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ORIGINAL PAPER

Disease Incidence and Genetic Analysis of Adult Plant Resistance to Leaf Rust in Some Egyptian Wheat Cultivars

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ABSTRACT

This research has been carried out to study the disease incidence and genetic analysis of adult plant resistance to leaf rust in eight Egyptian wheat varieties, Misr1, Misr2, Misr3, Gemmeiza11, Gemmeiza12, Sids1, Shandweel-1 and Sakha94 crossed with *Triticum spelta saharen*sis (*T.s.s.*) as a highly susceptible tester wheat variety at Bahtem Agricultural Research Station, Agr. Res. Center during 2018-2021 growing seasons. The nine wheat genotypes and F_2 plants of eight crosses with *T.s.s.* were estimated to disease incidence measurements and quantitative genetic analysis to leaf rust adult plant resistance. The nine wheat genotypes tested were divided into two resistance groups according to disease incidence measurements (FRS, r-value and AUDPC), the first group having the high and moderate levels of partial resistance *i.e*., Misr1, Misr2, Misr3, Gemmeiza12, Shandweel-1 and Sakha94, this group is of major importance for efficacious breeding for leaf rust durable resistance, while cultivars Gemmeiza11, Sids1 and *T.s.s.* were included in the second group with high values of FRS, r-value and AUDPC. The F_2 populations, F_1 and parents for each of the eight crosses were tested for adult plant disease severity. The quantitative analysis of the $F_1$and F_2 mean value of leaf rust severity in the eight crosses was mostly lower than the mean value estimated for their respective mid parents and indicated that rust resistance was partial dominance expecting crosses (*T.s.s.* × Sids1) in F_1 and (*T.s.s.* × Gemmeiza11) in F_2, the positive values were higher than the respective mid-parents, which indicates existence an over- dominance towards susceptibility of these crosses. The heritability in its broad-sense estimated from the variance parents $F_1$and F_2 for partial leaf rust resistance, is considered to be high in magnitude, since the values ranged from 63.99 to 96.51%. The number of genes of each analyzed parent is controlled by three, two and a pair of genes. Generality, this outcome in the adult plant stage suggests which selection for this trait may be possible in the first segregating generations. Although the delay would be more efficacious, according to the important role that dominance impacts play in trait expression the selection of resistant adult plants in the subsequent generation of segregation would be useful for the development of a high-yielding wheat genotype under Egyptian condition.

Keywords: Wheat, Adult plant stage, Leaf rust, *Puccinia triticina*, Quantitative resistance

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INTRODUCTON

Wheat (*Triticum aestivum*) is one of the prehistoric crops and the world's major crops and is likely to remain a mainstay of human nutrition for the prospective future. It is estimated that it contributes around 20% of calories and 20% of proteins for daily human consuming, and about 45% from calories and proteins in Central Asia and North Africa (Pena-Bautista *et al*., 2017). In year 2020/2021 worldwide wheat production reached more than 772 million tons. That was around ten million tons more than in the previous season, (Statista, 2021). The Egyptian wheat production was approximately 8.9 million tons, an increase of 1.48% over the previous year (Statista, 2020), The annual wheat consumption is about 19 million tons, the local production is about 8.9 million tons, and the local annual output and consumption gap is about 10.2 million tons. There are two ways to increase local wheat production to close this gap. The first method is increase wheat yield per unit area through vertical extension through development of new cultivars with high yields and resistance to abiotic and biotic stress and use the recommended cultivation methods. The second way is horizontal expansion, that is, increasing the wheat planting area. Egypt’s horizontal expansion is only available in the desert, where the soil has almost no water retention capacity, so improved wheat varieties are needed to tolerate drought stress, which may result in low food yields under these conditions.

Wheat plants suffer from many devastating diseases. Rust is the most important disease of wheat, as it can move great distances and form new virulent races that cause serious losses. (McVey *et al.*,2004; Huerta-espino *et al.*, 2011; Negm *et al.*, 2013 and Najeeb *et al.*, 2019). Leaf rust caused by *Puccinia triticina* Eriks. is a common wheat disease around the world and in Egypt, contributing significant crop losses. Susceptible wheat varieties suffer yield reduction about 5 and 60% (Smith, 2008). The severe and devastating rust epidemic led to the elimination and discarding of many new varieties of wheat shortly after they were released and used by farmers in agriculture. In Egypt, grain yield losses of susceptible wheat varieties exceeded 23% in favorable environmental conditions, especially in northern part of Delta. (Negm, 2004; Hassan *et al.*, 2012; Mabrouk, 2016 and Thabet and Najeeb, 2019). The breeding for natural resistance is much cheaper and more friendly with the environment than the use of fungicides (Huerta-Espino *et al*., 2011). Although the host's rust diseases genetic resistance generally provided passable protection without the need for chemicals (Loughman *et al.*, 2005, and Singh *et al.*, 2008). Genetic pyramid of leaf rust genes is necessary to obtain the long-term durability of leaf rust resistance in Egypt (Atia *et al.*, 2021). Quantitative resistance, which is delaying the pestilential and emergence of wheat leaf rust, is a major source of persistent resistance. Quantitative resistance is usually has durable more than qualitative ones. (Line and Chen, 1989). The strategy of pathologists and wheat breeders has always focused on adult plant resistance to determine and progress the level of resistance in order to increase the wheat yield by genetic enhancement of wheat varieties against rusts. (Bansal *et al*., 2008 and El-Orabey *et al*., 2020)

In this study, we aim to estimate the leaf rust disease incidence and determine the level of quantitative resistance in order to heritability, degrees of dominance, the number of resistance genes, variances and mean of leaf rust severity in each studied wheat cultivar, for find and evaluation leaf rust resistance genes in some Egyptian wheat varieties and trying to connect this genetic information to the performance and durability of resistance.

