرت تحملًا مماثلًا للحرارة في كلا موسمي النمو. يمكن أن تساعد هذه النتائج مربي النباتات في تطوير أصناف أكثر ملاءمة للظروف الأكثر دفئًا وجفافًا.

الكلمات المفتاحية: الوادي الجديد، قمح الخبز، المكرونه عملية التسلسل التحليلي الهرمي (AHP)، وتحليل معامل الإرتباط الجزئي، وتحليل معامل المسار.