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EFFECT OF LEAF RUST DISEASE ON VARIOUS MORPHO-PHYSIOLOGICAL AND YIELD ATTRIBUTES IN BREAD WHEAT

[a]Ghulam M.U. Din, [b]Muhammad A. Ali[1*], [a]Amjad Abbas, [c]Muhammad Naveed, [d]Javed Anwar, [d]Muhammad H. Tanveer

[a]Department of Plant Pathology, University of Agriculture Faisalabad, Pakistan.
[b]Centre of Agricultural Biochemistry & Biotechnology, University of Agriculture, Faisalabad, Pakistan.
[c]Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan.
[d]Wheat Research Institute, Ayub Agricultural Research Institute, Jhang Road, Faisalabad, Pakistan.

ABSTRACT

Leaf rust of wheat caused by *Puccinia triticina* is one of the most important diseases in the Pakistan and cause both yield and quality reduction. To investigate the effect of leaf rust of wheat on morph-physiological processes and grain yield, a field experiment was conducted using different wheat lines and varieties. The morpho-physiological attributes of the infected plant leaves were badly affected by the infection of leaf rust of wheat. The experiment comprised two treatments, one was inoculated with leaf rust spores manually and Morocco as a spreader while other keeping as a control. The results showed that there was -42.92, -23.72, -23.01, and -11.42, % decrease in chlorophyll content, flag leaf area, specific flag leaf area and relative water content in leaf rust (diseased) plot respectively while 21.24, 160.16% increase in relative dry weight and relative membrane permeability in the leaf rust plot. The results also revealed that leaf rust of wheat also reduces the yield components like number of grains per spike, spike length and 1000 grain weight (-52.38, -43.37 and -45.50 respectively). Thus, it could be concluded that leaf rust of wheat affect the morph-physiological process of wheat plants and badly reduce the yield as well.

Keywords: *Puccinia triticina*, Morpho-physiology, Grain yield, *Triticum aestivum*

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is grown as a staple food in most of the geographical regions of the world and has enormous genetic diversity (Slafer and Rawson, 1994). It has direct impact on the economic development of wheat growing countries including Pakistan (Lawlor *et al*., 2013). Wheat in Pakistan is infested by different biotic and abiotic factors. Rust diseases are air borne in nature and are serious menace to wheat production in the sub-continent. In particular, leaf rust caused by *Puccinia triticina* is the major constraints leading to yield losses up to 4% (German *et al*., 2007; Dueveiller *et al*., 2007; Bolton *et al*., 2008; Huerta-Espino *et al*., 2011). Leaf physiological events and morphology are badly affected by the leaf rust under severe condition (Shtienberg, 1992; Beasse *et al*., 2000; Bassanezi *et al*., 2001; Bastiaans, 1991). Air borne pathogens reduce the photosynthesis activity in infected leaves due to reduction in chlorophyll contents (Rabbinge *et al*., 1985; Bassanezi *et al*., 2002; Shtienberg, 1992; Van Oijen, 1990). To describe this effect Bstiaana (1991) suggested "virtual lesion" concept, which corresponds to the leaf area where photosynthesis is zero. Leaf rust of wheat reduces the leaf area by the water loss in the form of transpiration (Carretero *et al*., 2010). Similarly, under leaf rust infection both the flag leaf area and specific flag leaf area are reduced in wheat (Pazarlar *et al*., 2013). Leaf rust of wheat reduces relative water content and relative dry weight while specific flag leaf weight increases due to the infection of leaf rust (Ostazeski *et al*., 1970; Kuhn and Dawson, 1973; Johnson and Mian, 1983; Agrios *et al*, 1985; Funayama *et al*., 1997; Wintermantel, 2005; Taiwo and Akinjogunla, 2006). Yield contributing parameters were

*Corresponding Author:
Email: amjad.ali2001@gmail.com

significantly reduced in fungus affected crops (Ostazeski *et al*., 1970) while yield losses were mainly dependent upon the disease intensity and severity and stage of crop (Bancal *et al*., 2007; Carretero *et al*., 2010; Gaunt, 1995; Madden and Nutter, 1995; Serrago *et al*., 2009). Several studies have revealed the effect of leaf rust on various plant parameters. However, little is known about the effect of leaf rust on water status on the flag leaf and different yield components in wheat. In this study, it is investigated the impact of leaf rust disease on 12 morph-physiological and yield attributes in 35 varieties/advanced lines of wheat.

MATERIAL AND METHODS

Plant cultivation: Two plots were sown using 35 wheat (*Triticum aestivum*) lines/ verities *viz*., 102, 130, 120, 123, 127, 107, 128, 121, Galaxy -2013, 110, 134, 137, 142, 117, 111, Punjab-2011 , 113, 124, 140, 101, 104, Millet-2011, 112, 133, 136, 126, 144, 141, 115, 139, 106, Faisalabad-2008 , 118, Lasani 2008 and 135 under RCBD with three replicates during November 2015, in the research area of Department of Plant Pathology, University of Agriculture, Faisalabad, Pakistan. Among these two plots, one plot was inoculated three times (internal of eight days) with the inoculum of *Puccinia triticina*, which was taken from Ayub Agriculture Research Institute (AARI), while second plot kept as a control and treated with Tilt fungicide three times with the interval of eight days. The plant to plant and row to row distances were kept 15 and 30 cm respectively. The plots were periodically irrigated to ensure adequate water supply throughout the crop cycle. During the experiment, hoeing was done to remove the weeds while insecticides were sprayed, when necessary to control different types of insects in both plots.