MATERIALS AND METHODS

To estimate the incidence of disease, qualitative and quantitative resistance of the tested wheat varieties to leaf rust, crosses among the susceptible parent *Triticum spelta saharensis* and eight Egyptian bread wheat cultivars, *i.e.,* Misr1, Misr2, Misr3, Gemmeiza11, Gemmeiza12, Sids1, Shandweel-1 and Sakha94 were used. Data in Table (1) demonstrate name pedigree and release year of nine wheat genotypes, which provided by Wheat Disease Research Department. Agricultural Research Center, Egypt in 2018/2019 at Bahtem Agricultural Research Station. The parents' wheat varieties were grown at three different times. Crosses were made and F_1seeds were harvested and kept for growing in the next season (2019-2020) in rows of 3 m long and 30 cm apart and spaced 30 cm to allow production of F_2 seeds. In the following season (2020-2021) seeds obtained from F_1 plants and their parents were sown as single seeds for each progeny to be inspected individually to estimate their distribution frequencies (Table 1) and also were sown in three rows within plots in an experiment of a randomized complete block design with three replicates, All materials were exposed to disease stress by surrounding all plots by a spreader area, planted with a mixture of the two highly susceptible varieties to the leaf rust pathogen, *Triticum spelta saharenses* (*T.s.s*) and Morocco. The spreader plants were artificially inoculated before rust appearance during the second half of February to provide the tested plants with a permanent source of leaf rust inoculation at adult-stage under artificial inoculation condition (Stakman *et al.*, 1962). All regular cultural practices were applied during the growing season.

I. Leaf rust disease incidence:

Data were recorded as Final rust severity, Rate of leaf rust increase (r-value) and Area under disease progress curves (AUDPC) for each wheat genotype, at the time when rust first appeared until the early dough stage (Large, 1954). Leaf rust severity of each variety was registered every ten days after the onset of the first infection using the modified Cobb's scale (Peterson *et al.*, 1948). Adult plant resistance response and severity for leaf rust disease was recorded following the descriptions of (Roelfs *et al.*, 1992) and (Singh *et al.*, 2013).

Wheat leaf rust resistance behavior was assessed through host response, and different components of disease incidence and their development were estimated as follows (FRS), (r-value) and (AUDPC).

Table (1): Name, pedigree and release year of nine wheat genotypes used in this study.

	Genotypes	Pedigree	Release year
1	Misr1	OA SIS/ SKA UZ//4 *BCN/3/2* PASTORCMSS 00Y01 881T- 050M- 030Y- 030M- 030 WGY- 33M- 0Y-0S.	2011
2	Misr2	SKA UZ/ BAV92 CMSS 96M03 611S- 1M-010SY- 010M- 010SY-8M- 0Y- 0S.	2011
3	Misr3	ATT ILA *2/AB W65* 2/KACHU CMSS 06Y00258 2T-099 TOPM- 09 9Y- 099Z TM- 099Y-09 9M- 10WGY -0B- 0EGY.	2018
4	Gemmeiza11	BOW"S"/KVZ"S "//7C/SER182/3/ GIZA 168/SAKHA61GM5820- 3GM- 1GM- 2G M- 0G M.	2011
5	Gemmeiza12	OTU S/3/ SA RA/ THB// VE ECMSS97 Y00227S- 5Y-010 M-010Y- 010 M- 2Y- 1M- 0Y- 0GM.	2017
6	Sids1	HdH D2172/ Pavon"S"// 1158.57/ Maya74"S"S D46- 4S D- 2SD-1SD- 0S D.	1996
7	Shandweel-1	SITE /MO/ 4/NAC //3*PVN /3/MiR LO.	2011
8	Sakha94	OPA TA/R AYON //KAUZCMBW90Y3180-0TO PM-3Y-01 0M-010 M-010Y-10M -015Y- 0Y- 0AP- 0S.	2004
9	*Triticum spelta saharensis*	highly susceptible wheat variety.	

Final rust severity (FRS) was recorded as disease severity (%) by (Das et al., 1993).

Rate of leaf rust increase (r-value) as a function of time, was also estimated to be using the following formula adopted by Van Der Plank (1963):

$$\textbf{r-value} = \frac{1}{t_2 - t_1}\left(\log_e \frac{X_2}{1 - X_2} - \log_e \frac{X_1}{1 - X_1}\right)$$

Where:

$t_2 - t_1$ = the interval in days between these dates

X_1 = the proportion of the susceptible infected tissue (disease severity) at date t1

X_2 = the proportion of the susceptible infected tissue (disease severity) at date t2

Area under disease progress curve (AUDPC), was estimated by Pandey *et al.* (1989).

AUDPC= D [1/2 (Y1+Yk) + Y2 + Y3 + …Yk-1]

Where:

D = days between reading

Y_1 = first disease recording

Y_k = last disease recording

II. The genetic analysis:

Plants were divided into classes according to the level of leaf rust severity, *i.e*., 0-10; 11-20; 21-30; 31-40; 41-50; 51-60; 61-70 and 71-80. Plants grouped in the first three classes were considered as the low rust severity phenotypes, while other classes (more than 30%) were reckoning as the high rust severity phenotypes.

