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The Validation of Seed Rate of Some Bread Wheat Genotypes under New-Halfa, Sudan Conditions

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Abstract

The seed rates significantly influence wheat's vegetative, reproductive, and yield traits (*Triticum aestivum* L). Therefore, the response of genotypes to different seed rates is constantly studied to find a suitable combination. Wheat is one of the main crops produced by farmers in the northern, central, and eastern parts of Sudan. However, its yield and productivity could be higher due to inappropriate seed rates and low-yielding local cultivars in the study area. Therefore, this experiment was conducted to verify the response of three wheat genotypes to different seed rates on some of the characteristics of growth, yield, and yield components. The number of kernels per spike showed positive and highly significant associations with No. of seed per m^2, days to heading, and days to maturity. Grain yield showed a highly significant and positive correlation with the harvest index. The harvest index exhibited the highest and most positive direct effect on grain yield. While the highest indirect effect on grain yield was revealed by biomass. Our results concluded that the interaction between seed rate and genotypes was not significant ($P>0.05$) differences in phonological parameters and growth parameters. However, the analyzed results showed a high significance ($P<0.001$) among the combination of seed rates and varieties on yield and yield component. The combination of Sandal and 214 kg/ha was a higher (675 fertile spike/m^2) and ranked first, while the combination of Sandal and 166 kg/ha showed a lower 377 fertile spike/m^2. The combination of jawahir variety with 120 kg/ha and 195 kg/ha led to a higher thousand kernel weight (40.3, 40.4 g), which was ranked first. Using different seed rates has resulted in considerable variations among the biomass data of the three tested genotypes and promising line. Therefore, it can be recommended to use these genotypes with seed rate under the conditions of the study location should be about 120-140 Kg/ha, which will produce a sufficient number of good-quality spikes with adequate yield structure and quality.

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Introduction

Wheat is one of the most important cereal crops globally, and it is considered a stable food for about one-third of the world's population [1]. The total cultivated area in Sudan has increased substantially from less than 27.000 ha in the early 60s to 360.000 ha in the 90s. However, the area declined during 2000-2005 due to the unavailability of credits and the delay of the inputs. During 2006 - 2010 the cultivated areas increased to 277.000 ha due to encouraging production policies and expansion into new cultivation areas [2]. Wheat in Sudan is a major source of energy and proteins for the population inhabiting in Northern and Eastern parts. Furthermore, wheat has been selected as one of the target crops in the strategic goal of attaining national food self-sufficiency, income generation, poverty alleviation, and achieving socio-economic growth of the country Wheat in Sudan is produced exclusively under heat stress 24 °C to 40 °C with an average of 26 °C currently. Wheat is one of the most imported small cereal crops in Sudan, widely cultivated in a wide range of altitudes. Wheat producing area in Eastern Sudan lies between 15° to 18° N Latitude and 35° to 37° E longitudes with an elevation of 450 meters above sea level (masl).

Wheat estimated cultivation area in the Northern and the central clay plains in the Gezira schemes is about 168.000 ha, in the New Halfa scheme is about 25.200 ha, and in the Rahad schemes is about 18.900 ha. While in the semi-arid climate, the White Nile region is Sudan's major wheat cultivation area. New Halfa Scheme is the most important wheat-growing area in Eastern Sudan, the total estimated area is about 159.444 ha, and the estimated total production is 4.8 tons with average productivity of 32450 kg/ha (Halfa Scheme). However, the main reasons for low productivity or crop potential are biotic and abiotic constraints. Among the agronomic factors, seed rate is one of the most important production factors which need great emphasis for maximum yield of crops by determining the crop vigor and ultimate yield [3]. The use of inappropriate seed rates by small-scale farmers affects the ultimate crop yield. The higher seed rate leads to shorter spike length and a low number of grains per spike [4]. Reducing the seed rate may increase the number of tillers, the number of spikes per plant, and spikelet per spike, while the grain yield per hectare is reduced [5].

On the other hand, previous research results indicated that the use of proper seed rate encourages nutrient availability, proper sunlight penetration for photosynthesis, a good soil environment for the uptake of soil nutrients, and water use efficiency. Besides seed rate, the selection of variety is also an important factor affecting crop yield (IJOAS). Generally, breeders select high tillering capacity in their objective for high-yielding varieties. Therefore, variations in yield are unlikely to be observed within certain limits of the seeding rate (New Halfa). [6] reported that several bread wheat varieties differing in height, maturity, and tillering capacity have been developed in Sudan since the 1990s up to now at Wheat Research Program Unit using a variable genetic resource which raised a controversial argument by the producers claiming that the new varieties might have different seed rate requirements considering their genetic background. However, the varietal difference in seed rate requirements is an argument raised and suggested by the wheat production stakeholders in Sudan. The recent seed rate recommendation is 50-60 kg/fed for all released varieties in Sudan [6]. Extensive research is needed to determine the interactive effect of the optimal seed rate in each wheat cultivation area in the New Halfa Scheme, as one of the important agronomic management to improve production and productivity. Optimum seed rate can also reduce disease prevalence, such as stripe rust [7,8].

