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GENOTYPE X SOWING DATE INTERACTION EFFECT ON PRODUCTIVITY PERFORMANCE AND STABILITY OF WHEAT UNDER NEW VALLEY CONDITIONS

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ABSTRACT

Improving wheat productivity in Egypt's newly reclaimed desert lands, such as the New Valley, is vital for national food security. This study was designed to assess both yield performance and yield stability of 14 wheat cultivars (12 bread and 2 durum) when sown at three times (early, optimal, and late) during the 2022/2023 and 2023/2024 growing seasons. Data were collected on earliness, grain yield, and yield components. The analysis consisted of scatter plots, genotype x trait (G×T) biplots, and the multi-trait stability index (MTSI). Grain yield was greatest (approx. 25 ardb/feddan) for the optimal sowing date of November 20th, and early and late sowing reduced yield significantly (by approx. 20% and 39%, respectively). Consequently, mid-to-late November is the optimal sowing date. 'Misr 2' and 'Misr 4' were the highest yielding cultivars. The cultivars 'Sids 12', 'Sakha 95', 'Misr 1', and 'Misr 3' were identified as the most stable. Notably, the early maturing 'Sakha 96' performed better under late sowing, suggesting it is a valuable option for delayed planting dates.

Key Words: Wheat, Bread, Durum, Sowing dates, Grain yield, Adaptability and Multi-traits stability.

INTRODUCTION

Wheat is the foundation of global food security in that it provides staple food for more than one-third of the world’s population and is the primary source of caloric value and grain protein. In Egypt, wheat is beyond just an agricultural commodity; it is part of the national diet, culture, and socio-economic balance. However, Egypt has a large gap between local production and local consumption, and it is one of the largest wheat importers in the world. This reality is a significant threat to national food security and a big drain on the local economy. To this end, Egypt has developed an aggressive plan for horizontal agricultural expansion through the reclamation of desert lands. The El Wadi El Gedid (New Valley)

Governorate is a promising destination given the abundant land masses and availability of groundwater. These new environments are significantly different from the traditional soils and climate of the Nile Valley and Delta.

This necessitates applied research to determine the best agronomic practices that ensure sustainable productivity and successful cultivation in these areas. The selection of suitable and efficient wheat cultivars for coping with climatic changes is an important aspect to attain sustainable wheat productivity along with yield stability under abiotic stress and have the capacity to adapt to future climatic changes **(Mohiy *et al.,* 2021 and Dorrani-Nejad *et al.,* 2022).** The success of wheat cultivation in these new lands is integrally dependent on two synergistic factors: genetic selection and agronomic management. Selecting the right cultivar is the first step to high yields. Modern Egyptian wheat cultivars are dissimilar; they have different genetic makeups and thus are adapted to certain environments, potential yields, and biotic and abiotic stresses to varying degrees.

Abiotic stresses can significantly impact plant traits, resulting in decreases in grain yield potential. Wheat cultivars vary in their tolerance to abiotic stresses, and the selection of high-yielding, stress-tolerant cultivars has been a major component of wheat breeding programs in Egypt. The purpose of the wheat cultivars is to increase production and yield potential and provide resilience to abiotic stress pressures and biotic threats. One of the most significant influences on wheat productivity is the sowing date of the genotypes, as yield and quality are very sensitive to the sowing date. Determining how the different planting dates impact wheat productivity across areas where additional land is being cultivated is essential to optimize agricultural practices and ensure food security **(Ram *et al.,* 2020 and Neethu *et al.,* 2024).**

Therefore, genotype × sowing date interaction is a common focus of research to optimize productivity. Wheat breeding projects have the goal of increasing grain yield and earliness in wheat cultivars. Wheat breeders are challenged by negative drives such as favorable trade-offs for the yield components and genotype × environment interactions. Extensive field work was done to evaluate bread and durum wheat genotypes under abiotic stress conditions. Several stress tolerance indices exhibited strong relationships with each other, allowing for efficient ranking of stress-tolerant genotypes and the use of only a composite index. These processes resulted in new wheat cultivars adapted for hostile environments and newly developed reclaimed lands **(Liu *et al.,* 2021; El Fanah *et al.,* 2023).**

Graphical tools that measure and yet can select genotypes using stress tolerances, yield measurements, and associated traits include genotype-by-trait (GT) and the use of genotype-by-yield x trait (GYT) biplot graphs. Out of many options, these are incredibly efficient for interpreting the interpreted data. With breeding exercises, there are genotypes that correlate in some way, based on traits that are observed, meaning there are elite genotypes for grain yield and associated traits **(Ram *et al.,* 2020, El Fanah *et al.,* 2023)**; hence, the multi-trait stability index (MTSI) can be thought of as a science-based platform to define genotype performance and stability as a breeding strategy that includes multiple traits and environments or traits. The MTSI, by including grain yield and associated traits, meaning by creating a synthesis via component analysis by traits, is hence seen as a multi-purpose estate to measure the stability of high-yield genotypes. When adding both the development-adapted wheat cultivars and facilitating the global breeding projects, the aim is to unlock and increase the reliability of genotype assessment **(Pezeshkpour *et al.,* 2024)**. The purpose of the investigation was to determine the impact of the sowing date on the yield performance of 14 bread and durum wheat cultivars in new and diverse soil types and climatic zones. The objective was to ascertain the maximum yield with respect to earliness with regard to crops of wheat genotype for each sowing date and, multi-statistically and with MTSI, determine the best wheat vegetative growth and productivity for the respective sowing dates.

MATERIALS AND METHODS

Experimental site and plant materials

A field experiment was conducted at a private farm in Abo Huraira village, Al Farafra, New Valley Governorate, Egypt (27.0628° N, 27.8923° E). The plant materials consisted of 14 wheat cultivars: 12 bread (*Triticum aestivum* L.) and two durum wheat (*Triticum durum* Desf.). Names, pedigrees, and origins of all cultivars are detailed in Table 1. Before planting in each season, soil samples were collected from the experimental site at a depth of 0-30 cm for physical and chemical analysis (Table 2). The monthly mean air temperature (^{0}C) during the two growing seasons is depicted in (Fig.1).

Experimental design and field management

The fourteen wheat cultivars were evaluated in three planting dates: early (November 5), optimal (November 20), and late (December 5). Each sowing date was represented by a separate experiment laid out in a randomized complete blocks design (RCBD) with three replications.

The plot area was 4.2 m², organized in six rows 3.5 meters long with a spacing of 20 cm. The seeding rate was 400 seed m^{-2}. The fertilizers in each experiment were applied according to prevailing recommendations for the same region. Phosphorus was applied during seedbed preparation, at a base rate of 200 kg fed^{-1} (1 fed = 0.42 ha) of single superphosphate (15.5% P_2O_5). For potassium, this was applied at 50 kg fed^{-1} of potassium sulphate (48% K_2O) before seedbed preparation. Nitrogen fertilizer was applied at a rate of 300 kg fed^{-1} in the form of ammonium nitrate (33.5% N), split into five equal doses. Surface irrigation was used to supply water as needed. Other standard agricultural practices were performed as recommended.