Frequency distribution values were computed for the two parents, F_1 and F_2 populations for leaf rust severity, under the field conditions. In respect to mode of inheritance, the best agreement between the observed and expected proportions of the phenotypic parameter classes with respect to the severity% of leaf rust was determined by Chi square analysis (X^2) according to Steel and Torrie (1960). Furthermore, the minimum number of effective genes that control slow rusting resistance at each cross was determined by the formula of Wright (1968).

$$N = D^2 / 8(VF_2 - VF_1)$$

Where:

N = minimum number of effective genes

D = $P_1 - P_2$ (the difference between the mean response of the two parents)

VF_1 = Variance of F_1

VF_2 = Variance of F_2

Degrees of dominance was estimated according to the method suggested by Romero and Frey (1973). In this method, the degrees of dominance symbolized as h_1 and h_2 for F_1 and F_2, respectively, were calculated by the formula:

$$h_1 = (\bar{X}F_1 - \bar{X}MP)/D$$

$$h_2 = 2(\bar{X}F_2 - \bar{X}MP)/D$$

where:

$$D = \bar{X}h_p - \bar{X}MP$$

$\bar{X}F_1$, $\bar{X}F_2$ and $\bar{X}h_p$ are the means of F_1, F_2 and higher parent, sequentially, while $\bar{X}MP$ is the mid parent value. In addition, the F_1 and F_2 means were compared with Mid-parent value using ''t" test to determine whether h_1 and h_2 values were significantly different from zero.

Heritability in its broad sense was determined by Lush (1949) as follows:

$$h^2 = V_g / V_p \times 100$$

where:

h^2 =broad sense heritability

V_g = genotypic variance of F_2 individuals

V_p =phenotypic variance of F_2 individuals

Least significant differences at 1% and 5% were used to compare disease incidence measurements FRS and AUDPC with treatments according to Duncan (1955). Correlation coefficient was also used to detect the relationship between AUDPC as a good and better indicator of disease incidence expression over time and the heritability% as a qualitative analysis to wheat leaf rust resistance.

RESULTS AND DISCUSSION

I. Leaf rust disease incidence:

On the basis of final rust severity (FRS and IR) the nine tested wheat genotypes (Table 2 and Fig. 1B) were grouped into two groups of resistance, the first group having the high and the moderate levels of partial resistance *i.e.,* Misr1, Misr2, Misr3, Gemmeiza12, Shandweel-1 and Sakha94, the values of final rust severity and infection response were 10MS, 20MR, Tr.MR, 10S, Tr.S and 20MS, respectively, The resistance genes available in these materials outweigh the virulence of field leaf rust and, despite compatible host pathogenic responses, still result in statistically lower disease Prior to Ali *et al*., (2007); Li *et al*., (2010); Tabassum, (2011) and Safavi and Afshari, (2013) who also used the rust severity to evaluate the slow rusting behavior of wheat lines. This group is of major importance for efficacious breeding for leaf rust durable resistance Parlevliet (1988); Nzuve *et al.*, (2012) and Mabrouk *et al.*, (2019). On the other hand, cultivars Gemmeiza11 and Sids1 were inserted in the second group with high values of final rust severity, 40S and 50S, respectively, however the susceptible wheat genotype *T.s.s.* showed the highest final disease severity, 80S, this group having the low and moderate levels of partial resistance and considered the fast-rusting genotypes indicates that a passable epidemic pressure has been founded in each season for field experiments. The resistance genes available in these materials outweigh the virulence of field leaf rust and, despite compatible host pathogenic responses, still result in statistically lower disease severity. These results agree with the findings of Ali *et al.,* (2007); Li *et al.,* (2010); Tabassum (2011) and Safavi and Afshari (2013). Rust severity was also used to evaluate slow rust behavior of the wheat lines.

According to the tested wheat genotypes concerning with previous parameters of leaf rust disease incidence, r-value and AUDPC all wheat genotypes were significant at levels 1% and 5% (Table 2). Among the tested cultivars, Misr3 and Shandweel-1 revealed the lowest values of r-value (0.005), while the maximum mean of r-value (0.051) was observed on the highly susceptible parent *T.s.s.* the rest of cultivars have values ranged from 0.024 to 0.044. (Table 2 and Fig. 1C) compared to other parameters of slow rust. The infection rate of the tested varieties has a greater variation, in part because the rate of increase of the disease is a regression coefficient with a large error variation. Therefore, compared with FRS and AUDPC, the disease increase rate in this study seems to produce an unreliable estimate of slow rusting resistance. Wheat rust has similar results. Rees *et al.,* (1979); Broers, (1989); Negm (2004); Ali *et al.,* (2008); Safavi *et al.,* (2010); Boulot and Aly, (2014) and Mabrouk *et al.*, (2019).

AUDPC is a good index of disease severity over time Van der Plank (1963). Therefore, the chosen of cultivars with lower AUDPC values is agreeable in practical applications. According to AUDPC value, the tested wheat varieties were divided into two different groups to leaf rust resistance (Table 2 and Fig. 1A).

Table (2): Disease incidence measurements, (FRS) with (IR), (r-value) and (AUDPC) on nine wheat genotypes to leaf rust (*Puccinia triticina*) under field condition during 2020/2021 growing season.

