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Impact of Stem Rust Infection Levels on the Yield, Physicochemical and Technological Properties of Misr-1 Wheat variety

Omara, R.I.[1*], Asmaa, M. Marie[2], A.S. Abd El-Sattar[2] and R.E. Abdelghany[1]

[1]Plant Pathology Research Institute, Agricultural Research Center, Giza 12619, **Egypt**

[2]Department of Crops Technology Research, Food Technology Research Institute, Agricultural Research Center, Giza, **Egypt**.

[*]**Corresponding author:** redaomara43@gmail.com

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Abstract: The pathogenic fungus *Puccinia graminis* f. sp. *tritici* is the cause of wheat stem rust. Twenty bread wheat varieties were assessed in the current study, between 2020 and 2022 based on the final rust severity (FRS %) and the area under disease progress curve (AUDPC). Over the course of the three seasons, the Misr-1 variety registered the greatest disease parameters (FRS% and AUDPC). The estimation of losses in the Misr-1 variety at varying infection levels (0–100%) and their relationship to the physicochemical and technological properties of wheat flour were the main objective of this study. Compared with zero and 20% infection levels, estimated and actual losses (%) for 1000 kernel weight and yield/feddan were highest at 80 and 100% of the infection. A significant positive correlation was found between the degree of infection and the actual loss (%) of both1000 kernel weight and yield/feddan (ardab). The physicochemical characteristics of the wheat flour (82% extraction rate) extracted from the Misr-1 wheat variety at different level of stem rust revealed significant different values for 1000 kernel weight, moisture, protein, fat, and total carbohydrates contents, meanwhile no significant difference in the ash and crude fiber contents. The hectoliter weight and flour extraction rate decreased from 83.24 to 80.14 Kg/hl and from 65 to 61%, respectively, as the infection level increased from zero to 100%. Moreover, there was a significant decrease in wet gluten, dry gluten, gluten index, and hydration ratio as the infection level increased. As well as the infection levels increased from zero to 100%, the wet and dry gluten content declined from 31.13 to 30.08% and from 10.08% to 9.88%, respectively. Concerning the rheological properties, the rust infection significantly lowered the water absorption (WA) as well as the dough development time (DDT) and dough stability time (DST) of the wheat flour. Finally, all sensory parameters of the produced balady bread, showed no significant changes, with the exception of appearance and layer separation scores, which significantly declined from 8.85 to 8.15 and from 8.85 to 8.30, respectively. This may be due to the lowering gluten content and hydration ratio.

Key words: Wheat, stem rust, AUDPC, yield losses, physicochemical characteristics, Gluten content, rheological properties, sensory evaluation.

1. Introduction

Wheat holds great importance as a grain crop, particularly in Egypt where it has become a key component of the agricultural landscape. It serves as a primary crop in the Egyptian crop pattern, playing a vital role in the country's diet as bread is a staple food. Additionally, wheat is considered a strategic crop that provides economic benefits to Egyptian farmers. Egypt's total wheat production is approximately 9 million tons, with consumption at 20 million tons **(FAOSTAT, 2022).** Egypt is the world's largest importer of wheat and consumes a lot of bread. Wheat scientists must bridge the significant gap between production and consumption **(Abdelmageed *et al.*, 2018).** Rust infections (leaf, stem, and stripe) are among the most serious wheat diseases, causing major yield losses. According to **Knott (1989)**, wheat rust is a prevalent plant disease that can be found in almost all wheat-growing areas globally. Rust fungal infections are one of the leading causes of considerable wheat crop production losses **(Belayneh and Emebet, 2005).**