Materials and methods

Description of the experimental site

A field experiment was conducted at New Halfa Research Station, New-Halfa City, Sudan, during two consecutive seasons, 2018/2019 and 2019/2020. The site is located at 15° to 18° N latitude and 35° to 37° longitude with an elevation of 450 meters above sea level. The climatic conditions were favorable until the last week of January, with mean temperature ranging from 20 °C to 24 °C, and after that, the temperature increased, which remained higher until crop maturity. The soil of the experiment belongs to the *Khashm Elgirba* series, classified as sodic Haplusters, very fine smectitic, isophyperthermic with a clay percentage of around 60% and pH ranged from 4.8 to 8.8 [9]. The land was prepared by harrowing and then leveling the field; each treatment was assigned randomly to experimental plots. Seeds were manually sown in the last week of November for the 1st and 2nd seasons. The distance between the rows in each plot is 0.2 meters apart, each plot consisting of eight rows 6 meters in length. The seed rate was 12 g/m^2. Seeds were dressed in an insecticide Gaucho (Imidacloprid 35%WP) (Bayer Crop Science, USA) to control pests, especially termites and aphids. Urea was applied twice before the second and fourth irrigation (86 kg/ha of N). Irrigation was carried out at 10–12 days intervals to avoid water stress. Weeding was performed manually at least twice. The experiment was arranged in a Randomized Complete Block Design (RCBD) in factorial and replicated three times. The experimental site is free from major wheat diseases. The treatments consisted of the six seeding rates 95, 120, 142, 166, 190, and 214 Kg/ha with two bread wheat varieties (Bohaine and jawahir) plus one promising line named Sandal. Harvesting was done manually using hand sickles at the physiological maturity of the crop.

Data Collection and Measurements

The days to 50% heading (days) were measured by counting the days from the date of sowing until 50% of the plants in a plot produced a spike above the sheath of the flag leaf that was determined by visual observation. The days to 90% Days to maturity (days) were measured by counting the number of days from the date of sowing until maturity in each plot. Plant height was measured from 10 randomly selected plant samples per plot as the height from ground level to the tip spike, excluding the awns. It will record the average of ten selected main tillers from each plot at maturity across the treatment level. Spike number per m^2 was measured by observing the number of effective (fertile) tillers bearing spikes from four randomly selected, one-meter row lengths counted from each plot at physiological maturity across the treatment level. The number of Kernels per spike observed from the ten randomly selected spikes from the middle rows of each plot was taken. A thousand grains were counted randomly after harvesting from each plot, and their weights were measured with accurate balance. The total biomass or biological yield was measured by weighing the sun-dried total above-ground plant biomass (straw + grain) of the net plot and converted to ton per hectare. The grain yield was calculated by taking the weight of the grains from the net plot area and converted to kg per hectare after adjusting the grain moisture content to 12.5%. The harvest index (HI %) was computed as the ratio of gain yield to the grain yield plus straw of each plot expressed as a percentage. Statistical Analysis**,** data were subjected to analysis of variance using GenStat software.

Results and discussion

Seasonal variation

There was no significant difference detected in the two seasons in the Long Term Average (LTA) **(Figure 1)**. However, there are some variations from each other in terms of a relative increase or decrease in temperatures during the growing season at the different growth stages of the crop; this variation was expressed as a significant variation in grain yield; the average yield was 1089 Kg/ha and 2542 Kg/ha for 2018/2019 and 2019/2020 seasons, respectively. As well as some of the yield components include biomass, harvest index, spike/m^2, thousand kernel weight, and kernel/spike. Moreover, seasonal variations have no significant differences with phonological parameters **(Table 1)**.

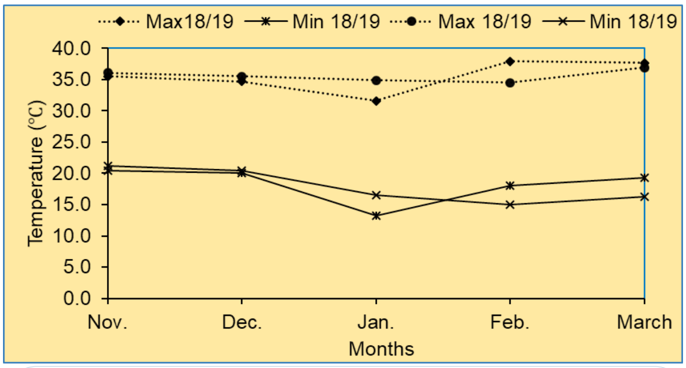

Figure 1: Monthly maximum, mean and minimum temperature (^{o}C) at New Halfa during 2018/19 and 2019/20 seasons.