No.	wheat genotype	Disease incidence measurements		
		FRS and IR	r- value	AUDPC
1	Misr1	10MS	0. 024 d	102.00 ef
2	Misr2	20MR	0.028 c	96.00 ef
3	Misr3	Tr.MR	0.005 e	18.00 g
4	Gemmeiza11	40S	0.044 b	515.00 de
5	Gemmeiza12	10S	0.024 d	130.00 de
6	Sids1	50S	0.031 c	650.00 b
7	Shandweel-1	Tr.S	0.005 e	45.00 fg
8	Sakha94	20MS	0.029 c	200.00 d
9	*T.s.s.*	80S	0.051 a	1250.00 a
L.S.D. 1%			0.000	98.405
L.S.D. 5%			0.004	71.428

IR = infection response (r-value) = Rate of disease increase (FRS) = Final rust severity (AUDPC) = Area under disease progress curve

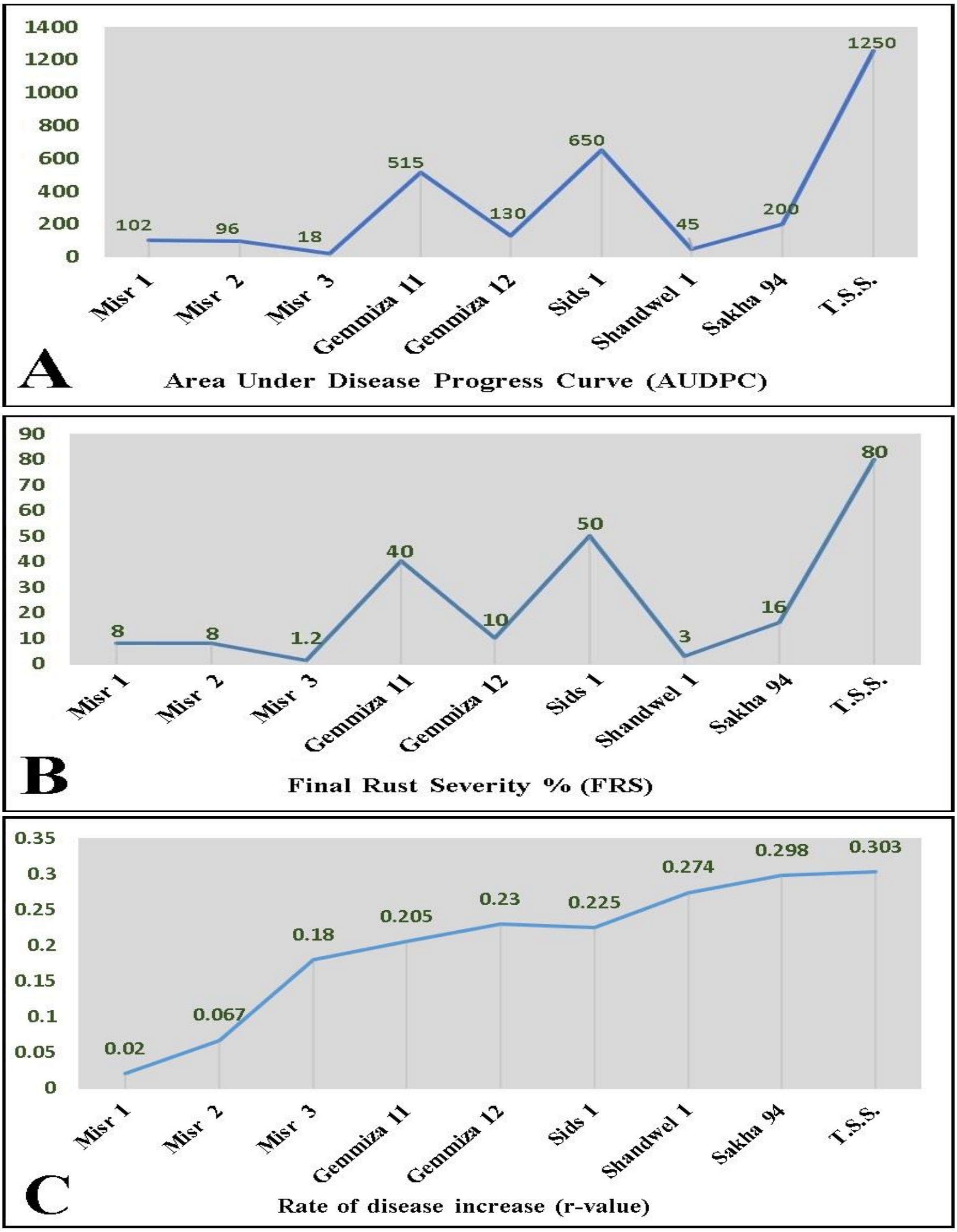

Fig. (1): leaf rust disease incidence measurements in nine wheat genotypes, (A) Area Under Disease Progress Curve (AUDPC); (B) Final Rust Severity % (FRS); (C) Rate of disease increase (r-value).

Wheat genotypes with an AUDPC value below 300 is between 18.00 and 200.00 and have high resistance to leaf rust or partial resistance, consisted of six wheat cultivars *i.e.*, Misr1, Misr2, Misr3, Gemmeiza12, Shandweel-1 and Sakha94 while, cultivars *i.e.*, Gemmeiza11, Sids1 and *T.s.s* having AUDPC value more than 300 ranged from 515.00 to 1250.00. These three genotypes could be characterized as low-level resistance or highly susceptible varieties to leaf rust due to Parlevliet, (1988); Brown *et al*., (2001); Singh *et al*., (2005); and Kaur and Bariana, (2010), varieties with a response to MS infection may have persistent resistance genes, like resistance to slow rust. Rust infection and spore formation occurred for the first time in these wheat varieties, but the final host response showed chlorosis and necrotic lesions. As shown by their AUDPC values, leaf rust develops slowly. None of studied varieties were marked as susceptible to field responses. Other researchers also used AUDPC to report differences in rust resistance between different wheat lines. Patil *et al.*, (2005) and Draz *et al.*, (2015).