Leaf chlorophyll, flag leaf area and specific flag leaf area: To measure the chlorophyll contents, chlorophyll meter (SPAD 502 plus, Minolta, Japan) was used. Measurement was done on both healthy and diseased flag leaves (on the three points of the flag leaves). For the measurement of flag leaf area, flag leaves were cut early in the morning, when leaves were in turgid position and their rate of transpiration is minimum at that time. Placed that leaves samples on the blank page for further investigation. Its length and width (from three places on leaf blade) was the resultant was multiplied with the constant factor (0.75) using the formula (lenght×average width×b), where "b" is the constant factor (Aldesuquy *et al*., 2014). Specific flag leaf area can be determined by drying the leaves in the oven at 72°C for 48 hours, after drying the leaves compute its dry weigh (g). Specific flag leaf area can be determined by the formula which was given by Ali *et al*. (2009).

$$\text{Specific flag leaf area} = \frac{\text{Flag leaf area}}{\text{Dry weight}}$$

Relative water content (%) and Relative dry weight: Relative water content provides a measurement of the "water deficit" of the leaf and may indicate the degree of stress expressed under diseased conditions. Fresh leaf samples taken from the growing crop weighted with the weighing balance and its fresh weight was noted, after that these leaves were placed in the water for 24 hours at 4°C, re-weighted and its turgid weight was determined and then these leaves were place in the oven for 48 hours at 72°C for the determination of dry weight. Relative water content of the leaves can be determined by the formula by (Teulat *et al*., 2003).

$$\text{Relativ water content}\frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

Relative dry weight of the leaves is the weight relative to the biomass of the plants leaves. For measurement of relative dry weight, fresh leaf samples of field grown crops were taken into the lab and placed in the water, chilled overnight, determined its turgid weight, then these leaf samples oven dried at 72°C for 48 hrs and re-weighed its dry weight. Relative dry weight was determined by the formula by (Ali *et al*., 2009).

$$\text{Relative dry weight} = \frac{\text{Dry Weight}}{\text{Turgid weight} - \text{Dry weight}}$$

Relative membrane permeability and specific flag leaf weight: Relative membrane permeability was determined as described by (Yang *et al*., 1996). The leaves were cut into equal pieces and transferred to test tube containing 20ml deionized distilled water. The test tube vortexed for 10s and solution was assayed for initial electrical conductivity (EC0). Than samples were placed in the refrigerator at 4°C for 24 hours, the electrical conductivity (EC1) was assessed. The same samples were then autoclaved at 120°C for 20 min. and determine (EC2). Percent relative membrane permeability can be determined as;

$$\text{Relative membrane permeability (\%)} = \frac{EC1-EC0}{EC2-EC0} \times 100$$

Specific flag leaf weight was determined as described by (Ali *et al*., 2009). Firstly, determine the flag leaf area, by the formula of (lenght×width×b), here "b" is the constant factor and its value is 0.75. Than assessed these leaf samples for the dry weight keeping in the oven at 72°C for 48 hrs.

$$\text{Specific flag leaf weight} = \frac{\text{Dry weight}}{\text{flag leaf area}}$$

Yield parameters: At the maturity seven plants were randomly selected from each plot and data were recorded for the number of grains per spike, spike length (cm), number of spikelet's per spike and 1000 grain weight (g).

STATISTICAL ANALYSIS

The data were statistical analyzed using the factorial under the randomized complete block design with the software Statistix 8.1. The mean value of data is tested with least significance difference (LSD) test at the probability at 5% ($p \leq 0.05$), with the standard error of the three replicate.

RESULTS

Varietal response against leaf rust infection: Analysis of variance indicated that the wheat lines/ varieties studies in this experiment were significantly affected by the leaf rust of wheat (*Puccinia triticina)* under natural condition (Table 1). Faisalabad 2008, Galaxy 2013, 135, 127, 118, 117, Millat 2011 and 107 showed susceptible response against leaf rust of wheat. While 123, 121, 124, 126, 115 Lasani-2008, 101 and 139 showed moderately susceptible response against leaf rust of wheat. While 144, Punjab-2011, 141, 134, 112, 102, 137, 110 and 106 showed intermediate (moderately resistant and moderately susceptible) behavior against leaf rust of wheat. The lines 142, 130, 136, 140, 120 and 128 showed moderately resistant against leaf rust of wheat while 104, 133, 111 and 113 showed resistant response against leaf rust of wheat.

Effect of leaf rust of wheat on the morph-physiological parameters: In the analysis of variance, statistically significant differences were recorded for both the varieties and treatments. Interaction between wheat genotypes and infection treatments was found significant for the chlorophyll contents, flag leaf area, specific flag leaf area, relative water contents, relative dry weight, relative membrane permeability and specific flag leaf weight (Table 2). Infection with leaf rust affected the chlorophyll contents, flag leaf area, specific flag leaf area, relative water content, relative dry weight, relative membrane permeability and specific flag leaf weight (Table 3). The results revealed that every line and variety was affected by the leaf rust under the natural field condition, like in the inoculated plot the "minimum" chlorophyll content, flag leaf area, specific flag leaf area, relative water content, relative dry weight and relative membrane permeability were noted in Faisalabad 2008, 113, 113, 113, 120 and 142 with the mean value of 26.09, 9.83, 58.62, 48.05, 0.33 and 21.39 respectively. While response of abovementioned variety and lines in the control plot for chlorophyll content, flag leaf area, specific flag leaf area, relative water content, relative dry weight and relative membrane permeability were different with the mean value of 43.80, 12.88, 72.91, 52.05, 0.33 and 14.83 respectively (Table 3). The results showed that -42.9%, -23.7%, -23.0% and -11.4 % decrease over control for various morpho-physiological traits like chlorophyll content, flag leaf area, specific flag leaf area and relative water content in Millat 2011, 113, 121 and 123 respectively (Table 4).