Table 1: Seasonal effect on phonology, growth yield, grain yield, and yield components averaged over three genotypes and six seed rate treatments at New-Halfa.

Parameter	Season 2018-19	Season 2019-20	Sig. level	SE±	C.V.%
Grain Yield (Kg/ha)	1089	2542	***	108.5	14.6
Biomass (Kg/ha)	4242	7047	***	169.9	7.4
Harvest Index (%)	25.6	36.3	***	1.67	13.2
Spike/m^2	484	554	***	14.4	6.8
Thousand Kernel Weight (gm)	36.1	37.9	***	1	6.6
Days to heading (day)	54.06	60.67	ns	0.462	2
Days to maturity (day)	87	97	ns	0.5	1.4
Plant Height (cm)	70.41	67	ns	1.3	4.6

Effect of seed rate on Phonological parameters

Days to 50% heading: Days to 50% heading indicated that the main factor of seed rate did not show a significant (P>0.05) difference **(Table 2)**.

Days to 90% physiological maturity

The variations in plant maturity in response to the different seeding rates were statistically significant (P<0.05). These results indicated that the increase of the seed rate from 95 kg/ha to 214 Kg/ha decreased the days to physiological maturity. Although the higher seed rate of 214 kg/ha attained days to physiological maturity date earlier, 92 days, the other seed rates also acquired the same days to physiological maturity with lower seed rates of 95 kg/ha and 142 Kg/ha **(Table 2)**. This might be due to the increase in plant population that increases intra-plant competition for nutrients and light, making plants no longer in the vegetative stage. This may have also contributed to the reduction of the grain-filling period because the higher seed rate hastened the heading and maturity compared to the lower seed rate [10]. The result of this study is in line with that of [11]; [10] reported that increasing the seed rate from 100 to 150 kg/ha decreased days to 90 physiological maturity. The result is also in agreement with [12], who reported that increasing seed rate levels promoted a tiff's early physiological maturity. Similarly, [13] also noted that increasing seed rate levels hastened bread wheat's physiological maturity. In contrast, [14]and [15] reported that rising seeding rates from 250-400 m^2 and 100-200 kg/ha grains prolong the number of days from sowing to maturity of wheat, respectively.

Growth parameters

Plant height (cm)

The analysis of variance indicated that the main factor of seed rate did not show a significant (P>0.05) difference in plant height. **(Table 3)**.

Table 2: Effect of seed rate on the phonology, yield and yield components of three wheat genotypes, 2018-19 and 2019-20 seasons at New Halfa.

Seed rate	Days to heading	Days to maturity	Plant height (cm)	Number of Spike/m^2	No. of Kernel /Spike	TKW (gm)	Grain yield (Kg/ha)	BIO (kg/ha)	HI (%)
(kg/ha)	58	93	69	443	29.7	38	1714	5536	36
95	57	92	69	480	29.7	36	1841	6010	37.6
120	57	93	69	511	32.7	35	1945	5877	36.9
142	57	92	68	515	32.8	34	1869	5497	37.9

166	57	92	67	541	30	29	1680	5190	35.7
190	57	92	68	623	30.7	31	1845	5759	38.1
214	57	92	68	519	31	34	1816	5645	37
Mean	0.752	0.9	2.1	23.4	2.72	2.2	176.7	276.8	1.62
LSD	2	1.4	4.6	6.8	13.2	9.9	14.6	7.4	6.6
CV%	ns	*	ns	***	***	*	*	***	*

TKW: Thousand Kernel Weight; BIO: Biomass; HI: Harvest index.

Yield and yield components

Tiller number (Number of Spike/m$^{2)}$

The variations in plant maturity in response to the different seeding rates were statistically significant (P<0.05). These results indicated that the increase of the seed rate from 95 kg/ha to 214 Kg/ha decreased the days to physiological maturity, and seed rate of 214 kg/ha gave more effective tillers m^{-2}, increased by 25% comparing to the rest of the seed rates.. Although the higher seed rate of 214 kg/ha attained days to physiological maturity date earlier (92 days), the other seed rates also reached the same days to physiological maturity with lower seed rates of 95 kg/ha and 142 Kg/ha **(Table 2)**. This might be due to the increase in plant population that increased intra-plant competition for nutrients and light, making plants stay no longer in the vegetative stage. This may have also contributed to the reduction of the grain-filling period because the higher seed rate hastened the heading and maturity compared to the lower seed rate [10]. The result of this study is in line with that of [10]; [11] reported that increasing the seed rate from 100 to 150 kg/ha decreased days to 90 physiological maturities. The result also agrees with [12], who reported that increasing seed rate levels promoted a tiff's early physiological maturity. Similarly, [13] also noted that increasing seed rate levels hastened bread wheat's physiological maturity. In contrast, [14] and [15] reported that rising seeding rates from 250-400 m^2 and 100-200 kg/ha grains prolong the number of days from sowing to maturity of wheat, respectively.