Table 1. Name, pedigree, selection history and origin of the studied bread and durum wheat cultivars

Name	Pedigree	Selection history
Sakha 95	PASTOR // SITE / MO /3/ CHEN / AEGILOPS SQUARROSA (TAUS) // BCN /4/ WBLL1.	CMA01Y00158S-040POY-040M-030ZTM-040SY-26M-0Y-0SY-0S.
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.
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.
Sids 14	BOW"S"/VEE"S"//BOW"S"/TSI/3/BANI SEWEF 1.	SD293-1SD-2SD-4SD-0SD.
Bani Sewef 5*	Dipper-2/Bushen-3.	CDSS92B128-1M-0Y-0M-0Y-3B-0Y-0SD.
Giza 171	SAKHA 93/GEMMEIZA 9.	S.6-1GZ-4GZ-1GZ-2GZ-0GZ.
Bani Sewef 7*	CBC509CHILE//SOOTY_9/RASCON_37/9/USDA595/3/D67.3/ABI//CRA/4/ALO/5/HUI/YAV_1/6/ARDENTE/7/HUI/YAV79/8/POD_9.	CDSS02-Y01233T-0T0PB-0Y-0M-26Y-0Y-0SD.
Gemmeiza 12	OTUS/3/SARA/THB//VEE	CMSS97Y00227S-5y-010M-010Y-010M-2Y-1M-0Y-OGM
Sakha 96	MINO/6/Sakha 12/5/Kvz//Cno 67/Pj 62/2/Yd"s"/Blo"s"/4/K 134(60)/Vee.	S. 16869-010S-07S-1S-2S-0S.
Sids 15	PARUS/PASTOR//FIDTY-20/3/PASTOR//MILAN/KAUZICW11.	SD20063-2AP-0TR-1TR-0SD.
Gemmeiza 11	BOW"S"/KVZ"S"//7C/SER182/3/GIZA168/SAKHA 61.	GM7892-2GM-1GM-2GM-1GM-0GM.

* Durum wheat

Table 2. Chemical and physical soil properties of New Valley experimental site.

	2022/2023	2023/2024
Sand (%)	70.03	67.7
Silt (%)	20.75	21.4
Clay (%)	9.22	10.9
Texture grade	Sandy Loam	Sandy Loam
CaCo3 %	3.63	3.45
pH	7.68	7.80
EC (ds m^{-1})	0.82	0.74
N (ppm)	10.22	11.30
P (ppm)	7.41	5.70
K (ppm)	225.00	290.00

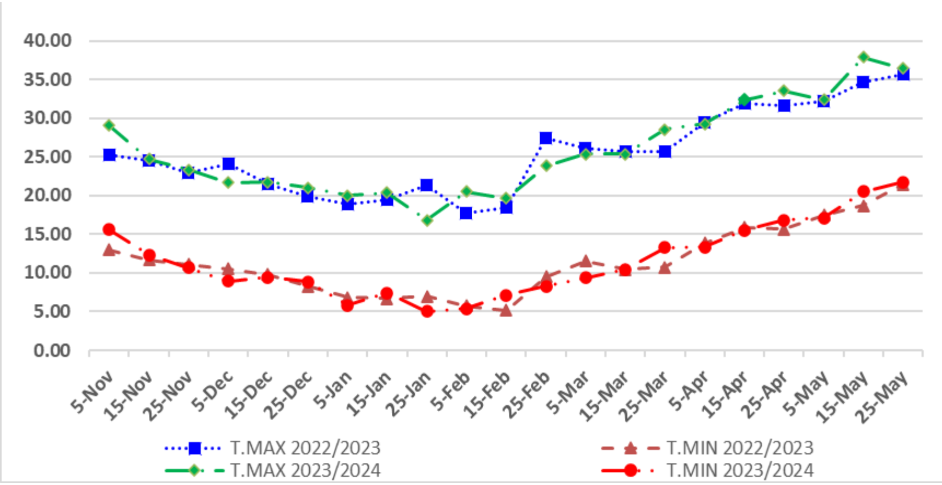

Figure 1. Mean 10-day minimum (Min) and maximum (Max) air temperatures during the 2022/2023 and 2023/2024 seasons at New Valley.

Sampling and measurements

For each wheat cultivar, the agronomic characteristics of number of days to heading (DH, day), number of days to maturity (DM, day), grain filling period (GFP, the number of days from heading to maturity), and grain filling rate (GFR, kg fed^{-1} $days^{-1}$ and equal to GY kg divided by GFP) were measured during the growing season. At harvest, data on grain yield and its attributes were recorded as follows: plant height (PLH) in cm, number of spikes per square meter (NSM^{-2}), number of kernels per spike (NKS^{-1}), and 1000-kernel weights (TKW, g: thousand-kernel weights).

At maturity, the four central rows in each plot were harvested to estimate the grain yield in kilograms per plot, which was converted to grain yield in ardabs per feddan (GY, ardb fed^{-1}, ardab = 150 kg, and one feddan = 4200 m²). Additionally, the time to heading was expressed in Growing Degree Days (GDD), calculated according to **Gomez & Richards (1997)** as GDD = Σ [(T_{max} + T_{min}) / 2 - Tb], where T_{max} and T_{min} are the daily maximum/minimum temperatures and Tb is the base temperature for development (Tb=0).

Statistical analysis

Prior to a combined analysis, **Levene's test (Levene, 1960)** was used to test homogeneity of error variances across the three sowing date experiments. As the test indicated that the variances were homogeneous ($P > 0.05$), the data were combined for an overall analysis of variance (ANOVA). Analyses of variance (ANOVA) was automated using **GENSTAT** software, **VSN International (2014),** and the treatment means were compared using the LSD test at 0.05 probability level according to **Waller and Duncan (1969).** A genotype by trait (GxT) biplot graph (a modified version of the GGE biplot graph) was employed by **Yan and Rajcan (2002).** Standardized values were used to illustrate the (GxT) biplot graph because the traits under study were assessed with multiple units. The (GxT) biplot graph was depicted using standardized values. The Multi-Trait Stability Index (MTSI) was constructed through R software using the Metan Ver. 1.9.0 for the multi-environment trial analysis tool, following **Olivoto & Lúcio (2020)**. The selection pressure was roughly at 25%.

RESULTS

According to the site characteristics, the soil in the experimental area was sandy loam, composed of 67.7% sand, 21.4% silt, and 10.9% clay. The soil pH is slightly alkaline at 7.80, and the electrical conductivity (EC) is low at 0.74 dS/m. These values suggest that salinity is not a factor limiting production, which will reduce the chances of salt stress affecting wheat grain yield. **Darwish and Fares (2020)** reported that we need to maintain low soil salinity and use an efficient irrigation schedule under sandy soils in New Valley in order to improve the wheat yield. As for the nutrient analysis, potassium levels were adequate, while nitrogen and phosphorus levels were low, indicating that we must fertilize regularly to ensure optimum plant nutrition. Soil characterization also indicated low carbonate accumulation, which would have reduced the risk of salt precipitation; low chloride also showed less risk for possible plant toxicity. The physicochemical properties of the soil are summarized in Table 2.

Figure (1) presents the variation in maximum and minimum air temperatures recorded during the two wheat growing seasons (2022/2023 and 2023/2024) in the New Valley region. Both seasons began with moderate maximum temperatures (~25°C in early November), which fell to a mid-winter (January) low and then rose consistently until late May, with the highest maximum temperatures occurring from late April to early May of each season. However, in the 2023/2024 season, maximum temperatures during grain filling and maturity (April to May) were higher (nearly 35°C) than the maximum temperatures, which were just over 30°C during the 2022/2023 season.

Minimum temperatures showed a similar seasonal trend; however, they were still higher in 2023/2024, particularly in December and January. Overall, this variability across seasons demonstrates the importance of accounting for genotype × environment interactions when assessing yield stability and adaptation, particularly under arid and semi-arid conditions.