Effect of leaf rust of wheat on yield parameters: Analysis of variance demonstrated that different treatments and genotypes were significantly divergent from each other for all the yield attributes studies (Table 2). Similarly, the interaction between the inoculated and control was significant for the number of grains per spike, spike length, number of spikelets per spike and 1000 grain weight. The means of different yield traits showed that leaf rust disease significantly decreased the yield contributing parameters (Table 3). The mean comparison between different treatments displayed that leaf rust of wheat decreased the number of grains per spike, spike length, number of spikelets per spike and 1000 grain weight. Similarly, most of the yield attributes were affected by the leaf rust in all the genotypes under field condition.

The number of grains per spike, spike length, number of spikelets per spike and 1000 grain weight were the most affected traits in 115, 133, 115 and Galaxy-2013 which on an average showed minimum mean values of 29.00, 6.17, 12.33 and 29.88 respectively for the yield attributes (Table 3). While the response of these lines/variety in the control plot for the number of grains per spike, spike length, number of spikelets per spike and 1000 grain weight were different with the mean value of 55.33, 8.33, 18.33 and 35.41 respectively. The results exhibited that minimum response of -52.38%, -43.77%, -36.00% and -45.50 % over control was observed in number of grain per spike, spike length, number of spikelets per spike and 1000 grain weight in the lines 142, 118, 144 and 112 respectively (Table 4).

Table 1. Response of different 35 wheat lines/Varieties against leaf rust (inoculated plot) under field condition.

Lines + Varieties	% Disease	Field Response
102	36.00	Intermediate
130	28.00	Moderately Resistant
120	14.67	Moderately Resistant
123	56.67	Moderately Susceptible
127	73.67	Susceptible
107	60.33	Susceptible
128	13.67	Moderately Resistant
121	51.67	Moderately Susceptible
Galaxy-2013	87.00	Susceptible
110	33.33	Intermediate
134	36.67	Intermediate
137	34.00	Intermediate
142	30.00	Moderately Resistant
117	62.00	Susceptible
111	8.67	Resistant
Punjab-2011	38.67	Intermediate
113	8.00	Resistant
124	48.00	Moderately Susceptible
140	27.33	Moderately Resistant
101	39.67	Moderately Susceptible
104	10.00	Resistant
Millat-2011	62.00	Susceptible
112	36.67	Intermediate
133	9.33	Resistant
136	28.00	Moderately Resistant
126	41.33	Moderately Susceptible
144	39.00	Intermediate
141	37.00	Intermediate
115	41.00	Moderately Susceptible
139	39.67	Moderately Susceptible
106	33.33	Intermediate
Faisalabad-2008	91.33	Susceptible
118	71.67	Susceptible
Lasani-2008	40.67	Moderately Susceptible
135	83.67	Susceptible

For the leaf rust of wheat Scale commonly (Cobb scale) used is 0-10% = Resistant, 11-30% = Moderately Resistant, 31-39% = Intermediate, 40-60% = Moderately Susceptible and > 60%= Susceptible.

Table 2. Mean squares from ANOVA for morpho-physiological and yield parameters in 35 wheat lines and varieties

Source of Variance	Disease Severity	Chlorophyll Content	Flag Leaf Area
Varieties	1052.8**	307.1**	439.032**
Treatment	59910.5**	19860.3**	450.795**
Varieties × Treatment	534.9**	28.6**	4.970**
Error	1.8	2.1	1.875
Source of Variance	Specific Flag Leaf Area	Relative Water Content	Relative Dry Weight
Varieties	1828.61**	397.448**	0.04217**
Treatment	2994.52**	182.486**	0.20367**
Varieties × Treatment	84.18*	3.391*	0.00161^{NS}
Error	44.79	1.696	0.00118
Source of Variance	Relative Membrane Permeability	Specific Flag Leaf Weight	Number Of Grains Per Spike

Varieties	569.8**		137.01**
Treatment	14400.4**		9874.29**
Varieties × Treatment	116.7**		92.80**
Error	1.2		2.20
Source of Variance	Spike Length	Number of Spikelet's per Spike	1000 Grain Weight
Varieties	5.356**	30.207**	220.53**
Treatment	134.240**	381.376**	2068.13**
Varieties × Treatment	4.386**	11.131**	75.42**
Error	0.805	1.626	0.86

Where ** = Highly Significant, * = Significant, NS= Non- Significant

Table 3. Effect of leaf rust on various morpho-physiological and yield parameters of 35 wheat lines/varieties under natural field condition