Number of kernel per spike

The potential of the wheat spike is determined by the number of field grains spike, an import yield component that was also influenced by different seed rates. Increasing seed rates caused a high significance (P<0.0001) reduction trend in kernels/spikes and influenced their data. Confirming the results of [16] and [17]. the maximum kernels/spike was 38, was observed in a seed rate of 95 kg/ha, which is superior when compared with the rest of the seed rates which showed the lowest kernels/spike was 29 in 190 kg/ha **(Table 3)**. As the seed rate was increased from 95 kg/ha to 166 kg/ha, the number of kernels per spike decreased by 2 %; this can be justified by the fact that at the higher seed rates, most of the grains will fade at an early stage because of competition between growing grains to absorb preserved matters and as the result low grains per spike would be produced [18,11].

Thousand kernels weight

Thousand kernel weight is an important yield component of wheat. The variance analysis revealed that the seed rate's main effect was significant (P<0.05). The maximum thousand-kernel weight (38.1 g) was recorded from a seed rate of 214 kg/ha, while the minimum thousand-kernel weight was recorded from a seed rate of 190 kg/ha, which is (35.7 g) **(Table 3)**. Although noted from the analysis data indicated fluctuation of value, statically seed rates of 95 kg/ha and 142 kg/ha had similar results, also seed rates of 120 kg/ha and 166 kg/ha **(Table 3)**. [11] Increased the seeding rate from 100 kg/ha to 150 kg/ha, and thousand kernel weight decreased by 4.2 % and 5.6%, respectively. This could be due to the high density, which increased the total number of tillers due to competition; then, the thousand kernel weight would be reduced. [19, 20], and [21] reported that the higher seed rate in bread wheat resulted in decreasing the 1000-kernel weight. Furthermore, reported that increasing the seeding rate significantly decreased thousand-kernel weight. However, in contrast with [22], who reported that 1000-kernel weight was raised with the seeding rate in studied winter wheat varieties. [23] Also reported that different seeding rates did not significantly affect thousand kernel weights.

Biomass yield

Biological yield is an important factor because farmers are also interested in straw in addition to grain. The variance analysis indicated that the seed rate's main effect showed a highly significant (P<0.001) impact on biomass yield. The maximum biomass yield (6010 kg/ha) was recorded at a seeding rate of 120 kg/ha, whereas the minimum biomass yield (5190 kg/ha) was recorded at a seed rate of 190 kg/ha **(Table 2)**. This is because biomass yield is mainly related to plant height and tiller number. Our results revealed that the maximum plant height and spike/m^2 number were gained from the lower seed rate, and the maximum biomass yield was also gained from the lower seed rate. Our results is in consistent with [11] findings. [23] Reported that the maximum biomass yield was detected at a seeding rate of 100 kg/ha, then 120 kg/ha, and 150 kg/ha. Similarly, [24] reported that, in wheat, the higher seed rate gives a higher number of plants and tillers, which leads to lower biomass yield. However, this result is in contrast with [10] and [15], who reported that the maximum biological yield was reported at a higher seed rate.

Grain yield (kg/ha)

Grain yield is a function of the integrated effect of the yield components, which were influenced differently by growing conditions and also affected by the variability in seed rate **(Table 2)**, which confirms the general knowledge that wheat yield components show compensatory ability and relations in response to seed rate changes, is the main reason of this phenomenon that enable crop justified yield components and remain grain yield over a wide range of sowing densities [18]. For instance, when the seed rate increased, causing an increase in the number of spikes/m^2 (P<0.001), number of kernels/m^2, and the kernel weight, it would mainly be compensated for by a decrease in the grain yield, biomass and harvest index. The data also depicts that the seeding rate statistically had a significant (P<0.05) on grain yield. The mean values of grain yield were observed to be 1680 kg/ha to 1945 kg/ha **(Table 2)**. Maximum grain yield (1945 kg/ha) was obtained with a seed rate of 142 Kg/ha. This could be due to its longest spike length, which plays a vital role in wheat, the number of grains per spike, and then leading to the ultimate yield. Thousand kernel weight is also an essential factor in increasing yield, [11], the minimum yield produced was 1680 kg/ha obtained with a seed rate of 190 Kg/ha; the results are consistent with the findings of [26], and [27] who reported that increasing seed rates with optimum fertilizer application resulted in increased spike number, grains spike, and grain yield.