Mean performance

Effect of sowing date on measured traits

The mean performance for days to heading (DH), days to maturity (DM), grain filling period (GFP), grain filling rate (GFR), and growing degree days (GDD) under the three sowing dates is detailed in Table 3. The early sowing date (5th Nov.) recorded the earliest heading (i.e., the lowest number of days to heading at 81.12 and 85.14 days in both seasons, respectively) and the longest grain filling period (60.88 and 57.36 days). In contrast, the 20th Nov. sowing date resulted in the highest number of days to heading (88.00 and 91.69 days) and to maturity (143.19 and 144.64 days), alongside the highest grain filling rate (68.08 and 72.12 kg fed^{-1} day^{-1}) and growing degree days (1313.21 and 1367.01°C). Finally, the late sowing date (5th Dec.) performed the lowest values for most earliness traits, including days to maturity, grain filling rate, and growing degree days, with the notable exception of days to heading.

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Effect of wheat cultivars

Wheat cultivars (Table 3) show significant varied responses regarding earliness characteristics and growing degree days across both seasons. Notably, Sakha 96 required the fewest days to reach heading (67.00 and 72.78 days) and maturity (129.11 and 133.67 days); besides, it accumulated the lowest growing degree days (1049.18 and 1113.10). In contrast, Sakha 96 exhibited the longest grain filling period (62.11 and 61.33 days) in the respective seasons. On the other hand, the bread wheat cultivar, Sids 15, recorded the highest number of days to heading (93.11 days) and the highest accumulation of growing degree days (1387.69), but it had the shortest grain filling period (50.22 days) in the first season, 2022/2023. Meanwhile, the wheat cultivar Sids 14 showed the longest duration for days to heading (95.33 days) and maturity (144.89 days) and accumulation of growing degree days (1408.93) in the second season. Notably, cultivar Misr 2 showed superiority, exhibiting the highest grain filling rate (60.86 and 72.49 kg/day/fed.) in both seasons, respectively.

Table 3. Mean performance of earliness traits of wheat cultivars under three sowing dates in both 2022/2023 and 2023/2024 seasons.

Sowing Date (SD)	DH* (day)		DM (day)		GFP (day)		GFR (kg/day/fed.)		GDD. C	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
5 Nov.	81.12	85.14	142.00	143.05	60.88	57.36	49.38	51.62	1291.30	1337.18
20 Nov.	88.00	91.69	143.19	144.64	55.19	53.60	68.08	72.12	1313.21	1367.01
5 Dec.	83.19	89.62	138.31	132.62	55.12	43.00	36.69	59.57	1196.4	1267.14
LSD 0.05	1.14	1.75	1.87	2.48	1.21	2.34	6.48	3.48	14.153	11.04
Cultivar (C)										
Sakha 95	83.33	89.78	140.78	138.67	57.44	48.89	51.31	67.62	1256.08	1335.46
Misr 1	83.78	86.44	140.56	138.22	56.78	51.78	54.49	62.95	1261.03	1295.15
Misr 2	86.78	93.78	144.22	142.00	57.44	48.22	60.86	72.49	1301.60	1406.07
Misr 3	83.78	91.22	142.11	141.11	58.33	49.89	49.22	60.67	1261.26	1336.54
Misr 4	85.22	93.11	142.33	141.89	57.11	48.78	53.73	68.00	1280.74	1373.88
Sids 12	81.56	82.67	135.89	138.78	54.33	56.11	55.32	59.20	1235.99	1243.23
Sids 14	85.78	95.33	144.33	144.89	58.56	49.56	46.08	56.62	1286.62	1408.93
Bani Sewef 5	86.00	90.67	145.56	141.11	59.56	50.44	48.47	59.75	1291.61	1350.38
Giza 171	82.89	89.89	142.89	139.67	60.00	49.78	44.11	61.54	1251.71	1338.74
Bani Sewef 7	87.11	90.56	142.89	140.78	55.78	50.22	51.24	61.95	1305.80	1347.67
Gemmeiza 12	84.22	93.22	142.78	139.78	58.56	46.56	44.30	61.33	1267.04	1381.52
Sakha 96	67.00	72.78	129.11	133.67	62.11	61.33	49.79	52.05	1049.18	1113.10
Sids 15	93.11	90.11	143.33	142.33	50.22	52.22	59.49	58.50	1387.69	1342.23
Gemmeiza 11	86.89	83.89	139.56	138.56	52.67	54.67	50.93	52.76	1301.05	1260.03
LSD 0.05	1.56	1.46	1.78	1.52	2.40	2.20	5.95	6.87	20.75	22.03

*DH; number of days to heading, DM: number of days to maturity, GFP: grain filling period, GFR: grain filling rate, GDD: growing degree days, S1:2022/2023, S2:2023/2024.

Effect of interaction (cultivars X sowing dates)

The interaction effect between wheat cultivars and sowing dates was significant on all earliness traits across both seasons (Table 4). Wheat cultivars exhibited divergent responses to the different sowing dates. Few cultivars showed an inverse relationship with sowing time. For instance, overall, the early cultivar Sakha 96 recorded the fewest days to heading across all sowing dates. While most cultivars headed faster with delayed sowing, Sakha 96 showed a distinct pattern: that the number of days to heading was increased under late planting (Table 4). This unusual response could indicate a cultivar-specific interaction with environmental variables like temperature or photoperiod. In addition, Sakha 96 had the longest grain filling period (71.33 and 66.33) with early sowing (5 Nov.) and the highest grain filling rate (68.44 and 75.85) with late sowing (5 Dec.).

Table 4. Mean performance of earliness traits as affected by the interaction of sowing dates and wheat cultivars in 2022/2023 and 2023/2024 seasons.

Cultivar	Sowing date	DH (day)		DM (day)		GFP (day)		GFR kg/day/fed.	
		S1	S2	S1	S2	S1	S2	S1	S2
Sakha 95	5 Nov.	81.00	88.33	141.00	142.00	60.00	53.67	54.99	57.67
	20 Nov.	86.67	93.67	142.00	143.33	55.33	49.67	67.44	79.95
	5 Dec.	82.33	87.33	139.33	130.67	57.00	43.33	31.50	65.23
Misr 1	5 Nov.	80.33	84.33	140.33	140.67	60.00	56.33	57.92	51.17
	20 Nov.	87.33	92.00	142.00	142.00	54.67	50.00	72.42	80.59
	5 Dec.	83.67	83.00	139.33	132.00	55.67	49.00	33.13	57.08
Misr 2	5 Nov.	83.33	90.67	144.33	146.00	61.00	55.33	59.61	59.60
	20 Nov.	94.00	101.67	145.67	148.67	51.67	47.00	84.85	90.03
	5 Dec.	83.00	89.00	142.67	131.33	59.67	42.33	38.12	67.85
Misr 3	5 Nov.	80.33	87.00	143.00	143.67	62.67	56.67	49.12	46.74
	20 Nov.	88.00	93.33	144.33	145.67	56.33	52.33	65.89	72.90
	5 Dec.	83.00	93.33	139.00	134.00	56.00	40.67	32.64	62.38
Misr 4	5 Nov.	82.67	90.00	143.00	146.33	60.33	56.33	52.86	58.19
	20 Nov.	92.00	96.67	144.33	147.00	52.33	50.33	77.65	86.14
	5 Dec.	81.00	92.67	139.67	132.33	58.67	39.67	30.68	59.66
Sids 12	5 Nov.	79.00	77.67	139.33	141.00	60.33	63.33	53.56	48.03
	20 Nov.	85.67	82.00	135.00	145.00	49.33	63.00	77.09	61.89
	5 Dec.	80.00	88.33	133.33	130.33	53.33	42.00	35.31	67.69
Sids14	5 Nov.	82.33	91.33	142.00	146.33	59.67	55.00	50.09	53.06
	20 Nov.	89.00	99.00	148.00	151.33	59.00	52.33	61.51	71.59
	5 Dec.	86.00	95.67	143.00	137.00	57.00	41.33	26.63	45.21
Bani Sewef 5	5 Nov.	84.33	86.67	146.33	143.00	62.00	56.33	48.03	52.03
	20 Nov.	90.67	94.00	147.00	147.00	56.33	53.00	69.75	71.27
	5 Dec.	83.00	91.33	143.33	133.33	60.33	42.00	27.63	55.95
Giza 171	5 Nov.	80.33	87.33	142.33	142.33	62.00	55.00	46.72	56.37
	20 Nov.	89.00	90.67	145.33	142.33	56.33	51.67	63.96	72.22
	5 Dec.	79.33	91.67	141.00	134.33	61.67	42.67	21.64	56.02
Bani Sewef 7	5 Nov.	85.33	87.67	142.33	144.33	57.00	56.67	53.77	54.34
	20 Nov.	92.67	93.33	145.00	143.67	52.33	50.33	73.59	79.53
	5 Dec.	83.33	90.67	141.33	134.33	58.00	43.67	26.37	51.98
Gemmeiza 12	5 Nov.	80.67	89.33	141.33	142.00	60.67	52.67	45.52	52.32
	20 Nov.	86.67	97.33	146.00	145.67	59.33	48.33	58.36	71.94
	5 Dec.	85.33	93.00	141.00	131.67	55.67	38.67	29.01	59.72
Sakha 96	5 Nov.	62.00	63.67	133.33	137.67	71.33	66.33	28.36	35.34
	20 Nov.	67.00	72.67	129.67	135.00	62.67	71.33	52.55	44.95
	5 Dec.	72.00	82.00	124.33	128.33	52.33	46.33	68.44	75.85
Sids 15	5 Nov.	90.33	87.33	147.00	146.00	56.67	58.67	46.40	50.58
	20 Nov.	93.00	90.00	146.00	145.00	53.00	55.00	67.38	64.93
	5 Dec.	96.00	93.00	137.00	136.00	41.00	43.00	64.70	59.99
Gemmeiza 11	5 Nov.	83.67	80.67	142.33	141.33	58.67	60.67	44.32	47.24
	20 Nov.	90.33	87.33	144.33	143.33	54.00	56.00	60.63	61.71
	5 Dec.	86.67	83.67	132.00	131.00	45.33	47.33	47.83	49.34
LSD 0.05		2.70	2.52	3.08	2.63	4.16	3.81	10.30	11.90