Under favorable conditions, the most severe disease is stem rust, caused by *P. graminis* f. sp. *tritici*. Under ideal environmental situations, the fungus can generate new physiological races that target resistant cultivars and propagate epidemically, resulting in up to 100 percent yield losses across wide areas during epidemic years. **(Admassu *et al.*, 2012; Regasa *et al.*, 2019).** A number of factors influence rust-related yield loss, including as variety susceptibility, infection period, disease progress rate, and disease duration **(Chen 2005).** This crop is affected by environmental and disease conditions, with temperature and moisture playing the most critical roles in causal disease severity and losses. Because temperature and moisture levels are the fundamental parameters that prevent rust epidemics from spreading year after year in the majority of wheat-producing locations **(Gladders *et al.*, 2007).** Now, the estimated loss up to 90% of varieties worldwide are susceptible to stem rust **(Singh *et al.*, 2013).** Its effect on green leaf area leads to decreased sugar availability for producing seeds. The flag leaf and the second leaf are the most significant leaves for producing sugar in developing grains. Flag leaf infection is anticipated to cause substantial reductions in crop yield. Flag leaves play a crucial role in grain filling, accounting for over 70% of the process **(Marsalis and Goldberg 2006)**. When infected, the plant's lifespan is hindered, leading to negative impacts on yield, including reduced grain filling, compromised grain quality, decreased flour yield, and diminished durability **(Mobarak *et al.*, 2010; Mabrouk *et al.*, 2022**). The findings revealed that rust diseases had an effect on carbohydrate, protein content, crude fiber, wet gluten, and dry gluten levels. The impact was amplified in highly vulnerable wheat varieties, Gemmeiza-11 and Sids-12, which decrease the protein content in grains by inhibiting the enzymes responsible for protein synthesis, specifically nitrate reductase, and increasing the activity of enzymes that break down tissues during seed formation when infected **(Al-Maaroof and Nori 2019). Ames (2003)** and **Edward *et al.* (2003)** suggest that protein and gluten levels are commonly utilized as indicators of wheat flour quality. They note that a greater protein content in grains is closely associated with an increase in gluten starch. The main objective of this study was to estimate losses in the Misr-1 variety at different infection levels (0–100%) and examine how the infection related to the physicochemical and technological characteristics of the wheat flour.

2. Materials and Methods

2.1. Pathological studies

Twenty wheat varieties, such as Misr-1, Misr-2, Misr-3, Misr-4, Gemmeiza-9, Gemmeiza-10, Gemmeiza-11, Gemmeiza-12, Sakha-93, Sakha-94, Sakha-95, Sakha-96, Giza-168, Giza-171, Sids-12, Sids-13, Sids-14, Shandweel-1, Shandweel-2, and Nubaria-2 were evaluated under field conditions at Al Qasasin Agricultural Research Station, Agricultural Research Center (ARC), Ismailia Governorate, during (2020-2022) growing seasons. The seeds were planted using a complete randomized block design, with three replications. The experimental unit included three rows, each measuring 3 meters in length and spaced 30 centimeters apart. The seed rate per row was 5 grams. It was encircled by a 1 m allay and a 1.5 m belt, which functioned as a spreader of stem rust-sensitive entry, known as "Morocco." During late tillering and late elongation, the spreader was artificially inoculated with a combination of races (TTDPD, TTCDP, and TTSSS), in addition to the natural infection. The severity of the disease was assessed on four times, with each assessment conducted every ten days, covering a span of three seasons. The measurement was expressed as the percentage of stems that were covered with rust pustules, following the methodology established by **Peterson et al., (1948).** The rust response (infection type) was recorded according to **Stakman *et al.* (1962)**. The collected data was used to determine the final rust severity (FRS). The area under the disease progression curve (AUDPC) was estimated according to **Pandey *et al.* (1989).**

2.2. Estimated yield loss at disease levels of stem rust

The Misr-1 variety registered the highest disease measures (FRS% and AUDPC) throughout the course of the three seasons. It was grown in six levels of disease severity (zero, 20, 40, 60, 80, and 100%). Three replicates of a randomized complete block design were used in the experiment. Each plot was totaling 42 square meters and consisted of 15 rows that were 7 meters long. To ensure disease spread, a one-square-meter border of the rust-prone variety, Morocco, was planted around the experiment. During the booting stage, the spreader variety was artificially inoculated with the pathogen. This inoculation procedure followed the method used by **Tervet and Cassel (1951).** Three applications of the fungicide Tilt (25% EC) were used to treat disease levels. The rate was 25 ml per 100 l of water. The first application was made when the desired level of disease was reached. Thousand kernels weight and grain yield/feddan, were measured. The estimated total loss for each disease level was calculated using the equation of **Calpouzos *et al.* (1976).** The equation is loss (%) = (1-Yd/Yh) x 100, where Yd is the yield of the disease plot at a disease level and Yh is the yield of the protected plot at a disease level (0%). The relationship between regression and coefficient was utilized to assess the influence of stem rust infection on yield, without considering other factors such as disease stress. This is referred to as the actual percentage loss.

2.3. Laboratory studies

All laboratory investigations were carried out at Food Technology Research Institute (FTRI), Agriculture research center (ARC).

2.3.1. Physical properties of Misr-1 wheat grains

The hectoliter weight (kg/hl) of the Misr-1 wheat grains at the six infection levels was measured using the Schoper System on a Dalle Molle balance (Caxias, RS, Brazil) following the American Association of Cereal Chemists method **(AACC) (2002)**. One thousand wheat grains were manually counted and weighed.