Harvest index

The variance analysis indicated that the seed rate's main effect showed a significant (p<0.05) difference in the harvest index. The maximum harvest index was (32.7%) obtained at a seeding rate of 142 Kg seed/ha and 166 Kg seed/ha, the same value, while the minimum harvest index was (29.7%) obtained at a seeding rate of 95 Kg seed/ha and 120 Kg seed/ha **(Table 4)**. The harvest index had an inter-relationship with grain yield and above-ground biomass yield; the highest harvest index was obtained because of greater grain yield. Our result is in contrast with the findings of [28], who demonstrated that the harvest index is an indicator of the genetic potential of the plant to produce economic yield, harvest index under control treatment can be accompanied by high grain yield under environmental stress. Similarly, [29] reported a positive relationship between grain weight and harvest index. The analysis of variance indicated that the main factor of interaction between seed rate and genotypes showed a highly significant (P>0.05) difference in harvest index. The highest harvest index of 36.7% and 36.2% were obtained by Bohaine and Sandal with seed rates of 166 Kg/ha, respectively. While the lowest harvest index of 25.6% and 26% were obtained by jawahir with seed rates of 166 Kg/ha and 95 Kg/ha, respectively. The 166 Kg/ha seed rate was obtained as the highest and lowest harvest index for the studied genotypes, possibly due to the plant potential.

Effect of genetic variability

It is a natural, expected result since the genotypes under test were selected based on their genetic variability.

Phonological Parameters

Days to 50% heading

Days to heading, the analysis of variance revealed that the main factor of variety was a significant (P>0.001) difference. The delay in the days to 50% heading was 68 days obtained by the Sandal genotype, which is a promising line, while the Bohaine genotype exhibited earliness to attain days to heading **(Table 3)**. Earliness for days to heading had the advantage of generally escaping terminal heat stress in Sudan and rust disease, especially in New Halfa. The genotypes exhibiting earliness to days to heading might have such an advantage in an area where terminal heat stress is one problem of wheat production in semi-arid region. This result agrees with the result reported by [30] and [11]. Who observed that the days to heading showed significant differences among wheat varieties.

Days to 90% physiological maturity

Genotype also had a significant (P<0.0001) effect on physiological maturity. Sandal promising line was late maturating, which took the most extended duration of 103 days. The Bohaine variety took the shortest period of 83 days **(Table 3)**. This result is in agreement with the result reported by [31], who report that the days to physiological maturity of wheat cultivars vary due to inherent differences between cultivars. In conformity with the present result, [32] reported that differences in maturity can be caused by the combined effect of genetic and environmental factors during crop growth and grain filling.

Growth parameters

Plant height (cm)

The crop height is mainly controlled genetically, and it can also be affected by environmental factors [31]. The analysis of variance revealed that the main factor of variety had a significant (P<0.0001) effect on plant height. In the case of genotype, the tallest plants (75 cm) were observed in the promising line Sandal, and the shortest plants (63 cm) were observed in the genotype Bohaine **(Table 3)**. The difference in the plant genotypes should be attributed to their genetic backgrounds [15]. The current result agrees with the result of [33], who reported that the tallness of wheat plants is mainly associated with the genetic background of the genotype.

Table 3: Varietal Difference of Three Wheat Genotype for Phonological and Growth Yield and yield components averaged over six seed rates and two season (2018-19 and 2019-20) at New Halfa.

Parameter	50% heading (day)	50% maturity (day)	Plant Height (cm)	Grain yield (Kg/ha)	Bio (Kg/ha)	HI (%)	TKW (g)	K/SP	No.of Spike/M
Genotypes									
Bohaine	51	84	63	1845	5425	32.6	36.5	28	510
Sandal	68	106	75	1924	5957	31.5	36.3	44	515
Gawahier	53	87	68	1677	5552	28.7	38.2	29	532
Mean	57	92.3	68.7	1815.3	5644.7	30.9	37	34	519
LSD	0.532	0.6	1.5	125	195.7	1.93	1.15	1.6	16.6
CV%	2	1.4	4.6	14.6	7.4	13.2	6.6	9.9	6.8
P	***	***	***	***	***	***	***	***	*

TKW: Thousand Kernel Weight; BIO: Biomass; HI: Harvest index; K/SP: Number of kernel/spike.

Yield and yield components

Tiller number

The studied genotypes had significant (P>0.05) differences in the number of effective tillers. Among the two genotypes and promising line, jawahir showed a higher significant number of tillers per m^2 than Sandal and Bohaine; the maximum value number of tillers obtained by Bohaine was 532 per/m^2, and the minimum value number of tillers obtained by Sandal was 510 per m^2 **(Table 3)**, this is because of the process of tillers production which is mainly controlled by genetic and environmental factors.