*DH; number of days to heading, DM: number of days to maturity, GFP: grain filling period, GFR: grain filling rate and S1:2022/2023, S2:2023/2024.

Likewise, Sids 15 showed an unusual response to sowing date, whereby the number of days to heading increased with delayed sowing. Sids 14 had the highest number of days to maturity in both seasons when sown on the best date, November 20th. Further, some cultivars had high rates of grain filling with late sowing, like Sakha 96, Sids 12, and Misr 2. Other cultivars, mostly the prominent ones (Misr 2, Misr 4, Misr 1, Bani Sewef 7, and Sakha 95), achieved peak performance at Nov 20th when they peaked GFR values.

Mean performance of plant height, grain yield and its components

Tables 5 and 6 show the average performance for plant height (PLH), grain yield (GY), and the main components of GY: number of spikes per square meter (NSM^{-2}), number of kernels per spike (NKS^{-1}), and 1000 kernel weight (TKW). The data shows the main effects of sowing dates and wheat cultivar and interactions between their meaning across the 2022/2023 and 2023/2024 growing seasons.

Effect of sowing date

Results in Table 5 shows that sowing on November 20th produced the highest mean values for all measured traits. The highest moisture yield was recorded for the 20 November sowing date; the grain yield was 24.84 and 25.28 ardab fed^{-1} for the two seasons, respectively. The NSM^{-2} values (343.41 and 362.42 spikes m^{-2}) and NKS^{-1} values (53.58 and 51.32) only clarified production, even though there were proportionally lower grain yields. Compared to the optimal Nov. 20th sowing, the early sowing on Nov. 5th resulted in an approximate 20% decrease in grain yield across both seasons, though it produced a relatively stable yield (19.90 and 19.62 ardab fed^{-1}, respectively). Nevertheless, it is curious to point out that while productive traits were less favorable since the grain yield was lower, the 1000-kernel weight recorded was the highest for the earliest sowing date.

The yield penalty in delaying the sowing date to December 5th was severe, with grain yield dropping more than 39%, or almost 50%, below the November 20th sowing date in both growing seasons. The December 5th sowing date was the lowest performance with grain yields of 13.08 and 17.05 ardb fed^{-1}. The NKS^{-1} values (44.33 and 43.65) and TKW (37.31 and 41.83 g) were also lower for the 1000 kernel weights, which meant that kernel development was at risk.

Effect of wheat cultivars

Results in Table 5 illustrate significant differences in cultivar performance for all studied traits. Comparing seasonal performance, most cultivars showed slightly higher grain yields and improved component traits in the second season compared to the first one. It was seen that all fourteen cultivars had one or more varietal characteristics to distinguish them from others. For example, the cultivar Misr 2 had the highest grain yield in both seasons of 22.89 and 23.09 ardb fed^{-1}. Yield was correlated with high values for plant height (approximately 114.44 cm in S1 and 116.67 cm in S2), NSM^{-2} values (378.22 in S1 and 391.19 in S2), and competitive NKS^{-1} (52.14 in S1 and 50.32 in S2) with a lower TKW compared to the other cultivars.

The grain yield of Misr 2 was statistically comparable to Misr 1 in season one and with Misr 1, Misr 4, Sakha 95, and Sids 12 in season two. To a lesser extent, cultivars Sids 12, Giza 171, Gemmeiza 11, and Bani Sewef 5 showed higher values for number of grains per spike and thousand-kernel weight compared to Misr 2 and had reductions in NSM□²; this impacted lower yield. In addition, Misr 3, Sids 14, and Sakha 96 were stable in grain yield, with Misr 3 producing 19.15 and 19.81 ardb/fed, Sids 14 yielding 18.02 and 18.91 ardb/fed, and Sakha 96 producing 19.77 and 20.27 ardb/fed in seasons one and two, respectively.

Effect of interaction (cultivars and sowing dates)

Analysis of variance confirmed a significant interaction ($P < 0.05$) between sowing dates and cultivars for several key traits, as detailed in Table 6. This interaction was season-dependent for some traits; for example, it was significant for plant height (PLH) and number of kernels per spike (NKS^{-1}) only in the second season, and for number of spikes per square meter (NSM^{-2}) only in the first one. In contrast, 1000-kernel weight and grain yield (GY) showed significant interaction across both growing seasons. The wheat cultivars and sowing dates had significant interaction effects on the agronomic characteristics recorded in both seasons (Table 6). At the later sowing date (5th December), the majority of the cultivars had high values for crop heights, NKS^{-1}, NSM^{-2}, and grain yield under the 20th November sowing date, implying that beneficial environmental conditions for vegetative and reproductive growth were achieved. Misr 2 and Sids14 exhibited the greatest heights measured (123.33 cm), whilst Bani-Sewef 5 was short-statured (86.67 cm) under the late sowing date (5th December). Bani-Sewef 5 clearly had some level of stress associated with the later planting. Under the second sowing date, Misr 2 exhibited the maximum number of spikes across all of the cultivars (430.00 NSM^{-2}), while Sids 15 produced the maximum number of spikes under the later sowing (421.52 NSM^{-2}). Sids 15 managed to maintain its ability to tiller vigorously despite the very late sowing date.

Overall, there was a general decrease in kernel number per spike with all cultivars with later sowing. The results reflect the detrimental effects of late planting on floral development and grain setting. Nevertheless, some cultivars, such as Sids 12, Sakha 96, Misr 2, and Gemmeiza 11, had high kernel numbers in both the 20th Nov. sowing date and late sowing. Most cultivars achieved the highest TKW at the 20th November sowing date, which probably indicates that this was the period of best grain filling.