2.3.2. Physicochemical properties of wheat flour

The moisture, crude protein, crude fiber, fat and ash contents of wheat flour (82%, extraction rate) was determined using the **AOAC (2005)** standard techniques. The color of the flour from various infection levels after milling was measured using a hand-held chromameter (model CR-400, Konica Minolta, Japan). The results were presented in terms of L* (lightness), a* (redness-greenness), and b* (yellowness-blueness).

2.3.3. Rheological properties (Mixolab test)

Wet and dry gluten percentages were determined in accordance with **AOAC (2005).** The Mixolab is a tool used to assess wheat flour's mixing qualities. Water absorption (WA), dough development time (DDT), and dough stability time (DST) are significant indicators of flour quality and processing characteristics. According to the method of International

Association for Cereal Science and Technology **(ICC, 2011)**, the effects of stem rust infection levels on the technological quality and mixing behavior of flour were assessed using a Mixolab analyzer (Chopin, Villeneuve-la-Garenne, France). The Mixolab device was used to measure WA (%), DST (min), and DDT (min). The mixing speed was set to 80 RPM, and the bowl weight was 50 g.

2.3.4. Preparation of balady bread

Balady bread was prepared from wheat flour (82% extraction rate). The dough formula included 100 g of flour, dry yeast (1 g), and salt (1 g), along with an amount of warm water added enough to form optimal bread dough uniformity, then mixed until a suitable consistency was achieved **(Yaseen *et al*., 2007)**. Dough samples were allowed to ferment at 30±2 °C with 80–85% relative humidity for 50 minutes. After that, the dough was portioned into equal round pieces on a fine wheat bran layer and allowed to ferment again for 30 minutes. Then flattened and left at 80–85% relative humidity and 30±2 °C for 15 min, and finally baked at 450–500 °C.

2.3.5. Sensory evaluation of bread

The bread loaves were allowed to cool to room temperature and then evaluated for sensory acceptability based on the nine-point hedonic scale (9= like extremely, 5= neither like nor dislike, and 1= dislike extremely) by ten panelists (members of the Food Technology Research Institute, Agricultural Research Center, Egypt). Appearance, layers separation, color of the crust and crumb, odor, crumb distribution, chewing ability, taste, and overall acceptability were evaluated according to the method of **Stone and Sidel (1992)**.

2.4. Statistical analysis

Using the SPSS 22 software program, the data were statistically analyzed at the 5% levels for variance and least significant difference (LSD). Using the SPSS 22 software package, the relationship between infection levels and the actual loss (%) of both 1000 kernel weight (g) and yield/feddan (ardab) was examined.

3. Results and Discussion

3.1. Evaluated of 20 wheat varieties against stem rust

The study recorded the disease severity (%) caused by stem rust on 20 wheat varieties. The severity was recorded from the first appearance of rust in each variety until the dough stage. The final rust severity (FRS%) and the area under the disease progress curve (AUDPC) were estimated for each growing season of the study (2020-2022) (Table 1 and Fig. 1). Misr-1, Misr-2, Sids-12 and Sids-13 varieties exhibited high percentages of FRS % and high values of AUDPC, during the three seasons. These data were (27.33% and 786.67), (19.67% and 560.00), (23.00% and 670.00) and (16.88% and 670.00) for the above varieties, respectively, during the three seasons (Table 1 and Fig. 1). Misr-1 and Misr-2 varieties were chosen from a selection of wheat genotypes from CIMMYT. They were then tested in Uganda, Kenya, and Ethiopia, and demonstrated their ability to resist stem rust disease, particularly against the Ug99 race **(Hamada *et al*., 2017).** Then these two varieties were imported for cultivation in these countries to overcome this race (Ug99), which now became susceptible **(Ashmmawy *et al.*, 2013; Omara *et al.*, 2017; Abdelaal *et al.*, 2018 and Shahin *et al.*, 2022)**. For this reason, new varieties of CIMMYT genotypes, such as Misr-4, were selected and evaluated in this study and were highly resistant to the disease (**Kumber *et al.*, 2022)**. Also, new varieties such as Sakha-96, Shandweel-2 and Nubaria-2 varieties showed complete resistance to stem rust where, they recorded 0.00 for the two disease parameters of the three seasons. The third season (2022) was recorded the least values of the two disease parameters. It is noticeable that the genetic background of resistance differs depending on the type of infection. This phenomenon is associated with the appearance of more aggressive races within populations of pathogen. As a result, the type of infection for some varieties may change over time **(Omara *et al.*, 2021 and Shahin *et al.*, 2022)**. Some kinds can be resistant for years before becoming susceptible (**Omara *et al.*, 2020**).