Lines + Varieties	Diseased Severity (%)		Chlorophyll Contents (Spade)		Flag Leaf Area (Cm^2)	
	Inoculated	Control	Inoculated	Control	Inoculated	Control
102	36.00±1.16	8.00± 0.58	41.29±0.97	54.66±0.51	25.92±0.87	28.62±0.50
130	28.00 ±0 .58	6.33± 0.88	46.42±0.50	61.84±1.07	24.50±1.07	27.85±1.10
120	14.67 ± 1.20	3.33± 0.88	49.32±1.26	70.63±0.43	23.16±0.83	27.95±0.71
123	56.67 ±0.88	8.33± 0.88	37.49±1.11	50.41±0.58	14.70±0.62	18.94±0.87
127	73.67 ± 0.67	9.00± 0.58	31.95±0.91	53.48±0.96	18.74±0.80	22.81±0.94
107	60.33 ±1.20	7.67± 0.88	35.17±0.93	49.73±0.52	21.16±0.75	25.58±0.52
128	13.67 ±0.88	7.00± 0.58	49.07±0.73	71.33±0.84	28.73±0.56	30.73±0.44
121	51.67 ±0.88	6.33± 0.67	38.10±0.73	61.52±0.51	19.63±0.89	25.54±0.61
Galaxy-2013	87.00±1.16	7.33± 0.88	27.80±1.01	53.71±0.80	25.28±0.86	28.27±0.78
110	33.33±0.88	3.33± 0.88	44.33±0.47	71.44±0.59	23.65±0.58	27.41±1.07
134	36.67±0.67	7.00±0.58	43.11±0.34	56.18±0.75	18.02±0.92	21.25±0.95
137	34.00±1.16	6.00±0.58	42.89±0.73	63.85±0.87	33.53±0.46	28.25±0.74
142	30.00±1.16	5.33±0.67	45.50±0.71	67.50±0.79	35.05±0.85	35.22±3.49
117	62.00±0.58	9.00±1.16	34.94±0.85	50.55±0.51	32.71±0.50	34.58±0.54
111	8.67±0.33	3.67±0.67	50.65±1.03	72.18±0.74	29.94±0.94	34.45±0.68
Punjab-2011	38.67 ±0.33	7.00±.58	40.33±0.74	56.44±0.73	28.91±0.91	31.72±0.52
113	8.00±0.58	2.33±0.33	51.21±0.92	77.07±0.80	9.83±0.72	12.88±0.64
124	48.00±0.58	6.00±0.58	38.41±0.52	61.61±0.58	14.52±0.59	17.95±0.62
140	27.33±0.88	5.00±0.58	47.13±0.79	70.38±0.46	30.57±0.47	32.51±0.50
101	39.67±0.88	7.00±0.58	45.30±0.65	57.03±0.77	16.95±0.58	21.32±0.78
104	10.00±0.58	6.00±0.58	50.88±1.19	63.33±0.70	30.07±0.99	32.99±0.94
Millat-2011	62.00±0.58	6.00±1.00	35.44±1.54	62.10±0.95	19.99±0.70	23.69±1.19
112	36.67±0.88	6.00±0.58	43.48±0.44	62.32±1.23	31.98±0.91	35.29±0.84
133	9.33±0.88	4.00±0.58	50.68±0.79	74.40±1.04	10.33±0.88	11.65±0.55
136	28.00±0.58	5.00±1.16	47.45±0.47	67.06±1.02	24.37±0.77	28.35±0.89
126	41.33±0.88	7.00±0.58	39.75±1.03	57.36±0.76	41.70±0.54	45.07±0.76
144	39.00±1.16	6.00±0.58	42.26±0.91	63.36±0.94	30.29±0.53	32.77±0.68
141	37.00±0.58	6.00±0.58	43.86±0.81	63.80±2.61	37.32±0.71	38.77±0.59
115	41.00±1.16	7.33±0.88	40.51±0.59	57.91±0.61	45.80±0.51	47.61±0.61
139	39.67±1.45	6.33±0.88	42.39±0.31	61.76±0.55	20.06±0.19	23.35±0.89
106	33.33±0.67	5.67±0.67	44.90±0.66	67.69±0.61	31.27±0.81	33.76±0.61
Faisalabad-8	91.33±0.88	38.00±0.58	26.09±0.85	43.80±0.58	22.90±0.86	25.72±0.86
118	71.67±0.88	26.33±1.20	34.08±0.64	46.91±0.58	40.50±0.61	44.69±0.43
Lasani-2008	40.67±0.88	7.33±0.88	39.90±0.79	59.28±0.85	34.54±0.32	37.80±0.55
135	83.67±0.88	8.33±0.88	29.97±0.81	50.17±0.89	14.70±0.66	18.54±1.37
LSD	2.17		2.32		2.21	

The results are mean± standard error

Table 3. Continued.