By comparison, for the sowing date of 5th December, TKW showed general and marked reductions with the exceptions of Misr 4, Gemmeiza 12, and Bain Sewef 7, which are likely the result of earlier cessation of grain filling due to high terminal temperatures. For grain yield, the results indicated that the 20th November sowing date had the highest grain yield, which is ideal for growers hoping to achieve high grain yield. Some cultivars had a better yield than others as a result of favorable conditions during the first season, in descending order: Misr 2, Misr 4, Misr 1, Bani Sewef 5, Bani Sewef 7, and Sids 12.

In summary, one of the new cultivars, which was released this year and called Sakha 96, had a great performance in contrast to the other cultivars. Unlike most cultivars, Sakha 96 grain yield was increased with delayed planting. The advantage of Sakha 96 for improved performance was due to its ability to maintain more kernels per spike and a heavier 1000-kernel weight from fully compensating for terminal heat stress generally associated with later planting.

Table 5. Mean performance of plant height, grain yield and its components of wheat cultivars under three sowing dates in 2022/2023 (S1) and 2023/2024 (S2) seasons.

Sowing date	PLH (cm)		NS M^{-2}		NKS^{-1}		1000-KW, g		GY, ardeb/fed	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
5 Nov.	100.36	102.98	292.76	310.68	51.63	49.19	51.63	51.75	19.90	19.62
20 Nov.	105.71	114.17	343.41	362.42	53.58	51.32	51.43	50.94	24.84	25.28
5 Dec.	97.02	101.43	311.87	368.47	44.33	43.65	37.31	41.83	13.08	17.05
LSD 0.05	3.78	8.97	21.24	22.49	1.87	2.93	0.94	1.28	2.15	0.56
Cultivar										
Sakha 95	107.78	111.67	329.00	371.00	49.20	48.02	45.60	48.38	19.61	21.95
Misr 1	96.67	105.00	335.00	373.00	46.92	46.82	47.03	47.05	20.62	21.52
Misr 2	114.44	116.67	378.00	391.00	52.14	50.32	41.52	43.20	22.89	23.09
Misr 3	99.44	102.22	318.00	385.00	48.50	46.61	45.06	45.59	19.15	19.81
Misr 4	102.22	106.67	345.00	340.00	49.23	49.20	44.02	47.37	20.09	22.16
Sids 12	97.78	98.33	294.00	322.00	53.83	52.08	46.29	47.27	19.77	21.73
Sids 14	108.33	115.00	322.00	362.00	46.24	46.50	48.25	46.78	18.02	18.91
Bani Sewef 5	101.11	97.78	273.00	328.00	51.92	47.43	47.49	51.02	19.01	20.06
Giza 171	111.11	113.89	253.00	316.00	52.29	47.61	49.95	53.64	17.37	20.49
Bani Sewef 7	92.22	97.22	294.00	344.00	48.78	46.36	48.53	51.95	18.72	20.80
Gemmeiza 12	99.44	108.89	337.00	339.00	51.18	48.32	42.93	45.49	17.32	18.94
Sakha 96	88.89	98.33	305.00	325.00	49.37	47.89	52.87	49.14	19.77	20.14
Sids 15	97.78	107.78	366.00	367.00	45.49	44.83	43.53	45.47	19.63	20.27
Gemmeiza 11	97.22	107.22	275.00	296.00	52.72	50.77	51.97	52.04	17.87	19.24
LSD 0.05	4.36	3.63	31.76	33.84	4.89	3.99	3.22	2.61	2.03	1.95

*PLH; plant height, cm, NS M^{-2}: number of spikes per square meters, NKS^{-1}: number of kernel per spike, TKW:1000-kerenl weight, and GY, ardeb/fed; grain yield

Table 6: Mean performance of plant height, grain yield and its components as affected by the interaction of wheat cultivars and sowing dates in 2022/2023 (S1) and 2023/2024 (S2) seasons

Cultivar	Sowing date	PLH	NSM^{-2}	NKS^{-1}	1000-KW, g		GY, ardeb/fed	
		S2	S1	S2	S1	S2	S1	S2
Sakha 95	5 Nov.	110.00	317.00	50.53	49.62	51.10	21.93	20.63
	20 Nov.	121.67	340.00	49.60	53.54	53.16	24.92	26.44
	5 Dec.	103.33	329.00	43.93	33.64	40.87	11.98	18.77
Misr 1	5 Nov.	106.67	312.00	49.63	53.26	48.82	23.18	19.19
	20 Nov.	115.00	374.67	50.00	51.44	50.56	26.38	26.83
	5 Dec.	93.33	318.67	40.83	36.40	41.79	12.29	18.53
Misr 2	5 Nov.	116.67	350.00	50.08	43.31	46.43	24.27	22.01
	20 Nov.	123.33	430.00	52.37	46.56	43.82	29.24	28.17
	5 Dec.	110.00	354.67	48.50	34.70	39.35	15.15	19.10
Misr 3	5 Nov.	96.67	314.00	49.30	48.50	49.10	20.52	17.67
	20 Nov.	106.67	337.33	51.83	49.82	47.69	24.73	24.95
	5 Dec.	103.33	302.00	38.70	36.86	39.99	12.20	16.82
Misr 4	5 Nov.	103.33	334.67	49.85	50.78	50.92	21.23	21.86
	20 Nov.	113.33	389.33	52.55	50.34	49.88	27.07	28.87
	5 Dec.	103.33	310.67	45.20	30.92	41.31	11.98	15.76
Sids 12	5 Nov.	93.33	284.67	51.27	52.57	50.18	21.47	20.28
	20 Nov.	108.33	316.67	55.73	49.98	50.47	25.36	25.96
	5 Dec.	93.33	281.67	49.23	36.32	41.17	12.48	18.96
Sids14	5 Nov.	111.67	302.67	49.50	51.60	49.10	19.76	19.47
	20 Nov.	123.33	360.33	48.37	52.26	49.12	24.19	24.85
	5 Dec.	110.00	304.00	41.63	40.90	42.11	10.13	12.41
Bani Sewef 5	5 Nov.	95.00	248.33	52.85	52.92	54.19	19.76	19.54
	20 Nov.	111.67	326.67	49.37	50.56	55.54	26.16	25.02
	5 Dec.	86.67	243.33	40.07	38.98	43.34	11.11	15.62
Giza 171	5 Nov.	111.67	218.00	49.30	57.67	61.92	19.29	20.62
	20 Nov.	121.67	276.67	50.43	55.13	55.95	23.96	24.91
	5 Dec.	108.33	265.33	43.10	37.06	43.06	8.87	15.95
Bani Sewef 7	5 Nov.	93.33	257.33	51.50	57.05	57.73	20.44	20.55
	20 Nov.	108.33	338.67	53.03	55.74	53.45	25.51	26.70
	5 Dec.	90.00	286.00	34.53	32.80	44.67	10.20	15.16
Sakha 97	5 Nov.	106.67	329.33	46.17	51.35	50.94	18.36	18.34
	20 Nov.	115.00	398.67	54.20	46.88	48.08	22.87	23.07
	5 Dec.	105.00	282.67	44.60	30.56	37.46	10.73	15.42
Sakha 96	5 Nov.	88.33	245.33	48.83	52.40	50.03	13.53	15.65
	20 Nov.	101.67	287.33	45.27	57.99	50.35	21.93	21.35
	5 Dec.	105.00	382.67	49.57	48.23	47.06	23.85	23.43
Sids 15	5 Nov.	103.33	330.71	42.20	46.59	48.59	17.56	19.79
	20 Nov.	115.00	345.05	49.47	46.34	48.16	23.68	23.82
	5 Dec.	105.00	421.52	42.83	37.66	39.66	17.65	17.21
Gemmeiza 11	5 Nov.	105.00	254.52	47.67	55.13	55.39	17.31	19.11
	20 Nov.	113.33	286.43	56.27	53.49	56.92	21.83	23.04
	5 Dec.	103.33	284.05	48.39	47.29	43.82	14.47	15.56
LSD 0.05		6.28	55.01	7.11	5.58	4.52	3.51	3.38