Table (1). Final rust severity (FRS%) and area under disease progress curve (AUDPC) for 20 wheat varieties of stem rust during 2020-2022 growing seasons

Variety	Final stem rust severity (%)				AUDPC			
	2020	2021	2022	Mean	2020	2021	2022	Mean
Misr-1	29.50	30.00	22.50	27.33	860.00	870.00	630.00	786.67
Misr-2	29.50	20.00	19.50	23.00	570.00	540.00	570.00	560.00
Misr-3	3.65	6.15	3.65	4.48	103.00	183.00	103.00	129.67
Misr-4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gemmeiza-9	15.15	6.65	12.15	11.32	403.00	163.00	363.00	309.67
Gemmeiza-10	5.65	4.65	6.15	5.48	143.00	123.00	183.00	149.67
Gemmeiza-11	5.65	15.15	10.65	10.48	143.00	463.00	303.00	303.00
Gemmeiza-12	10.65	10.65	12.15	11.15	303.00	263.00	363.00	309.67
Sakha-93	10.65	4.65	8.65	7.98	303.00	123.00	223.00	216.33
Sakha-94	4.65	5.65	4.65	4.98	123.00	143.00	123.00	129.67
Sakha-95	6.65	5.65	5.65	5.98	163.00	143.00	143.00	149.67
Sakha-96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Giza-168	10.65	10.65	8.65	9.98	263.00	303.00	223.00	263.00
Giza-171	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sids-12	19.50	20.00	19.50	19.66	860.00	580.00	570.00	670.00
Sids-13	19.50	10.65	20.50	16.88	570.00	263.00	590.00	474.33
Sids-14	10.65	10.65	8.65	9.98	303.00	303.00	223.00	276.33
Shandweel-1	4.65	8.65	8.65	7.32	123.00	223.00	223.00	189.67
Shandweel-2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nubaria-2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L.S.D $_{0.05}$ for: Variety (V) Year (Y) V×Y	 1.462 1.565 2.522				 8.422 8.119 7.476			

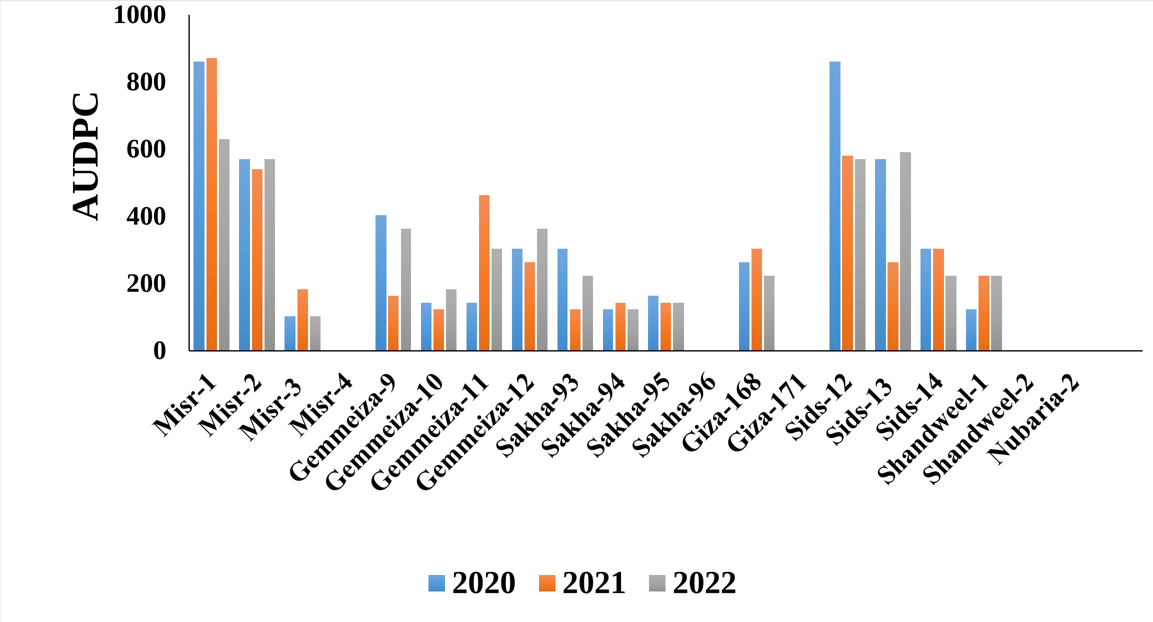

Fig. (1). AUDPC for 20 wheat varieties of stem rust during 2020-2022 growing seasons.