Lines + Varieties	Specific Flag Leaf Area		Relative Water Content (%)		Relative Dry Weight	
	Inoculated	Control	Inoculated	Control	Inoculated	Control
102	113.16±5.63	124.56±3.39	68.91±0.89	69.50±0.81	0.51±0.03	0.45±0.01
130	122.74±2.39	130.50±1.90	67.47±0.91	68.18±1.34	0.47±0.03	0.43±0.00
120	157.14±17.86	171.62±4.83	66.69±0.86	68.65±0.99	0.33±0.03	0.33±0.01
123	82.57±7.64	99.61±2.00	54.08±0.85	61.05±1.30	0.49±0.04	0.45±0.00
127	94.74±9.48	112.19±0.65	62.19±0.97	64.09±0.57	0.54±0.04	0.47±0.01
107	92.81±7.99	111.40±4.38	60.03±0.99	62.12±1.29	0.66±0.04	0.54±0.01
128	102.78±2.31	107.30±1.81	60.89±0.77	62.09±1.16	0.61±0.03	0.56±0.01
121	75.63±3.31	98.22±0.26	54.78±0.75	55.70±0.20	0.62±0.04	0.52±0.00
Galaxy-2013	93.78±2.88	96.60±2.46	65.14±0.88	66.67±1.07	0.63±0.04	0.61±0.03
110	88.10±5.93	101.43±1.80	58.56±0.83	60.43±0.25	0.66±0.04	0.56±0.00
134	78.85±6.16	88.46±1.95	56.43±0.84	58.05±1.22	0.59±0.04	0.53±0.00
137	108.58±5.49	89.22±0.52	76.62±0.94	78.01±1.75	0.66±0.03	0.56±0.00
142	94.78±0.84	93.46±8.66	70.67±0.42	73.55±0.55	0.74±0.03	0.64±0.01
117	109.29±3.67	107.25±3.25	76.62±0.94	80.19±1.08	0.64±0.03	0.60±0.01
111	103.75±7.04	109.11±3.57	73.94±0.93	75.61±0.81	0.63±0.03	0.61±0.03
Punjab-2011	116.30±7.70	126.99±2.69	65.40±0.73	66.69±0.87	0.48±0.03	0.42±0.00
113	58.62±6.82	72.91±0.65	48.05±1.11	52.05±1.33	0.68±0.06	0.56±0.02
124	81.69±8.32	86.94±0.95	58.86±1.00	60.06±1.92	0.53±0.04	0.53±0.01
140	102.12±2.96	108.38±0.61	74.49±0.92	75.50±0.56	0.64±0.03	0.57±0.00
101	95.35±9.41	108.08±7.12	70.25±2.31	71.79±1.94	0.51±0.05	0.47±0.04
104	107.85±6.52	113.72±1.07	72.57±0.82	72.33±1.04	0.55±0.03	0.50±0.01
Millat 2011	74.16±2.42	87.62±2.52	63.44±0.89	63.02±0.15	0.66±0.04	0.56±0.01
112	97.21±5.12	103.86±1.09	70.61±0.80	74.79±1.25	0.65±0.03	0.58±0.00
133	60.87±4.08	64.66±0.99	56.71±1.09	57.61±1.04	0.57±0.05	0.49±0.01
136	90.44±3.37	102.49±0.14	73.01±1.14	73.58±1.55	0.73±0.04	0.62±0.01
126	97.05±1.37	98.82±2.20	78.14±1.21	79.91±1.70	0.76±0.03	0.73±0.04
144	97.84±1.96	103.52±1.02	55.12±0.65	56.92±1.20	0.63±0.03	0.55±0.00
141	100.95±1.27	102.96±0.85	76.02±0.88	76.54±1.86	0.74±0.03	0.66±0.00
115	93.56±2.03	95.91±1.81	56.03±0.61	58.28±0.98	0.61±0.02	0.58±0.00
139	87.72±5.12	98.94±5.14	57.17±0.94	60.12±1.18	0.66±0.04	0.55±0.00
106	94.89±2.75	97.43±0.95	75.53±0.89	77.80±0.60	0.67±0.03	0.64±0.00
Faisalabad-8	109.26±2.35	113.52±0.75	60.49±0.81	65.96±0.42	0.49±0.03	0.47±0.01
118	106.84±4.37	111.99±3.32	77.98±0.76	79.31±0.59	0.64±0.03	0.61±0.02
Lasani-2008	101.87±4.08	106.21±2.82	73.20±1.68	74.41±1.80	0.64±0.04	0.58±0.02
135	77.69±3.64	89.45±2.86	61.80±1.05	62.58±0.55	0.56±0.04	0.50±0.01
LSD	10.81		2.10		0.06	

Table 3. Continued.

Lines + Varieties	Relative Membrane Permeability		Specific Flag Leaf Weight		Number of Grains per Spike	
	Inoculated	Control	Inoculated	Control	Inoculated	Control
102	84.71±0.66	41.87±0.51	0.009±0.000	0.008±0.000	41.00±1.16	40.00±0.58
130	58.39±0.44	38.43±0.87	0.008±0.000	0.008±0.000	36.00±0.58	43.67±0.33
120	63.19±0.26	48.62±0.74	0.007±0.001	0.006±0.000	30.67±0.88	50.00±0.58
123	33.54±0.59	28.72±0.58	0.012±0.001	0.010±0.000	44.00±0.58	52.67±0.88
127	61.74±0.59	46.32±1.04	0.011±0.001	0.009±0.000	47.33±0.88	52.33±0.88
107	55.40±0.42	41.76±1.19	0.011±0.001	0.009±0.000	54.00±1.16	57.67±0.88
128	64.22±0.83	51.66±0.73	0.010±0.000	0.009±0.000	38.67±0.88	57.67±0.88
121	58.07±0.87	44.06±1.26	0.013±0.001	0.010±0.000	45.00±1.16	61.33±0.88
Galaxy-2013	55.89±0.57	43.80±0.52	0.011±0.000	0.010±0.000	45.33±0.88	52.67±0.88
110	57.73±0.58	41.50±0.88	0.011±0.001	0.010±0.000	44.00±0.58	55.67±0.88
134	48.40±0.52	38.66±0.67	0.013±0.001	0.011±0.000	38.00±0.58	47.00±1.16
137	51.72±0.55	39.52±0.60	0.009±0.000	0.011±0.000	41.33±0.88	54.67±0.88
142	21.39±0.86	14.83±0.48	0.011±0.000	0.011±0.001	30.00±0.58	63.00±0.58
117	51.60±0.66	36.48±0.77	0.009±0.000	0.009±0.000	53.33±0.88	56.33±0.33
111	61.43±0.91	32.94±0.61	0.010±0.001	0.009±0.000	40.00±0.58	56.33±0.88
Punjab-2011	61.91±1.43	27.20±0.95	0.009±0.001	0.008±0.000	39.00±0.58	50.33±0.88
113	55.43±0.68	29.03±0.72	0.018±0.002	0.014±0.000	46.00±0.58	58.00±1.16
124	26.41±0.69	16.83±0.55	0.012±0.001	0.012±0.000	44.67±0.88	61.00±1.16
140	43.29±0.83	27.69±0.50	0.010±0.000	0.009±0.000	38.00±0.58	55.00±1.16
101	54.61±0.47	25.80±0.55	0.011±0.001	0.009±0.001	41.33±0.88	54.67±0.88
104	43.08±0.75	29.80±0.64	0.009±0.001	0.009±0.000	36.00±0.58	64.67±1.20
Millat-2011	63.50±0.52	52.03±1.06	0.014±0.000	0.011±0.000	45.33±0.88	57.33±0.88
112	61.59±0.63	48.55±0.63	0.010±0.001	0.010±0.000	34.00±0.58	53.00±1.16
133	39.71±1.00	30.95±0.92	0.017±0.001	0.015±0.000	32.67±0.88	53.33±0.88
136	55.43±0.60	33.88±0.59	0.011±0.000	0.010±0.000	48.67±0.88	55.33±1.20
126	58.29±0.73	41.83±0.58	0.010±0.000	0.010±0.000	50.00±0.58	60.33±0.67
144	49.04±0.38	37.46±0.81	0.010±0.000	0.010±0.000	46.67±0.88	62.67±0.88
141	60.39±0.69	45.20±0.88	0.010±0.000	0.010±0.000	38.67±0.88	59.33±0.88
115	38.68±0.53	27.87±0.58	0.011±0.000	0.010±0.000	29.00±0.58	55.33±0.88
139	61.79±0.49	46.91±0.55	0.011±0.001	0.010±0.001	47.00±1.16	51.33±0.88
106	59.37±0.70	48.91±0.52	0.011±0.000	0.010±0.000	44.00±0.58	62.00±0.58
Faisalabad-8	53.77±0.60	40.73±0.70	0.009±0.000	0.009±0.000	41.33±0.88	53.00±1.16
118	50.18±1.37	37.06±1.00	0.009±0.000	0.009±0.000	40.67±0.88	69.00±0.58
Lasani-2008	51.65±0.68	38.80±0.52	0.010±0.000	0.009±0.000	43.67±0.88	48.33±0.88
135	64.70±0.69	24.87±0.64	0.013±0.001	0.011±0.000	53.00±0.58	63.33±0.88
LSD	1.74		1.47		2.39	