*PLH; plant height, cm, NSM^{-2}: number of spikes per square mater, NKS^{-1}: number of kernels per spike, TKW:1000-kerenl weight, and GY, ardeb/fed; grain yield

Graphical presentations

1- Scatter plot of mean performance of wheat cultivars across the three sowing dates

The scatterplot presented in Figure 2 illustrates the grain yield performance of the 14 wheat cultivars across three sowing dates (5 Nov., 20 Nov., and 5 Dec.) in two seasons. The recommended sowing date (20th Nov.) produced about 25 ardab of wheat grain yield compared with around 20 ardb fed^{-1} in the early sowing date (5 Nov.) and around 15 ardb fed^{-1} in the late sowing date (5 Dec.). The results rank Misr 2 and Misr 4 as the best for stability and good grain yield over all sowing dates and seasons. The grain yield values for these cultivars grouped closely, usually at the high end of the performance range, which was over 28 ardeb fed^{-1} for most instances. Sakha 95 displayed solid performance as well, with reasonable yields over all planting dates. Its grain yield values ranged from 25 to around 27 ardeb fed^{-1} for the recommended sowing date, with slightly more variation in the second season, with late sowing conditions.

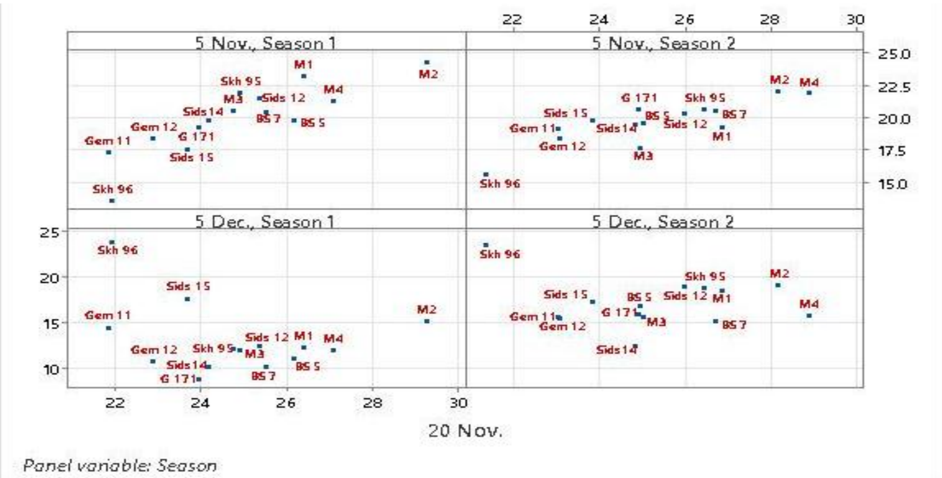

Fig. 2. Scatterplot for grain productivity of wheat cultivars (ardb fed^{-1}) under three sowing dates (5 Nov., 5 Dec. vs 20 Nov) in 2022/2023- 2023/2024 seasons.

In contrast, Sakha 96 had notably lower yields and more variation when sown early. For example, even with late sowing, Sakha 96 managed approximately 20 to 25 ardeb per feddan, indicating it was very susceptible to planting time. Therefore, being an early-maturing cultivar, Sakha 96 is more suited to late sowing than early sowing. The mid-levels of performance cultivars (Mids 2, Sids 12, Misr 1, and Misr 3) generated moderate grain yield values that fluctuated minimally with regard to sowing date and season. The cultivars such as Gemmeiza 11, Gemmeiza 12, Sids 14, and Sids 15 generally yielded low under most conditions. Therefore, the cultivars listed in the least adaptable group for this area were those that also generated amongst the lowest yield values.

2- Genotype * traits biplot graph

The G×T biplot analysis of wheat genotypes and traits shown in Figure 3 illustrated that principal component 1 (PC1) explained 46.37% of the total variation, while principal component 2 (PC2) explained a further 23.74% and together accounted for 70.11% of the total variation of the cultivars as related to their agronomic traits. The wheat genotypes were positioned in various quadrants which were associated with traits. Misr 2 and Misr 4 were strongly aligned with grain yield (GY) and number of spikes per square meter (NSM^{-2}), indicating high performance and a significant positive contribution of these traits. These genotypes were in the sector closest to GY, reinforcing their superiority in grain productivity. Similar patterns were observed for Misr 1, Misr 3, Sakha 95, and Sids 15, which were also positioned within the same trait-associated sector. Conversely, Sids 14 and Gemmeiza 12 were closely related to days to heading (DH) and days to maturity (DM), suggesting a tendency toward longer maturity periods for both cultivars.

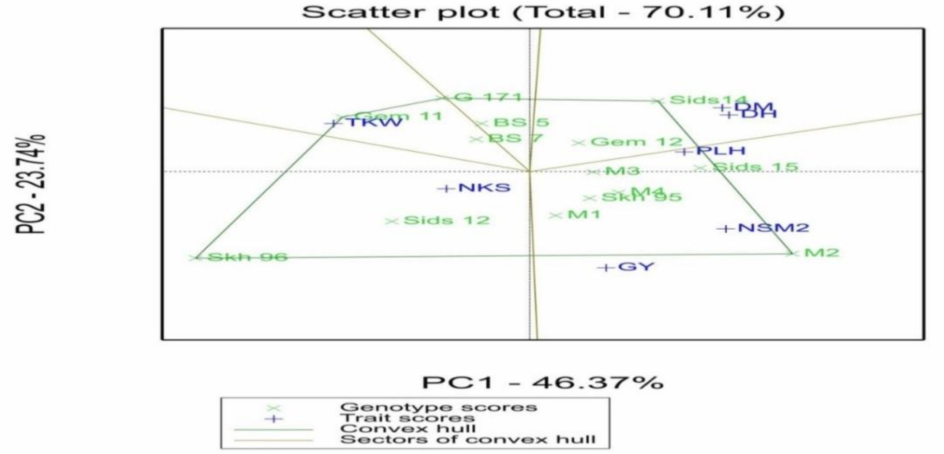

Fig. 3. G*T biplot graph (Total - 70.11%) of interaction of studied agronomic characters and wheat cultivars during 2022/2023- 2023/2024 seasons.

In contrast, the early maturing Sakha 96, placement was approximately 180° from the DH and DM traits indicating a negative association, meaning it has better performance under late sowing environments and less competitive yield capacity than much of the late maturing genotypes. Gemmeiza 11 and Giza 171 were also in proximity to TKW position, indicating some possible advantage with this trait related to grain yield performance.

Multi-Trait Stability Index (MTSI)

The Multi-Trait Stability Index (MTSI) provides a comprehensive evaluation for the productivity and stability of wheat cultivars by combining grain yield (GY) with key yield component traits, namely the number of spikes per square meter, the number of kernels per spike, and thousand-kernel weight, as shown in Table 7 and Fig. 4. In this study, the lower MTSI values reflect better performance and stability among environments for the 2022/2023 and 2023/2024 growing seasons.