3.2. Estimated of yield loss (%)

The previous results showed that the Misr-1 variety recorded the highest disease parameters during the three seasons. Accordingly, the relationship between disease levels (from 0 to 100%) and losses was studied in this variety. Most previous studies relied on studying disease losses as a whole without studying them at infection levels (**Ashmmawy *et al.*, 2013; Omara *et al.*, 2016 and Mabrouk *et al.*, 2022)**. Therefore, losses were studied with different levels of infection during the two growing seasons. In season 2021, estimated and actual losses (%) of 1000 kernel weight and yield/feddan were the highest at disease levels 80 and 100%. The data loss was (41.03 and 39.88%) and (46.68 and 45.37%) of 1000 kernel weight, as well as (52.50 and 51.23%) and (56.72 and 55.35%) of yield/feddan, respectively (Table 2).

Table (2). Estimated and actual losses % of 1000 kernel weight (g) and yield/feddan (ardab) in Misr-1 infection with *P. graminis* f. sp. *tritici* during 2021 growing season.

Infection level (%)	1000 kernel weight (g)			Yield/feddan (ardab)		
	1000 kernel weight (g)	Estimated loss (%)	Actual loss (%)	Yield/feddan (ardab)	Estimated loss (%)	Actual loss (%)
0	48.54	0.00	0.00	20.17	0.00	0.00
20	42.89	11.63	11.30	18.99	5.85	5.71
40	35.65	26.55	25.80	15.56	22.86	22.31
60	32.89	32.24	31.33	12.44	38.32	37.40
80	28.62	41.03	39.88	9.58	52.50	51.23
100	25.88	46.68	45.37	8.73	56.72	55.35
$LSD_{0.05}$	3.846			3.582		

Also in season 2022, the highest estimated and actual losses (%) of 1000 kernel weight and yield/feddan were recorded at disease levels 80 and 100% (Table 3). While, the loss (%) of 1000 kernel weight (g) and yield/feddan (ardab) was the lowest at disease level 20% during the two seasons (Tables 2 and 3). The reason is that the causative fungus consumes the nutrients produced in the leaves instead of transferring them to the grains. This greatly affects the size and shape of the pimples and gives them an atrophic appearance **(Ali *et al.*, 2016 and Mabrouk *et al.*, 2022)**. The final result is significant yield loss associated with different levels of infection, as observed in this study, especially since this disease affects leaves, stems, and spikes (**Ashmmawy *et al.*, 2013; Aktas and Zencirci 2016; Draz *et al.*, 2018; Al-Maaroof and Nori, 2019)**. Furthermore, certain researchers, like **Marsalis & Goldberg (2006)** and **Khushboo *et al*. (2021),** have elucidated that a decrease in crop yield is typically attributed to a decline in both the quantity and size of grains, diminished dry matter, inadequate root development, compromised grain quality, unfavorable environmental factors, and the stage of infection. This is due to the detrimental impact of rust fungi on crop yield, as they reduce the surface area of healthy leaves, consequently affecting the supply of sugar to developing seeds.

Table (3). Estimated and Actual losses of 1000 kernel weight (g) and yield/feddan (ardab) in Misr-1 infection with *P. graminis* f. sp. *tritici* during 2022 growing season

Infection level (%)	1000 kernel weight (g)			Yield/feddan (ardab)		
	1000 K.W. (g)	Estimated loss (%)	Actual loss (%)	Yield/feddan (ardab)	Estimated loss (%)	Actual loss (%)
0	47.02	0.00	0.00	19.95	0.00	0.00
20	45.91	2.36	2.26	17.72	11.18	11.09
40	36.09	23.24	22.30	15.45	22.56	22.37
60	33.00	29.81	28.61	12.90	35.34	35.04
80	26.88	42.83	41.10	9.59	51.93	51.49
100	24.89	47.06	45.16	8.37	58.05	57.56
$LSD_{0.05}$	3.997			4.179		

3.3. Association between disease levels and yield loss (%)

The association between disease levels and actual loss (%) of both 1000 kernel weight (g) and yield/feddan (ardab) for wheat stem rust was determined through correlation analysis of 2021 and 2022 seasons. Figure (2) shows a significant positive correlation between disease levels and actual loss (%) of both 1000 kernel weight and yield/feddan (ardab). Correlation coefficient (R^2) was 0.9719 and 0.9596 of 1000 kernel weight of 2021 and 2022 seasons, respectively. Also, the estimated values of correlation coefficient (R^2) were 0.9759 and 0.9916 of yield/feddan of 2021 and 2022 seasons. The findings corroborate those of **Ochoa and Parlevliet (2007)**, who previously demonstrated a substantial correlation between yield loss (%) and AUDPC. Furthermore, under the Egyptian conditions, **El-Shamy *et al.* (2011)** identified a significant relationship between disease severity (%) and reduction (%) in kernel weight as well as grain yield per plant.