Interaction between disease incidence measurements FRS and AUDPC with treatments (cultivars) is presented in ANOVA, Table (3).

Table (3): ANOVA for Rate of disease increase (r-value) and Area under disease progress curve (AUDPC) to leaf rust of 9 wheat genotypes evaluated in Bahtem location during 2020/21 growing season.

Source of variation	Degree of freedom	r-value				AUDPC			
		Square sum	Mean sum of square	F cal	F prob	Square sum	Mean sum of square	F cal	F prob
Replication	2	3.555	1.777			13667.555	6833.777		
Treatment	8	0.231	0.021	714.79	6.011	3975270.00	496908.75	291.862	7.451
Error	16	0.006	4.077	-	-	27240.444	1702.527	-	-
Total	26	-	-	-	-	-	-	-	-

II. The genetic analysis: qualitative analysis:

The qualitative analysis of data was achieved due to reaction of progenitor populations, F_1 and F_2 against the pathogen of wheat leaf rust in the adult plant stage. The frequency of leaf rust disease severity distributions for the F_1, F_2 and their two respective parents of the eight crosses with parent (*T.s.s*) (Table, 4) expressed high susceptibility to leaf rust with disease severity from 61-80%. While the eight parents showed different levels of leaf rust severity %. However, the cultivar Sids1 exhibited high degrees of disease severity ranged from 51-70%. On the other hand, the rest parents, Misr1, Misr2, Misr3, Gemmeiza12, Shandweel-1 and Sakha94 showed low to moderate rust severity ranged from 0-30%, in addition to Gemmeiza11, ranged from 21-40%.

The disease severity of F_1 plants in the tested crosses *i.e.*, (*T.s.s.* × Misr1), (*T.s.s.* × Misr2), (*T.s.s.* × Misr3), (*T.s.s.* × Gemmeiza12), (*T.s.s.* × Shandweel-1) and (*T.s.s.* × Sakha94) ranged from 0-30% in addition to (*T.s.s.* × Gemmeiza11) ranged from 11- 40% and was lower than those calculated for their respective mid-parents' values. This result indicated that the susceptibility was partially dominant over resistance. On the other hand, the disease severity of F_1 plants to cross (*T.s.s.* × Sids1) ranged from 61-80%. This result indicated that the resistance in this cross was dominant over susceptibility.

The frequency of the eight tested crosses distribution revealed that F_2 plants showed a wide range of rust severity ranged from 0 to 80% (Table 4), the numbers of F_2 plants having low: high rust severity, being 25:275 in cross (*T.s.s.* × Sids1). This number coincided with the theoretically expected proportions of 1:15 with P values of 0.136. These outcomes affirmed that at least two pairs of independent recessive genes control leaf rust. therefore, find that three dominant recessive genes in the cross (*T.s.s.* × Gemmeiza11) the numbers of F_2 plants have low: high rust severity being 7:293 expected ratio was 7:57 in order with P. values 0.282 Table (4). On the other hand, the numbers of F_2 plants have low: high rust severity were 275:25, 280:20 and 271:29 in crosses between (*T.s.s.* × Misr2, *T.s.s.* × Gemmeiza12 and *T.s.s.* × Sakha94). These numbers corresponded to the theoretically expected ratios of 15: 1 in sequence with P values of 0.136, 0.766, and 0.014, respectively. These outcomes affirmed that at least two independent dominant gene pairs control leaf rust in each of these crosses, while one dominant gene was found in crosses (*T.s.s.* × Misr1), (*T.s.s.* × Misr3) and (*T.s.s.* × Shandweel 1), the numbers of F_2 plants have low: high rust severity were 219:81, 217:83 and 214:86, expected ratio was 3:1 in order with P. values 0.424, 0.286 and 0.142, respectively. These results revealed the inheritance mode of this trait. Therefore, plants with partial (field) resistance to leaf rust can be selected in the early generation while, delaying the selection to later generations would be more fruitful because of the importance of dominance effects. These outcomes are in compact with the finds of Hassanein (1961); Kuhn *et al*., (1980); Bjarko and Line (1988); Shehab EL-Dine and Abd El-Latif (1996); Boulot (1997); Negm (2004); Youssef (2011); Omara (2013); Abd EL-Badia (2015); Mabrouk (2016) and EL-Orabey *et al*., (2020).

To quantitatively investigate the genetic action of resistance of wheat fields, the parental populations, F_1 and F_2 for each of the eight crosses were analyzed to leaf rust in the adult plant under field condition. The population mean ($\bar{x}$) and the variances (S^2) of the parents, F_1 and F_2 were used to determine the degrees of dominance of F_1 (h_1) and F_2 (h_2), the heritability in the broadest sense and the number of functional genes for each cross (Tables 4 and 5).

Means and degrees of dominance:

The mean of susceptible parent of wheat leaf rust *Triticum spelta saharensis* and the other eight varieties used, *i.e.*, Misr1, Misr2, Misr3, Gemmeiza11, Gemmeiza12, Sids1, Shandweel-1 and Sakha94 were 73, 5.6, 10, 5.4, 29, 16, 58, 5.6 and 17, respectively Table (5). The obtained data show that the mean values of the resistance to rust of the F_1 plants in the eight crosses 6, 5.4, 6, 32, 5.4, 72, 18 and 16, respectively, these means were lower in Misr2, Gemmeiza12 and Sacha-94 as their respective mid parent values, suggesting the presence of partial dominance for resistance. otherwise, crosses (*T.s.s.* × Gemmeiza11) and (*T.s.s.* × Sids1) had higher mean values of rust severity (3 2 and 72) that were higher than their respective mid parent values, suggesting the existence of over dominance for susceptibility in these crosses.