Number of kernel per spike

The current result revealed that the main effect of genotype had a highly significant (P<0.0001) difference in the No. Of kernels/spikes, the Sandal genotype produced the highest number of kernels/spikes (44). While the lowest number of kernels/spike was (28) obtained by Bohaine **(Table 3)**. Bohaine and Jawahir genotypes had similar kernels per spike. The result of this study is in line with [34], who reported that significant differences were found among genotypes in the number of kernel/spikes. However, our results also contrast with, who stated that the wheat genotypes did not influence the number of grains per ear obtained in distinct seeding densities.

Thousand kernels weight

The analysis of variance revealed that the main effect of varieties had highly significant (P<0.001). The result also showed the Jawahir genotype obtained a maximum thousand kernel weight (38.2g), whereas Bohaine and Sandal genotypes obtained (36.5 and 36.3 g) respectively **(Table 3)**; this may be due to the late maturity of the Sandal variety compared with Jawahir genotype. The difference in 1000 kernel weight among the wheat genotypes may be attributed to the variable inherent potential of the three genotypes. More tillers per m^2, several grains spike, and higher test weight might have contributed to higher leaf area, which could be responsible for more [35].

Biomass yield

The analysis of variance indicated that the main effect of varieties showed a high significance (P<0.001) effect on biomass yield. The result also showed that the Sandal genotype obtained the maximum biomass yield (5.957 t/ha), whereas Bohaine and Jawahir genotypes obtained that (5.425 and 5.552 t/ha), respectively **(Table 3)**.

Grain yield

The analysis of variance indicated that the main effect of genotypes showed a high significance (P<0.001) effect on grain yield. The result also showed that the Sandal genotype obtained a maximum grain yield (1924 kg/ha) whereas Jawahir genotype obtained a minimum of (1677 kg/ha) **(Table 3)**. Although the productivity range among the genotypes are not far apart from each other, in the case of Jawahir genotype the productivity range is lower than the range of the two genotypes due to decreasing moisture in the grain filling period because it might have suffered from unfavorable environmental condition late in the growing season.

Harvest Index

The analysis of variance indicated that the main effect of genotypes showed a highly significant difference (P<0.001) in the harvest index. The result also showed that the Bohaine genotype obtained a maximum harvest index (of 32.6%), whereas the Jawahir genotype obtained a minimum (28.7%) harvest index **(Table 3)**.

Table 4: The gain yield of three Wheat genotypes affected by six seed rate treatments at New-Halfa, Sudan. Over 2018-19 and 2019-20 seasons.

Seed rate	Genotypes	DH (days)	DM (days)	PH (cm)	SP/m² (number)	K/SP (number)	TKW (g)	GY (kg/ha)	Bio (kg/ha)	HI (%)
95	Bohaine	51	85	63	468	29	35	1907	5790	32
	Sandal	69	107	76	432	52	36	1648	5052	32
	Jawahir	54	88	70	430	33	36	1587	5765	26
120	Bohaine	50	84	64	457	30	35	1889	6020	31
	Sandal	68	106	75	501	48	37	1898	5996	31
	Jawahir	54	87	69	482	31	40	1736	6014	27
142	Bohaine	51	85	62	510	29	36	1798	5058	36
	Sandal	68	106	77	539	47	38	2246	6894	32
	Jawahir	53	87	69	484	29	36	1789	5681	30
166	Bohaine	51	84	62	553	29	38	1885	4964	37
	Sandal	68	107	76	377	43	37	2262	6354	36
	Jawahir	53	85	66	615	30	39	1460	5172	26
195	Bohaine	51	84	60	503	27	34	1522	4838	28
	Sandal	68	106	73	567	34	33	1642	5320	29
	Jawahir	53	87	68	554	27	40	1876	5412	33
214	Bohaine	50	84	64	566	25	41	2071	5882	33
	Sandal	69	106	72	675	42	37	1849	6128	29
	Jawahir	54	86	68	629	27	37	1615	5268	30
LSD		1.303	1.5	3.7	40.6	3.9	2.8	306.1	479.3	4.7
CV%		2	1.4	4.6	6.8	9.9	6.6	14.6	7.4	13
P		NS	NS	NS	***	***	***	***	***	***

TKW: Thousand Kernel Weight; BIO: Biomass; HI: Harvest index; K/SP: Number of kernel/spike; GY: Grain yield; SP/M: Number of spike per square meter; DH: Days to heading; DM: Days to maturity; PH: Plant height.

Table 5: Correlation Coefficients of combined analysis, 2018/2019 and 2019/2020 seasons, New-Halfa, Sudan.