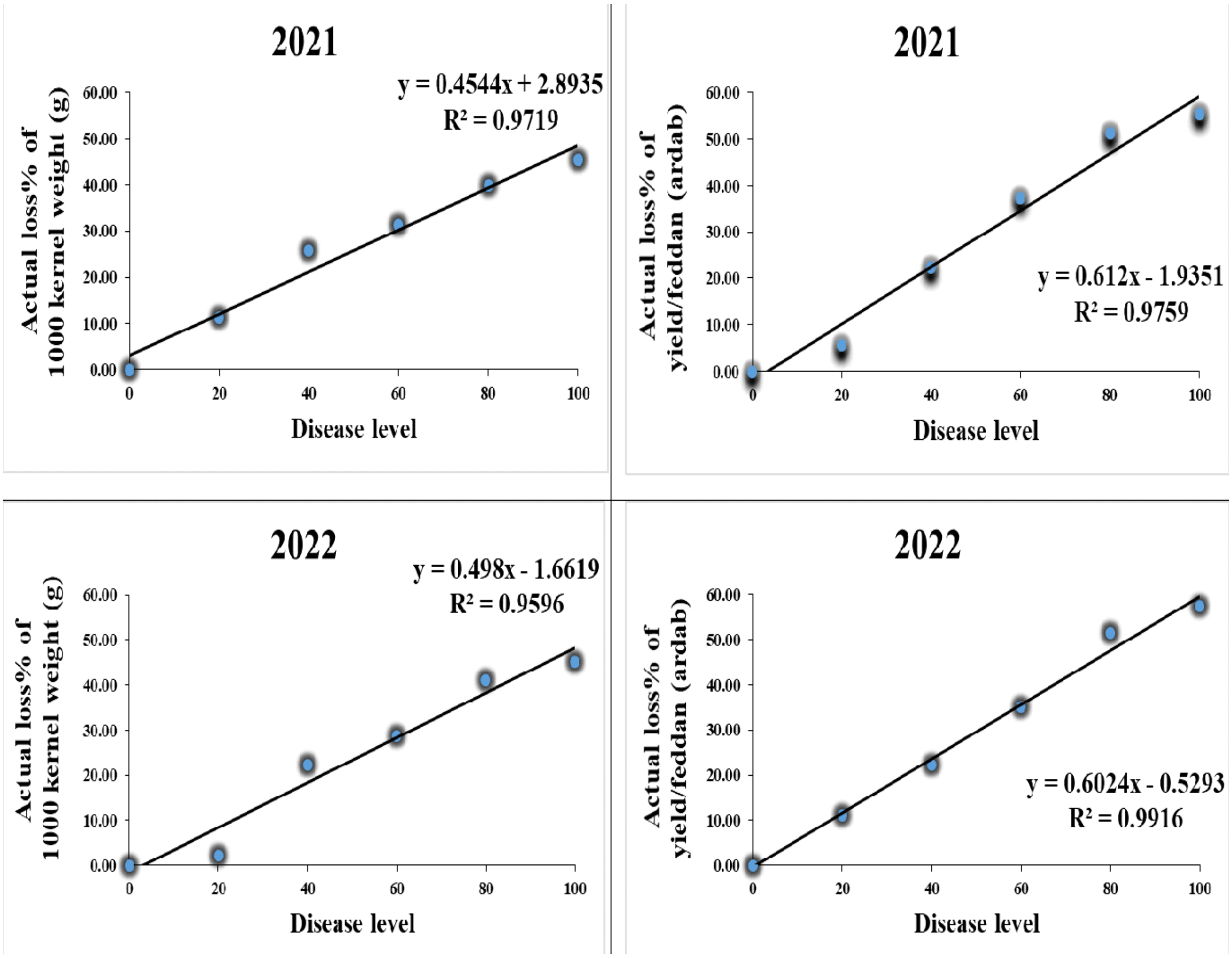

Fig. (2). Correlation coefficient between disease levels and actual loss (%) of both 1000 kernel weight (g) and yield/feddan (ardab) for stem rust of 2021 and 2022 growing seasons.

3.4. Physicochemical and technological characteristics

In the current study, no significant difference between the obtained results over the course of the two seasons (2021 and 2022) based on the different rust infection levels. So, all listed results are mean of the two seasons.