Table 3. Continued.

Lines + Varieties	Spike Length (Cm)		Number of spikelets per spike		1000 Grain Weight (gm.)	
	Inoculated	Control	Inoculated	Control	Inoculated	Control
102	7.50±0.58	8.30±0.44	18.00±0.58	21.00±0.58	37.44±1.41	43.92±0.75
130	8.17±0.44	9.33±0.44	19.67±0.88	22.00±0.58	44.73±1.70	51.28±0.79
120	7.50±0.58	8.50±0.58	15.00±0.58	18.67±0.88	35.47±1.29	47.25±0.74
123	9.50±0.58	10.33±0.60	18.67±0.88	22.33±0.67	39.47±1.10	43.76±0.55
127	8.50±0.58	9.50±0.58	19.00±1.16	22.00±1.53	32.92±1.77	40.51±0.53
107	10.33±0.44	11.33±0.44	22.67±0.88	25.67±0.88	42.83±1.75	51.25±0.90
128	9.33±0.44	10.50±0.76	19.67±0.88	22.00±1.53	35.48±1.01	40.44±0.57
121	9.33±0.44	12.33±0.73	18.67±0.88	22.33±0.88	32.55±1.11	36.47±0.56
Galaxy-2013	9.33±0.44	10.50±0.87	18.00±0.58	20.67±0.88	29.89±0.79	35.41±0.56
110	9.00±0.29	10.50±0.87	16.00±0.58	18.33±1.45	32.58±1.13	41.35±0.89
134	8.50±0.58	9.17±0.44	18.33±0.88	21.67±0.67	43.41±1.18	50.33±0.67
137	8.60±0.49	9.33±0.44	18.67±0.88	21.33±1.20	46.41±1.98	53.04±0.79
142	7.53±0.58	11.67±0.44	16.00±0.58	18.33±0.67	30.66±1.49	37.62±0.36
117	10.67±0.73	9.83±0.17	21.00±0.58	24.00±0.58	48.88±1.44	56.50±0.94
111	8.50±0.29	10.33±0.44	16.33±0.88	18.67±1.20	37.80±1.22	43.41±0.65
Punjab-2011	8.33±0.44	10.50±0.76	14.00±0.58	16.00±0.58	33.69±1.23	40.84±1.04
113	8.67±0.44	10.83±0.73	17.00±0.58	20.00±0.58	43.43±1.93	50.17±1.49
124	8.67±0.17	11.33±0.73	16.00±0.58	19.67±0.88	41.32±2.58	54.03±0.68
140	8.50±0.58	10.33±0.60	15.33±0.88	18.67±0.88	32.69±1.45	46.43±0.61
101	8.50±0.58	9.67±0.44	16.00±1.16	17.67±1.20	37.32±2.41	38.66±0.61
104	7.33±0.60	12.50±0.29	13.33±0.33	19.00±1.16	31.51±1.93	43.52±0.39
Millat-2011	10.17±0.44	9.50±0.58	21.00±0.58	16.00±0.58	50.14±1.88	37.55±0.56
112	7.00±0.29	9.00±0.29	15.67±0.88	23.00±1.16	30.35±1.99	55.69±0.60
133	6.17±0.60	8.33±0.44	13.67±0.88	17.67±0.88	35.73±2.40	37.55±0.76
136	11.00±0.58	10.50±0.29	21.00±0.58	16.67±0.88	50.66±1.46	40.44±0.67
126	11.83±0.88	10.17±0.73	22.00±0.58	23.00±1.16	46.48±0.95	58.51±0.55
144	9.00±0.29	11.50±0.58	16.00±0.58	25.00±0.58	32.77±1.38	53.41±0.49
141	8.00±0.29	10.67±0.44	16.00±0.58	18.33±0.33	34.73±1.37	37.47±0.56
115	6.50±0.58	10.00±0.29	12.33±0.67	18.33±0.33	43.76±1.37	41.70±1.25
139	9.33±0.73	9.33±0.44	17.00±0.58	14.67±0.88	47.09±2.06	50.55±0.52
106	8.50±0.29	12.50±0.58	17.00±0.58	20.00±0.58	47.20±2.09	54.58±0.43
Faisalabad-8	8.00±0.58	10.17±0.44	16.00±0.58	21.00±0.58	41.57±2.07	52.65±0.64
118	7.67±0.44	13.63±0.47	16.00±0.58	21.00±0.58	43.91±1.43	47.61±0.50
Lasani-2008	10.33±0.44	8.50±0.58	20.33±0.33	19.33±0.88	52.51±2.26	47.62±0.43
135	10.50±0.58	11.83±0.33	22.00±0.58	23.67±0.67	53.96±2.37	59.48±0.46
LSD	1.45		2.06		1.50	