F_2 means for the eight crosses were 19.5, 11.3, 18.46, 55.33, 11.33, 51.2, 18.6 and 12.26, respectively, these mean values were lower than their respective mid-parental value, suggesting the presence of a partial dominance of resistance to susceptibility and the outcome affirmed by F_1's (Table 5 and Fig.2A). Except for the cross (T.s.s. × Gemmeiza11), which was higher than the values of their respective mid-parent, which indicates the existence of an over-dominance towards susceptibility in these crosses. The expression of the actions of the genes measured as degree of dominance h_1 and h_2 is shown in Table (5).

The evaluated values of h_1 were -0.98, -1.14, -0.98, -0.86, -1.01, +0.86, -0.63and -1.03 for the eight crosses (*T.s.s.* × Misr1), (*T.s.s.* × Misr2), (*T.s.s.* × Misr3), (*T.s.s.* × Gemmeiza11), (*T.s.s.* × Gemmeiza12), (*T.s.s.* × Sids1), (*T.s.s.* × Shandweel-1) and (*T.s.s.* × Sakha94) in sequence. Significantly negative values of h_1 indicated the existence of a partial domain of resistance. While the evaluated value of dominance degrees for F_1 (h_1) was + 0.86 for crosses (*T.s.s.* × Sids1). The significantly positive values of h_1 indicated the existence of an over-dominance of susceptibility in this cross. The evaluated value of dominance degrees for F_2 (h_2) was -1.17, -1.91, -1.22, +0.39, -1. 68, -1.90, -1.23, -and –2.33 for the eight crosses *i.e.*, (*T.s.s.* × Misr1), (*T.s.s.* × Misr2), (*T.s.s.* × Misr3), (*T.s.s.* × Gemmeiza11), (*T.s.s.* × Gemmeiza12), (*T.s.s.* × Sids1), (*T.s.s.* × Shandweel-1) and (*T.s.s.* × Sakha94), respectively, the negative value evaluated in these crosses indicated the partial dominance of resistance to leaf rust, except cross (T.s.s. × Gemmeiza11), which has positive values of h_2 + 0.39, suggesting the presence of over-dominance over susceptibility suggesting resistance in this cross. The expression of gene actions, measured as dominance degree indicated that the significantly negative values of h_1, h_2 indicated the presence of partial dominance for resistance and the significantly positive values of h_1, h_2 indicated the presence of over-dominance for susceptibility. This result was affirmed by Milus and Line (1986); Shehab EL-Dine *et al.*, (1991); Chen and Line (1992); Shehab EL-Dine and Abd EL-Latif (1996); Boulot (1997); Negm (2004); Youssef (2011); Abd EL-Badia (2015); Mabrouk (2016) and EL-Orabey *et al*., (2020).

Variances and heritability estimate:

Variances (S^2) calculated for the parents, F_1's and F_2's of the eight crosses are listed in Table (5). The variance value of the *T.s.s.* the first susceptible parent. and the other eight varieties used, *i.e*., Misr1, Misr2, Misr3, Gemmeiza11, Gemmeiza12, Sids1, Shandweel-1 and Sakha94 were 16, 5.64, 25, 3.84, 24, 9, 21, 5.64 and 16, respectively The F_1 variance of the eight tested crosses were, 9, 3.84, 9, 24, 3.84, 21, 21 and 20, respectively. The value of F_2 variance was commonly high for each tested cross. This value was 267.41, 111.31, 204.64, 54.55, 99.98, 107.56, 263.04 and 129.86 in sequence. On the other hand, the heritability estimates in its broad calculated from the variances of parents, F_1 and F_2 for eight crosses are presented in (Table 5 and Fig. 2B). The heritability value for each studied cross is considered to be high. However, these values were 96.51, 89.63, 96.00, 63.99, 91.79, 74.98, 96.11 and 84.97% for the eight crosses under study *i.e*., (*T.s.s.* × Misr1), (*T.s.s.* × Misr2), (*T.s.s.* × Misr3), (*T.s.s.* × Gemmeiza11), (*T.s.s.* × Gemmeiza12), (*T.s.s.* × Sids1), (*T.s.s.* × Shandweel-1) and (*T.s.s.* × Sakha94), respectively.

Table (4): Leaf rust frequency distribution of F_2 bread wheat crosses among *Triticum spelta saharensis* and each of 8 varieties as well as their respective parents and F_1 at the adult stage under field conditions inoculated with *Puccinia triticina* during 2020/2021 growing season.