3.4.1. Physical and milling properties

The impact of different rust levels on the physical and milling properties of wheat grains (Misr-1 variety) is shown in Table (4). As the infection level increased from Zero to 100%, the hectoliter weight and flour extraction rate significantly reduced from 83.24 to 80.14 Kg/hl and from 65 to 61%, respectively. This could be a result of a stem rust infection that leads to the wheat grains shrink **(Mobarak *et al*., 2010)**. The highest differences in hectoliter weight and flour extraction rate were recorded when the infection level was 100%. Meanwhile, the 20% infection level showed the least differences. The findings were consistent with those of **Mousa (2001**), who observed an increase in bran weight at the same time that stem rust infection. A significant difference was observed in the extraction percentages of bran and flour across varying levels of infection intensity. These are in line with earlier research by **Chen *et al*. (2002)** and **Wang *et al*. (2004)** that found comparable trends. It is hypothesized that a stem rust infection is the main cause of a decrease in hectoliter weight and flour percentage when compared to a zero percent infection level. The observed decrease is most likely due to the shrinkage of wheat grains, which is caused by low moisture content combined with lower carbohydrate contents within flour extraction conditions **(Ali *et al*., 2016).**

Table (4). Physical characteristics and milling properties of Misr-1 wheat variety at different stem rust infection levels

Infection level (%)	Hectoliter weight (kg/ hl^{-1})	Difference	Milling properties			
			Flour %	difference	Bran %	Difference
0	83.24	0.00	65.0	0.00	35.0	0.00
20	82.77	0.56	64.6	0.62	35.4	-1.14
40	82.20	1.25	63.5	2.31	36.5	-4.29
60	81.99	1.50	62.4	4.00	37.6	-7.43
80	81.96	1.54	62.0	4.62	38.0	-8.57
100	80.14	3.72	61.0	6.15	39.0	-11.43
$LSD_{0.05}$	0.034		0.581		1.462	

Values are means of the two seasons (2021 and 2022).

3.4.2. Physicochemical properties of wheat flour

The chemical characteristics of wheat flour extracted from wheat grains (Misr-1 variety) infected by different stem rust levels are presented in Table (5). The results demonstrated that, at different infection levels, ranged from zero to 100%, there were significant different values of moisture, protein, fat, and total carbohydrates (TC) contents. Additionally, there were a noticeable difference at infection levels of 80 and 100% compared to that of zero and 20% infection levels. On the other hand, the results showed no significant difference to the ash and crude fiber contents (Table 5). The results revealed an increase in the protein content from 12.07 to 12.30% at different infection levels (from zero to 100%). It has been reported that, the shrinking of the kernels by stripe rust increased the protein content of the wheat grains **(Ochoa and Parlevliet, 2007).** The total protein content of rusted cereal tissues may increase by 20-50%, where a large portion of this protein can be used to develop the fungus body, especially during the sporulation and afterward. Furthermore, even while the host protein content decreases, the evidence for accelerated RNA metabolism implies that rust infection may improve the synthesis of some host protein **(Bushnell and Roelfs 1984)**. Regarding the color characteristics, as shown in Table (5), no significant difference in the lightness (L*) values of the flour at the infection levels of stem rust up to 40%, but they significantly reduced at higher infection levels. This result might be explained by the more grains shriveling as a result of increasing rust infection levels.

Table (5). Physicochemical properties of Misr-1 wheat flour (82%, extraction rate) at different stem rust infection levels

Infection level (%)	Chemical composition						Color characteristics		
	Moisture (%)	Protein (%)	Ash (%)	Crude fiber (%)	Fat (%)	TC (%)	L*	a*	b*
0	8.13	12.07	0.86	0.47	0.49	86.11	95.42	-0.37	13.35
20	8.50	12.10	0.85	0.46	0.48	86.11	95.41	-0.24	13.08
40	8.79	12.16	0.85	0.45	0.48	86.06	95.41	-0.27	13.17
60	8.98	12.19	0.84	0.44	0.46	86.07	95.38	-0.26	13.19
80	8.09	12.22	0.84	0.43	0.45	86.06	95.33	-0.29	13.10
100	8.38	12.30	0.83	0.42	0.43	86.02	94.90	-0.33	13.06
$LSD_{0.05}$	0.473	0.064	ns	ns	0.030	0.040	ns	0.023	0.041

ns= non-significant, TC is total carbohydrates. Protein, fat, crude fiber and ash were calculated at dry basis, L* is the lightness, a* is the redness, b*is the yellowness (+), Values are means of the two seasons (2021 and 2022).