According to Table 7, Sids 12 had the lowest MTSI value (0.372), therefore it was the most stable and productive genotype among the cultivars studied. Sakha 95 ranked second best with an MTSI of 0.541 followed in rank by Misr 1 (0.706) and Misr 3 (0.846). The identified most stable genotypes accounted for 90% of the variance explained in the Principal Component analysis (PCA): PC1 explained 71.6 %; PC2 accounted for 88.2%; PC3 contributed to 95.8% of the total variance. The remaining MTSI rankings (Misr 2 (1.16), Bani Sewef 5 (1.17), and Gemmeiza 12 (1.36)) indicated average/moderate stability and moderate productivity. These genotypes had adequate performance values, although these were lower than those of the top performance rankings. However, they relatively lacked the same adaptability and consistency. Genotypes Sakha 96 (4.45) and Bani Sewef 7 (2.15) had the greatest MTSI values indicating weak stability and productivity (likely fluctuating performance in the different environments) and did not have a chance to produce relatively stable yields.

Table 7. Multi-Trait Stability Index (MTSI) using grain yield (GY) and its main components (NSM^{-2}, NKS^{-1} and TKW) to estimate productivity and stability for wheat cultivars during 2022/2023- 2023/2024 seasons.

Cultivar	MTSI
Sids 12	0.372
Sakha 95	0.541
Misr 1	0.706
Misr 3	0.846
Misr 2	1.16
Bani Sewef 5	1.17
Gemmeiza 12	1.36
Gemmeiza 11	1.36
Sids14	1.41
Misr 4	1.64
Giza 171	1.89
Sids 15	1.89
Bani Sewef 7	2.15
Sakha 96	4.45

*Selected genotypes: Sids 12, Sakha 95, Misr 1 and Misr 3 with 90% of principal component analysis (PC1:71.6, PC2: 88.2 and PC3: 95.8)

The relationship between GY and the main components (NS/M2, NK/S, and TKW) in the MTSI-R plot illustrated significant variation in performance among genotypes in Fig 4. The selected genotypes (Sids 12, Sakha95, Misr 1, and Misr 3) were all located in close proximity to the ideal region of the MTSI-R plot. These genotypes provided optimal integration of high GY and trait stability performance. This was expected due to their lower MTSI; therefore, they have potential as cultivars under many potentially viable patterns of agricultural practice. Genotypes Misr 3, Misr 2, and Bani Sewef 5, were located in close proximity to the center of the MTSI-R plot indicating lower stability or more limited suitability for selection under the current field experimentation conditions. As above, values in this Figure are largely consistent with the scatter plot findings above.

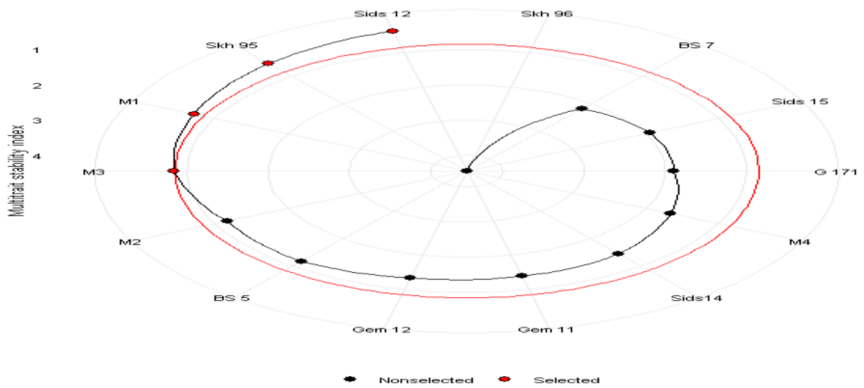

Fig.4. MTSI-R plot using grain yield and its components to estimate productivity stability for wheat cultivars during 2022/2023- 2023/2024 seasons.

DISCUSSION

Mean performance of earliness and grain yield traits

The temperature profiles for the two growing seasons were contrasting, which may be of significance in terms of crop response. The winter period was notably warmer in 2023/2024, which might have improved early season vigor **(Porter & Gawith, 1999)**, but this same season recorded higher maximum temperatures in the grain-filling period. It is well documented that terminal heat stress can reduce final kernel weight by reducing the grain-filling period **(Asseng *et al.*, 2011).** This may account for the tempo in 1000-kernel weight that occurred in 2023/2024, representing the effects of late-season heat in terms of wheat productivity.

For some earliness-based traits, sowing date was surprisingly influential: days to heading, days to maturity, grain filling period (GFP), grain filling rate (GFR), growing degree days (GDD), yield, and yield components.

The advantage of the sowing date of 20th November is apparent, as it produced the highest grain yield; this is likely attributable to the fact that the plant has had the opportunity to complete its life cycle in synchronization with environmental conditions favorable to it. Firstly, the moderate temperatures during early growth were helpful in prolonging the vegetative phase, meaning that it was a perfect sowing date for substantial growth necessary for tillering and achieving maximum spikes per unit area. Furthermore, the grain-filling phase was completed under ideal moderate temperatures, allowing for optimal assimilate partitioning and transportation strategies. The high number of grains per spike and increased kernel weight under the second sowing date indicate that this yield was primarily spatially determined and cyclically driven, considering how cultivar-specific sensitivity under thermal time and photoperiod determines yield potential. Thus, any variation from this sowing date (either earlier or later) alters this balance, as predictable yields are expected to be lowered heavily in this response. The information may further demonstrate that the high grain fill rate achieved in the late-sown cultivar illustrates the efficient conversion of assimilates into grain over a compressed time window due to physiological adaptation late in the season to stress. **Yahya et al. (2020)** showed that 23 November sowings achieved the highest values for vegetative and reproductive traits (14 cultivars of wheat). Likewise, El-**Maghraby et al. (2016)** in Sohag reported that 25 November sowing was better than early (25 October) and late (25 December) sowings in terms of the yield components and total grain yield. The direct relationship to grain filling rate from delayed sowing indicates profound evidence of physiological adaptation of Sakha 96 to late-season stress and reduced thermal time.

This trait demonstrates a significant benefit for a late-sown cultivar and its capacity to convert assimilates into grain in a smaller growing season. The sowing date is important to wheat development, and delayed sowing will often advance all the phenological stages due to greater accumulated temperatures in a shorter growing period, resulting in accelerated heading and maturity. This may appear to be an advantage for earliness but often has negative impacts for yield because of a shortened growing season. The shortened vegetative period includes less photosynthesis and tillering, which leads to the number of spikes per square meter, grain number per spike, thousand-kernel weight (TKW), and ultimately grain yield being reduced. In a number of studies there is evidence that late sowing shortens the grain filling period and places the crop under higher temperature stress during the critical periods of flowering and grain filling stages. As a result of this heat stress, it can reduce the probability of successful flowering, decrease floret fertility, increase senescence rate, and, most concerning, cause greater numbers of shriveled grains with lower kernel weights. Both **Bangar *et al.* (2020) and Zhang *et al.* (2024)** provided evidence to support the conclusion that late sowing decreased the length and rate of the grain fill period and that often higher temperatures during the reproductive period would adversely affect both grain yield and grain quality.

El-Sayed *et al.* (2018) reported that delayed sowing produced shorter growth phases, consequently shortening the duration and rate of grain filling. These results illustrate the importance of sowing date on optimizing wheat phenological development, resource use efficiency, and yield stability when cultivated under arid/semi-arid climatic conditions.

Genotypic diversity among wheat cultivars occurs because of their diverse genetic basis and respective abilities to adapt and tolerate different environments. In this study, several cultivars (which include Misr 2, Misr 4, Sakha 95, Bani Sweif 5, Bani Sweif 7, and Sids 12) better expressed their yield potential when sown on the best date of 20 November. Misr 2 achieved the highest grain yield of approximately 28.5 ardab/feddan when sown on 20 November. This result confirms that Misr 2 demonstrates excellent adaptability and high potential yield when grown in optimal growing conditions with ideal thermal and photoperiodic conditions. On the contrary, when sown late in the season, nearly all cultivars suffered a reduction in grain yield due to heat stress during the grain-filling stage **(Elbatrawy *et al.*, 2023)** that exceeded 50% in some cases.