Table 4. Percentage increase/decrease over control of morpho-physiological and yield parameters of 35 wheat lines/varieties.

L/V	CC	FLA	SFLA	RWC	RDW	RMP	GPS	SL	SPS	TGW
102	-24.6	-9.42	-9.16	-0.85	14.23	102.31	2.50	-9.64	-14.3	-14.8
130	-25.0	-12.0	-5.9	-1.05	7.80	51.95	-17.6	-12.5	-10.1	-12.8
120	-30.2	-17.1	-8.4	-2.85	2.37	29.97	-38.7	-11.8	-19.6	-24.9
123	-25.6	-22.4	-17.1	-11.4	7.82	16.78	-16.5	-8.06	-16.4	-9.80
127	-40.3	-17.9	-15.6	-3.00	16.41	33.29	-9.55	-10.5	-13.6	-18.7
107	-29.3	-17.3	-16.7	-3.35	21.14	32.65	-6.36	-8.82	-11.7	-16.4
128	-31.2	-6.51	-4.2	-1.93	8.45	24.31	-33.0	-11.1	-10.6	-12.3
121	-38.1	-23.2	-23.0	-1.64	18.39	31.80	-26.6	-24.3	-16.4	-10.8
Galaxy 2013	-48.3	-10.6	-2.92	-2.30	2.95	27.61	-13.9	-11.1	-12.9	-15.6
110	-37.9	-13.7	-13.1	-3.09	17.25	39.12	-21.0	-14.3	-12.7	-21.2
134	-23.3	-15.2	-10.9	-2.78	11.55	25.22	-19.2	-7.27	-15.4	-13.7
137	-32.3	18.70	21.70	-1.78	17.45	30.87	-24.4	-7.86	-12.5	-12.5
142	-32.6	-0.47	1.41	-3.92	16.58	44.19	-52.4	-35.4	-12.7	-18.5
117	-30.9	-5.42	1.91	-4.45	6.81	41.45	-5.33	8.47	-12.5	-13.5
111	-29.8	-31.1	-4.91	-2.21	3.57	86.48	-29.0	-17.7	-12.5	-12.9
Punjab 2011	-28.3	-8.87	-8.41	-1.93	13.58	127.57	-22.5	-20.6	-12.5	-17.5
113	-33.6	-23.7	-19.6	-7.69	21.24	90.97	-20.7	-20.0	-15.0	-13.4
124	-37.7	-19.1	-6.04	-2.00	1.11	56.92	-26.8	-23.5	-18.6	-23.5
140	33.04	-5.96	-5.78	-1.33	12.89	56.33	-30.9	-17.7	-17.9	-29.6
101	-20.6	-20.5	-11.8	-2.15	8.68	111.68	-24.4	-12.1	-9.43	-3.45
104	-19.7	-8.87	-5.16	0.33	9.18	44.58	-44.3	-41.3	-29.8	-27.6
Millat 2011	-42.9	-15.6	-15.4	0.67	18.83	22.05	-20.9	7.02	31.25	33.51
112	-30.2	-9.39	-6.40	-5.59	11.15	26.85	-35.9	-22.2	-31.9	-45.5
133	-31.8	-11.3	-5.87	-1.57	16.71	28.28	-38.7	-26.0	-22.6	-4.86
136	-29.2	-14.1	-11.8	-0.78	17.13	63.61	-12.1	4.76	26.00	25.25
126	-30.7	-7.48	-1.79	-2.21	5.17	39.34	-17.1	16.39	-4.35	-20.6
144	-33.3	-7.57	-5.49	-3.17	14.68	30.91	-25.5	-21.7	-36.0	-38.7
141	-31.3	-3.72	-1.95	-0.67	11.42	33.60	-34.8	-25.0	-12.7	-7.32
115	-30.0	-3.80	-2.45	-3.86	6.12	38.77	-47.6	-35.0	-32.7	4.93
139	-31.4	-14.1	-11.3	-4.90	18.76	31.73	-8.44	0.00	15.91	-6.83
106	-33.7	-7.38	-2.60	-2.92	5.04	21.39	-29.0	-32.0	-15.0	-13.5
Faisalabad 2008	-40.4	-11.0	-3.75	-8.30	3.68	32.01	-22.0	-21.3	-23.8	-21.0
118	-27.4	-9.37	-4.60	-1.67	6.37	35.41	-41.1	-43.8	-23.8	-7.77
Lasani-2008	-32.7	-8.62	-4.09	-1.62	9.98	33.13	-9.66	21.57	5.17	10.26
135	-40.3	-20.7	-13.2	-1.25	11.24	160.16	-16.3	-11.3	-7.04	-9.29