No.	Cross name	No. of tested	Disease severity classes								observed ratio		Expected	Probability	
		Plants	0-10 %	11-20 %	21-30 %	31-40 %	41-50 %	51-60 %	61-70 %	71-80 %	L	H	ratio	X2	Pb
1	*T.s.s.* × Misr1	P1 50							10	40					
		P2 50	47	3											
		F1 50	45	5											
		F2 300	120	77	22	31	29	21			219	81	3:1	0.640	0.424
2	*T.s.s.* × Misr2	P1 50							10	40					
		P2 50	25	25											
		F1 30	48	2											
		F2 300	192	66	17	15	10				275	25	15:1	2.22	0.136
3	*T.s.s.* × Misr3	P1 50							10	40					
		P2 50	48	2											
		F1 50	45	5											
		F2 300	134	39	44	55	28				217	83	3:1	1.38	0.286
4	*T.s.s* × Gemmeiza11	P1 50							10	40					
		P2 50			30	20									
		F1 50		5	10	35									
		F2 300			7		35	192	66		7	293	7:57	1.159	0.282
5	*T.s.s.* × Gemmeiza12	P1 50							10	40					
		P2 50		45	5										
		F1 50	48	2											
		F2 300	195	45	40	15	5				280	20	15:1	0.089	0.766
6	*T.s.s.* × Sids1	P1 50							10	40					
		P2 50						35	15						
		F1 30							15	35					
		F2 300			25	10	45	185	35		25	275	1:15	2.22	0.136
7	*T.s.s.* × Shandweel-1	P1 50							10	40					
		P2 50	47	3											
		F1 50		35	15										
		F2 300	142	51	21	47	21	18			214	86	3:1	2.15	0.142
8	*T.s.s.* × Sakha -94	P1 50							10	40					
		P2 50		40	10										
		F1 50	5	35	10										
		F2 300	180	70	21	10	19				271	29	15:1	2.97	0.014

H = High rust severity ≥ 30%; L = Low rust severity ≤ 30 %; Pb = Values higher than 0.05 indicate no significance of X.

Table (5): Leaf rust severity mean, variance, degrees of dominance, heritability in its broad sense (%) and number of genes for 8 bread wheat crosses at adult stage, under field conditions in 2020/2021 growing season.

No.	Cross name	No. of tested Plants	$\bar{X}$	S^2	Degrees of dominance		Heritability %	No. of genes
					h1	h2		
1	*T.s.s.* × Misr1	P1	73.0	16.00				
		P2	5.6	5.64				
		F1	6.0	9.00	-0.98			
		F2	19.5	267.41		-1.17	96.51	2.19
2	*T.s.s.* × Misr2	P1	73.0	16.00				
		P2	10.0	25.00				
		F1	5.4	3.84	-1.14			
		F2	11.3	111.31		-1.91	89.63	4.61
3	*T.s.s.* × Misr3	P1	73.0	16.00				
		P2	5.4	3.84				
		F1	6.0	9.00	-0.98			
		F2	18.46	204.64		-1.22	96.00	2.91
4	*T.s.s.* × Gemmeiza11	P1	73.0	16.00				
		P2	29.0	24.00				
		F1	32.0	24.00	-0.86			
		F2	55.33	54.55		+0.39	63.99	7.21
5	*T.s.s.* × Gemmeiza12	P1	73.0	16.00				
		P2	16.0	9.00				
		F1	5.4	3.84	-1.01			
		F2	11.33	99.98		-1.68	91.79	5.83
6	*T.s.s.* × Sids1	P1	73.0	16.00				
		P2	58.0	21.00				
		F1	72.0	21.00	+0.86			
		F2	51.2	107.56		-1.90	74.98	0.32
7	*T.s.s.*× Shandweel-1	P1	73.0	16.00				
		P2	5.6	5.64				
		F1	18.0	21.00	-0.63			
		F2	18.6	263.04		-1.23	96.11	2.41
8	*T.s.s.* × Sakha -94	P1	73.0	16.00				
		P2	17.0	16.00				
		F1	16.0	20.00	-1.03			
		F2	12.26	129.86		-2.33	84.97	3.88
[A] Correlation between AUDPC in (Table 2) and Heritability %							-0.897[A]	

A negative and significant strong correlation (-0.897) was recorded between AUDPC as a better indicator of disease incidence previously mentioned in Table (2) and heritability % values to eight tested crosses. High levels of heritability are an indication of high success rates in restoring desired genes in future generations. Furthermore, these high estimates indicate that selection for this trait may be possible in the first segregating generations. A delay would be more efficacious according to the important role that dominance impacts play in development of this property. These outcomes coincide with those of Bjarko and Line 1988; Shehab EL-Dine *et al*., (1991); Shehab ELDine & Abd EL-Latif (1996); Boulot (1997); Negm (2004); Omara (2013) Abd EL-Badia (2015); Mabrouk, (2016) and EL-Orabey *et al.* (2020)