	DH	DM	PH	SP/M²	K/SP	TKW	BIOMASS	SEED/M²	GY	HI
DH	**1.00000**									
DM	0.88507 <.0001	**1.00000**								
PH	0.79847 <.0001	0.78927 <.0001	**1.00000**							
SP/M²	0.05954 0.5405	0.01689 0.8623	-0.10615 0.2742	**1.00000**						
K/SP	0.67547	0.67832 <.0001	0.63271 <.0001	-0.06092 0.5311	**1.00000**					
TKW	-0.28983 0.0023	-0.26907 0.0049	-0.17014 0.0783	0.10298 0.2889	0.06176 0.5255	**1.00000**				
Biomass	0.55393 <.0001	0.55885 <.0001	0.54168 <.0001	0.10957 0.2590	0.43740 <.0001	0.00442 0.9638	**1.00000**			
SEED/M²	0.60847 <.0001	0.59318 <.0001	0.46680 <.0001	0.52021 <.0001	0.80750 <.0001	0.08845 0.3627	0.46191 <.0001	**1.0000**		
GY	0.15758 0.1034	0.23089 0.0162	0.30354 0.0014	0.00362 0.9703	0.15725 0.1041	0.17170 0.0756	0.57801 <.0001	0.13954 0.1498	**1.00000**	
HI	-0.28911 0.0024	-0.20203 0.0360	-0.12526 0.1965	-0.07696 0.4286	-0.17615 0.0682	0.20888 0.0300	-0.17986 0.0625	-0.20652 0.0320	0.68993 <.0001	**1.00000**

TKW: Thousand Kernel Weight; BIO: Biomass; HI: Harvest index; K/SP: Number of kernel/spike; GY: Grain yield; SP/M²: Number of spike per square meter; DH: Days to heading; DM: Days to maturity; PH: Plant height.

Table 6: Path Coefficients and direct and indirect effect of different variables on grain yields, combined analysis, 2018/2019 and 2019/2020 seasons, New-Halfa, Sudan.

	DH	DM	PH	SP/M²	K/SP	TKW	Biomass	SEED/M²	HI	GY
DH	**-0.02698**	-0.02388	-0.02155	-0.00161	-0.01823	0.007821	-0.01495	-0.01642	0.007801	0.15758
DM	-0.015	**-0.01695**	-0.01338	-0.00029	-0.0115	0.004562	-0.00947	-0.01006	0.003425	0.23089
PH	0.041838	0.041356	**0.052398**	-0.00556	0.033153	-0.00891	0.028383	0.024459	-0.00656	0.30354
SP/M²	0.008401	0.002383	-0.01498	**0.1411**	-0.0086	0.01453	0.01546	0.073402	-0.01086	0.00362
K/SP	0.13045	0.131	0.122192	-0.01177	**0.193125**	0.011927	0.084473	0.155948	-0.03402	0.15725
TKW	0.002239	0.002079	0.001314	-0.0008	-0.00048	**-0.00773**	-3.4E-05	-0.00068	-0.00161	0.1717
BIOMASS	0.410451	0.414097	0.401374	0.081189	0.324105	0.003275	**0.740981**	0.342266	-0.13327	0.57801
SEED/M2	-0.15936	-0.15535	-0.12226	-0.13624	-0.21148	-0.02317	-0.12097	**-0.2619**	0.054088	0.13954
HI	-0.23445	-0.16383	-0.10158	-0.06241	-0.14285	0.16939	-0.14586	-0.16748	**0.810944**	0.68993

TKW: Thousand Kernel Weight; BIO: Biomass; HI: Harvest index; K/SP: Number of kernel/spike; GY: Grain yield; SP/M²: Number of spike per square meter; DH: Days to heading; DM: Days to maturity; PH: Plant height.

Seed rate X genotype interaction

The interactive effect of seed rate and genotypes was highly significant for grain yield (P<0.001). However, other phonological characters were not affected **(Table 4)**. These results indicated that the studied genotypes responded differently to increasing or decreasing the seed rates of (120-140 Kg/ha).

The combined analysis of variance indicated that the main factor of interaction between seed rate and genotype did not show any significant (P>0.05) difference in phonological parameters and growth parameters. However, the current results reveal that the high significance (P<0.001) is affected by the interaction of seed rates and genotypes on yield and yield component. The combination of Sandal and 214 kg/ha produced a higher 675 fertile spike/m², which was the first ranked **(Table 4)**, while in the combined analysis, the combination consisted of the Sandal and 166 kg/ha seed rate, showed a lower 377 fertile spike/m². The highest kernel per spike was (52) obtained by Sandal, and 95kg/ha seed rate. And the lowest kernel per spike was (25) obtained by Bohaine and 214 kg/ha seed rate. The combination of one thousand kernel weight, Gawahier variety, 120 kg/ha and 195 kg/ha produced the higher values (40.3, 40.4 g), which were the first ranked **(Table 3)**, while in the combined analysis, the combination of Sandal variety and 195 kg/ha seed rate was obtained a lower value (32.5 g). Using different seed rates has demonstrated significant variations in biomass across the three studied genotypes. The current results indicated that the mean of the total biomass ranged from 4838 kg/ha (Bohaine) to 6894 kg/ha (Sandal) genotype. The highest harvest index of (36.7% and 36.2%) were recorded by Bohaine and Sandal with a seed rate of 166 Kg/ha, respectively. While the lowest harvest index of (25.6% and 26%), were obtained by Jawahir with a seed rate 166 Kg/ha and 95 Kg/ha, respectively.