An interesting result was the trend noticed with Sakha 96, which produced a better grain yield when sown late. This result suggests that some late beautiful cultivars may demonstrate better yield performance when they effectively impose a greater thermal accumulation when grown in a short-duration, hot environment that enhances the grain filling rates **(Ahmed, 2021).**

The cultivars Gemmeiza 11, Gemmeiza 12, Sids 14, and Sids 15 demonstrated a generally low yield performance when sown under most of the conditions demonstrated. The results show that these cultivars were among the least adapted to the region studied.

These findings demonstrate that selection of cultivars is not only based on yield potential but also on response pattern to environmental stresses (e.g., heat) and crop management (e.g., sowing date). Similarly, **El-Sayed *et al.* (2018) and Yahya *et al.* (2020)** report that the genotype × environment (GE) had a large influence on the stability and productivity of wheat cultivars grown under the arid and semi-arid conditions of Egypt.

Multi-selection analyses (Scatter plot, G*Y biplot and MTSI)

The scatterplot analysis indicated that Misr 2 and Misr 4 had the greatest grain yield and stability across all sowing dates and exhibited little response to variation in sowing time. Sakha 95 had higher yield with minimum response to sowing time only under late sowing. Sakha 96 had much lower and less consistent yields that were much lower early in sowing.

The biplot analysis confirmed that Misr 2 and Misr 4 were in close proximity to high grain yield, while some genotypes such as Sakha 96 and Sids 12 were close to the specific traits they excelled in (i.e. higher numbers of kernels per spike) but overall were not productive across all traits of productivity. Gemmeiza 11, for example, had some potential in 1000 kernel weight, but otherwise did not compete for total grain yield.

The Genotype × Trait (GT) biplot provided a clear picture of the relationships between genotypes and their key traits, aiding in the identification of superior genotypes for grain yield and other essential characteristics. Previous studies **(Yan, 2014; Gab Alla et al., 2018; Darwish et al., 2023)** have emphasized the usefulness of GT biplot analysis for selecting genotypes based on stress tolerance, grain yield, and related agronomic traits. **Ram *et al.* (2020) and Elfanah *et al.* (2023)** also found that GT biplot analysis is an effective method to screen genotypes across multiple environmental conditions.

Further, **Darwish *et al,* (2023)** listed that Sids 14, Sakha 95, and Giza 171 were more successful under Sids conditions and Misr 2 and Giza 171 populations were the best in the area surrounding West El-Minya in the north. **Gab Alla *et al.* (2018)** undertook the Genotype × Environment (G × E) biplot analysis and studied the characters in some bread wheat genotypes and recommended selecting cultivars for breeding from a number of agronomic traits in order to improve yield stability with respect to the environmental impact of climate change. In a similar fashion, **Mohiy *et al.* (2021)** also employed Genotype × Environment (G × E) biplot analyzing twelve wheat cultivars made in Middle and Upper Egypt, seeking yield stability, and yielding potential, while noting temperature extremes under heat stress. They concluded by recommending these cultivars (Sids 12, Sids 14, Misr 1, Misr 2 and Giza 171) for breeding programs seeking high yielding and heat-stable cultivars.

The MTSI analysis confirmed that the wheat cultivars researched had a significant effect on grain yield and agronomic trait variables. The wheat cultivars Sids 12, Sakha 95, Misr 1, and Misr 2 displayed traits that exhibit strong adaptability and stable yield across the six environments tested. Selecting grain-cultivated wheat cultivars has strong implications for ensuring optimal sowing date to improve wheat productivity and grain-filling potential. Additionally, while thinking about their potential for selection for breeding, to raise wheat production; and because these cultivars presented genetic potential in conjunction with non-selections, indicating areas for future improvement.

MTSI represents an important resource for plant breeders, providing an easy-to-use, effective mechanism for identifying strengths and weaknesses of the new wheat cultivars. The quantity of studies recognizing the role of MTSI in breeding programs has exploded. **Cairns *et al.* (2013), Olivoto *et al.* (2021), Zuffo *et al.* (2020), Yue *et al.* (2022), and Munda *et al.* (2023)** have shown that MTSI is useful for ranking elite cultivars on performance and stability of ambivalence—whether mean performance or usual stability in stress conditions. MTSI has been used in breeding programs on cultivars of several crops, but not wheat. MTSI has been used in breeding programs for rice **(Sharifi *et al.,* 2020)** and lentils **(Pezeshkpour *et al.,* 2024)**, as well as maize hybrids **(Olivoto *et al.,* 2021, and Yue *et al.,* 2022)**. MTSI is a versatile tool that can potentially improve crop resilience and improve productivity. The thorough evaluation revealed great utility of multi-trait selection indices to support wheat breeding programs with biplot analyses. Breeder's decisions can occur based on improving the confidence of yield stability, sustainable tolerance to stress, and productivity by linking breeders through MTSI. All are relevant facets in promoting food security for future generations around the world, as well as sustainable agriculture.

CONCLUSION

The present study concluded that November 20th is the optimum sowing date for maximizing wheat yield in the New Valley, as late planting severely reduces yield by nearly 40% due to terminal heat stress. While the cultivars Misr 2 and Misr 4 demonstrated the highest yield. Multi-trait stability analysis selected Sids 12, Sakha 95, Misr 1, and Misr 3 as the most stable genotypes across different conditions. A significant finding is the unique performance of Sakha 96, which excelled under late sowing, revealing its exceptional tolerance to heat. Therefore, Sakha 96 is highly recommended for late planting scenarios to mitigate yield loss. These findings provide a clear framework for farmers to enhance productivity by aligning cultivar choice with strategic sowing dates.

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تأثير التفاعل بين التركيب الوراثي وتاريخ الزراعة على أداء وثبات إنتاجية القمح تحت ظروف الوادي الجديد"

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يُعد تحسين إنتاجية القمح في الأراضي الصحراوية المستصلحة حديثًا في مصر، مثل الوادي الجديد، أمرًا حيويًا للأمن الغذائي القومي. هدفت هذه الدراسة إلى تقييم محصول وثبات 14 صنفًا من القمح (12 من قمح الخبز و2 من القمح الديورم) تحت ثلاثة مواعيد زراعة (مبكر، أمثل، ومتأخر) خلال موسمي النمو 2023/2022 و2024/2023. تم تسجيل البيانات الخاصة بصفات التبكير، ومحصول الحبوب، ومكوناته. وشمل التحليل الإحصائي أشكال الانتشار، والرسوم البيانية للتفاعل بين الصنف والصفة (G×T biplots)، ومؤشر الثبات متعدد الصفات (MTSI). أدى موعد الزراعة الأمثل في 20 نوفمبر إلى تحقيق أعلى محصول حبوب (حوالي 25 أردب/ فدان)، بينما تسببت الزراعة المبكرة والمتأخرة في انخفاض معنوي في المحصول بنسبة تقارب 20% و39% على التوالي. وبناءً عليه، تُعتبر الفترة من منتصف إلى أواخر نوفمبر هي ميعاد الزراعة المناسب. أظهرت النتائج أن الصنفين 'مصر 2' و 'مصر 4' كانا الأعلى في المحصول. وكانت الأصناف 'سدس 12'، و 'سخا 95'، و 'مصر 1'، و 'مصر 3' هي الأكثر ثباتًا. والجدير بالذكر أن الصنف مبكر النضج 'سخا 96' أظهر أداءً أفضل تحت ظروف الزراعة المتأخرة، مما يجعله خيارًا مفضلاً لمواعيد الزراعة المتأخرة.