Abbreviations: L/V= Lines/Varieties, CC= Chlorophyll content, FLA= Flag leaf area, SFLA= Specific Flag Leaf Area, RWC= Relative water content, RDW= Relative dry weight, RMP= Relative membrane permeability, GPS= Number of grains per spike, SL= Spike length, SPS= Number of spikelets per spike, 1000 GW= Thousand Grain weight

DISCUSSION

In the changing climate, plants are constantly exposed to the abiotic and biotic stress, like rusts, which are the most serious problem of the wheat in the present era, and are capable to affect the moisture status and yield parameters under greenhouse and natural condition. However, little information is available on the effect of leaf rust of wheat to the relative membrane permeability, specific flag leaf area and specific flag leaf weight and other traits.

In the present study, leaf rust of wheat interfered with morph-physiological characteristics, growth and yield parameters which leads to the reduction of chlorophyll content, flag leaf area, specific flag leaf area, relative water content, specific flag leaf weight, number of grains per spike, spike length, number of spikelets per spike and 1000 grain weight (Ostazeski *et al.,* 1970; Kuhn and Dawson, 1973; Johnson and Mian, 1983; Agrios *et al.,* 1985; Funayama *et al.,* 1997; Wintermant *el al.,* 2005; Taiwo and Akinjogunla, 2006).

Chlorophyll contents are essential component of photosynthesis which allow the plants to absorb energy from light. Several studies revealed that in the diseased leaves chlorophyll contents were less as compared to healthy leaves (Bastiaans, 1991 and Lopes *et al.,* 2001). Chlorophyll contents always showed positive correlation with the rate of photosynthesis, however by infecting with leaf rust of wheat, rate of photosynthesis decreased (Spitters *et al.,* 1990; Shtienberg, 1992). The transpiration is mainly influenced by the abiotic factors such as temperature, light and water status but may also be affected by foliar pathogens like leaf rust disease. This disease may interfere with the plant's transpiration rate by penetrating stomata and/or increase water permeability of cell membranes by releasing the toxic molecules (Goodman, 1986 and Lucas, 1998). The rate of transpiration is usually more in the susceptible varieties as compared to resistant varieties. However, with the increasing the rate of transpiration, the relative water content was decreased (Ayres, 1995; Shtienberg, 1992). Moreover, when visible diseased symptoms appeared, pathogens fleetingly boost water loss by increasing the evaporation surface through the development of infection structures on the plant surface, by detrimental impact on the plant cuticle, and causing the cell death consequentially in uncontrolled water loss (Bassanezi *et al.,* 2002). Air borne pathogens cause an increase in the transpiration rate of the leaves because any pathogen which damage the surface area of the plant leaves will boost cuticular transpiration which result in an increased rate of water loss (Lucas, 1998). Leaf rust showed positive correlation with the high nitrogen biofertilizer and biotrophic pathogen establishment. However, when leaf rust produce visible symptoms, Hence the deficiency of the nitrogen occurs (Robert *et al.,* 2002; Tiedemann, 1996). The slight nitrogen deficiency enhances the soluble sugar content of the infected leaves (Bancal and Soltani, 2002) which may increase the carbohydrates level and it is easily available for the fungus. When carbohydrates easily available for the fungus it affects the physiology, and reduce the average yield potential. Air borne pathogen interfere with the plant's minerals uptake depending upon the pathogen and on infected plant tissue which leads into the reduction of the growth and yield parameters. Our results showed that yield parameters such as number of grains per spike, spike length and number of spikelets per spike and 1000 grain weight and physiological parameters like chlorophyll contents, flag leaf area, specific flag leaf area, relative water content, relative dry weight, relative membrane permeability and specific flag leaf weight were significantly reduced by the leaf rust of wheat. These results were supported by other authors (Taiwo and Akinjogunla, 2006; Ostazeski *et al.,* 1970; Wintermantel, 2005, Cornish *et al.,* 1990 and Zuckerman *et al.,* 1997).

CONCLUSIONS

Based on the results of the present study, chlorophyll content, flag leaf area, specific flag leaf area, relative water content (%), relative dry weight, relative membrane permeability, specific flag leaf weight, number of grains per spike, spike length, number of spikelets per spike and 1000 grain weight were reduced when wheat genotypes were exposed to the leaf rust. Because of the fact that plant leaves are directly related with photosynthetic activities which provide energy for the growth and defense against plant diseases, reduction in the photosynthesis caused decline in overall growth, and reduced the quantity and quality of the grains. Results also show that the diseased leaves had increased the relative membrane permeability and relative dry weight as compared to the healthy ones. The highest reduction in chlorophyll content, flag leaf area, specific flag leaf area and relative water content were recorded in these lines and varieties 834, 113, 121 and 123 respectively, while relative membrane permeability, relative dry weight and specific flag leaf weight were increased in the infected leaves. And also highest reduction in the number of grains per spike, spike length, number of spikelet's per spike and 1000 grain weight were recorded in these lines 142, 118, 144 and 112 respectively.

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