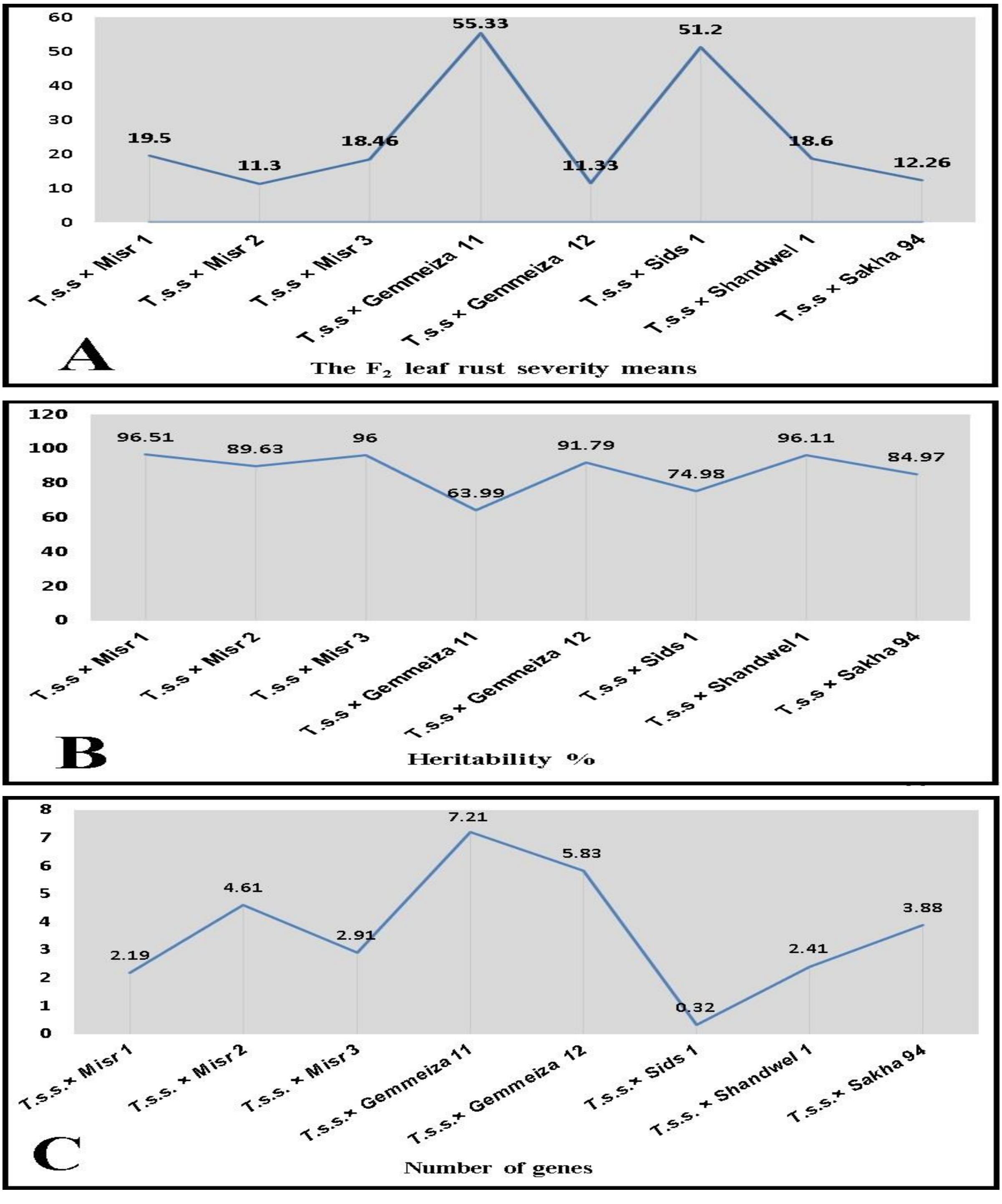

Fig. (2): The quantitative analysis to wheat leaf rust resistance in eight crosses, (A) The F_2 leaf rust severity means; (B) Heritability %; (C) Number of genes.

Number of genes:

The mean values of leaf rust severity of the parent and the variance of F_1 and F_2 were used to quantify the number of genes that determine field resistance in the wheat varieties tested. The outcomes obtained from (Table 5 and Fig. 2C) show that the crosses between *T.s.s*. and all of the varieties *i.e.*, Misr1, Misr2, Misr3, Gemmeiza11, Gemmeiza12, Sids1, Shandweel-1 and Sakha94 showed that the differences between each parent are controlled by three or two pairs of genes. The calculated gene numbers were 2.19, 4.61, 2.91, 7.21, 5.83, 0.32, 2.41, and 3.88, respectively. The number of genes of all analyzed parents is controlled by one or seven pairs of genes. in general., these results in the adult plant stage suggest that selection for this trait may be possible in the first segregating generations. A delay would be more efficacious according to the important role that dominance impacts play in the development of this property. These outcomes coincide with those of Da-Silva *et al.*, (2012); Loladze *et al.*, (2014); Mabrouk, (2016) and EL-Orabey *et al.,* (2020).

CONCLUSION

The results (Figs. 1 and 2) show the existence of different resistances in the wheat genotypes tested to leaf rust in the adult plant stage under field conditions. The wheat cultivars *i.e.*, Misr1, Misr2, Misr3, Gemmeiza12, Shandweel-1 and Skha-94 showed low values of severity means, r-value and AUDPC so considered have good levels of partial resistance, according to thier crosses between the highly susceptible variety *T.s.s.* The results showed that the F_1 and F_2 plants showed lower values of mean leaf rust severity, indicating the presence of partial dominance for resistance. The heritability value was high in these five crosses more than 84.97%. The leaf rust resistance controlled by two or three gene pairs confirmed that at least one dominant gene or two independent dominant genes pairs the high evaluated value indicates that the selection for this character in early segregating generations could be possible. On the other hand, wheat genotypes Gemmeiza11 Sids1 and *T.S.S.* showed high values of FRS, r-value and AUDPC so they are considered highly susceptible varieties and have fast rusting resistance to leaf rust. The crosses Gemmeiza11 and Sids1 with *T.s.s.* showed that value of mean leaf rust severity was higher than their respective parents values has respective mid parent value indicating the presence of over dominance toward susceptibility, The heritability value was lower than 75% in two crosses, although the cross (*T.s.s.* × Gemmeiza11) has seven resistance genes to leaf rust, it may be infected and highly sensitive to leaf rust because the expression of resistance genes depends on the inheritance of leaf rust. Host-parasite interactions plant development stages, temperature conditions and interactions between resistance genes and suppressor genes or other resistance genes in the wheat genome, such that selection for this trait delays generation segregation according to the important role of heritability. Dominance impacts would be more effective when expressing this property.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

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