Correlation coefficient

Phenotypic and genotypic correlations between the various characters are presented in **Table 5**. Days to heading had a positive correlation with days to maturity **(**0.88507**). The number of kernels per spike was positive and highly significantly correlated with No. of seed/m^2 **(**0.80750**), days to 50% heading (0.67547**) and days to maturity (0.67832**). Plant height exerted a significant and positive correlation with days to heading **(**0.79847**) and days to 90% to maturity (0.78927**), the works of [36] support these findings. A significant and positive phenotypic correlation was observed for days to maturity with plant height. Grain yield also showed a highly significant and positive correlation with harvest index (0.68993**), Spike number per m^2 showed a positive with grain yield **(**0.00362**) similar result was observed by [37] who reported that a positive correlation of grain yield with the number of grains per spike was found, however, the same trait revealed negligible, negative and non-significant correlation with the number of kernels per spike **(**-0.06092**) and harvest index **(**-0.07696**), many previous authors had reported similar results between grain yield and spike number [38,39,40]. Grain yield had a significant and positive correlation with days to maturity (0.23089*), which contrasts the findings of [41], who reported that the grain yield was negatively correlated with days to maturity.

Path coefficient analysis

As correlation does not allow the partitioning of genotypic correlation coefficients into direct and indirect effects, they are further analyzed by path coefficient analysis [42] by using grain yield as a dependent variable. The direct and indirect effects of different characters on grain yield are presented in Table 6. In this study. The highest and positive direct effect on grain yield was (0.810944) exhibited by harvest index, followed by biomass which showed (0.740981); similar findings were reported by [43] and [44], harvest index and biomass parameters could be used as direct selection criteria in any breeding program designed to increase grain yield, suggesting its importance in the breeding program for developing wheat genotypes with higher grain yield. Generally, characters that exerted a positive direct effect and positive and significant correlation coefficient with grain yield were known to affect grain yield in the favorable direction and need much attention during selected cases. However, the lowest negative direct effects were (-0.00773) and (-0.01695) recorded by thousand kernels weight and days to 90% to maturity, respectively. These results, in contrast with the finding of [45], reported opposed results in rice cultivars. The highest indirect effect on grain yield were (0.414097, 0.401374, 0.410451, 0.342266, and 0.324105), all of them recorded by biomass; similar findings were reported by [43] and [44]. The indirect effects via other characters were mostly negligible. Therefore, its correlation coefficient with grain yield was mainly due to their direct effect.

Conclusion

The optimum seeding rate for winter wheat in Sudan is environment specific because of soil quality, water content, and winter survival. Our results have shown that the planting density of winter wheat should be about 120-140 Kg/ha at an optimal planting date, producing a sufficient number of good-quality spikes with adequate yield structure and quality.

The interaction between seed rate and genotypes showed no significant (P>0.05) differences in phonological parameters and growth parameters. However, the results showed a high significance (P<0.001) among the combination of seed rates and genotypes on yield and yield component. The combination of Sandal and 214 kg/ha was a higher (675 fertile spike/m^2) and ranked first, while the combination of Sandal and 166 kg/ha showed a lower 377 fertile spike/m^2.

The combination of Jawahir with 120 kg/ha, and 195 kg/ha showed a higher thousand kernel weight (40.3, 40.4 g), which was ranked first. Using different seed rates resulted in big variations among the biomass data of the three tested varieties.

The harvest index of the tested genotypes varied in response to the seed rate, which was from 95 to 214 Kg/ha. The number of kernels per spike was positive and highly significantly correlated with No. of seed/m^2, days to heading**,** and days to maturity. Plant height significantly and positively correlated with days to heading and days to maturity**.** Grain yield showed a highly significant and positive correlation with harvest index, while the same trait showed a positive and non-significant association with spike number per m^2**.** The highest and positive direct effect on grain yield was exhibited by the harvest index. The lowest and negative direct effects were recorded by thousand kernels weight and days to maturity. However, the highest indirect effect on grain yield was recorded by biomass.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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