3.4.3. Gluten content and rheological properties of wheat flour (82% extraction rate)

The results demonstrated that, at different infection levels, ranged from zero to 100%, there were significant different values of wet gluten, dry gluten, gluten index, and hydration ratio. As shown in Table (6), the wet and dry gluten content decreased (from 31.13 to 30.08% and from 10.08% to 9.88%, respectively) as the infection levels increased. Gluten is an important component of wheat as it provides baked products structure and texture and enables a variety of bakery products to be made from it. The wet gluten content indicates the protein quality and baking quality of flour. The quality of gluten is defined by the elasticity and extensibility degree. The gluten index and hydration ratio significantly reduced from 86.26% and 208.83% to 82.27% and 204.45%, respectively as the infection levels increased from zero to 100% (Table 6). Gluten index values were determined by **Magdic *et al*. (2006)** and ranged from 62% to 98%. Gluten Index can be used as a quick and accurate tool to describe the gluten strength of wheat flour **(Horvat 2002)**. **Esteller *et al*. (2005)** reported that gluten is classified into non-vital and vital wheat gluten. Non-vital gluten is the gluten that undergoes irreversible denaturation and it absorbs an amount of water related to the size and distribution of its particles. In contrast, vital dry gluten rehydrates rapidly and resumes its inherent functionality when it comes in contact with water.

Data listed in Table (6) illustrate the impact of stem rust infection levels (from zero to 100%) on Mixolab parameters and color characteristics of wheat flour (82%) of Misr-1 wheat variety. A Mixolab study showed that rust infection significantly reduced the water absorption (WA) as well as the dough development time (DDT) and dough stability time (DST) of the wheat flour (Table 7). The DDT (min) indicates the gluten strength, while the DST (min) refers to the dough elasticity. As the levels of infection increased from zero to 100%, the values in water absorption (%), development time (min) and stability time (min) decreased from 55.2%, 5.83 min, and 7.8 min to 53.1%, 1.53 min, and 6.74 min, respectively. These decreases may be due to the lower in gluten contents as well as the gluten index, as shown in Table (6). It has been demonstrated that fungal infections generally degrade gluten proteins, which lowers the baking quality **(Wieser *et al.* 2023)**. **Cuniberti *et al.* (2003)** found that water absorption (%) correlates favorably with protein composition. Water absorption is an important criterion for evaluating wheat cultivar quality. Furthermore, the Mixolab's development and stability times are mostly determined by changes in protein quality. According to **Uhlen *et al.* (2004),** the development and stability time depend on polymeric protein rather than total protein content in wheat flour. Additionally, **Faubion and Hoseny (1990)** noted that the dough development time is a measure of the quality of protein, since stronger flour requires a longer development time than weaker ones.

Table (6) Effect of stem rust infection levels on gluten content and Mixolab parameters of the Misr-1 wheat flour (82% extraction rate)

Infection level (%)	Gluten content				Mixolab parameters		
	Wet gluten (%)	Dry gluten (%)	Gluten index	Hydration ratio (%)	Water absorption (%)	Development time (min)	Stability time (min)
0	31.13	10.08	86.26	208.83	55.2	5.83	7.8
20	30.98	10.07	86.11	208.12	55.0	4.71	7.51
40	30.85	10.07	86.02	206.36	54.6	4.18	7.34
60	30.66	10.02	85.20	206.06	54.1	3.9	7.30
80	30.43	9.98	83.80	204.91	53.7	3.5	7.23
100	30.08	9.88	82.27	204.45	53.1	1.53	6.74
$LSD_{0.05}$	0.246	0.049	0.52	1.23	0.43	0.84	0.11

3.4.4. Sensory properties of balady bread

Organoleptic acceptability is the main factor that limits consumer acceptance of balady bread. The effect of different stem rust infection levels on the sensory parameters (appearance, separation of the layers, color of the crust and crumb, crumb distribution, odor, chewing ability, taste, and overall acceptability) of the produced balady bread are represented in Table (7). No significant differences were found among sensory parameters at different infection levels, except for the scores of appearances and layers separation as shown in Table 8. As the infection levels increased from zero to 100%, the appearance and layers separation scores significantly decreased from 8.85 to 8.15 and from 8.85 to 8.30, respectively. This could be due to the decreasing gluten content and hydration ratio as the infection levels increased. **Uheln *et al*. (2004)** found that changes in baking quality are linked to variations in the composition of gluten protein, specifically high-molecular-weight glutenin subunits, which are vital to dough resistance and mixing. They also found that higher protein content enhances dough extensibility. Consequently, protein level and quality have a major effect on the baking ability of wheat flour.

Table (7). Effect of stem rust infection levels sensory properties of balady bread produced from Misr-1 wheat flour

Infection level (%)	Appearance (9)	Layers separation (9)	Crust color (9)	Odor (9)	Crumb color (9)	Crumb distribution (9)	Chewing ability (9)	Taste (9)	Overall acceptability (9)
0	8.85	8.85	8.80	8.75	8.80	8.80	8.75	8.80	8.80
20	8.85	8.85	8.80	8.70	8.80	8.80	8.80	8.80	8.75
40	8.75	8.70	8.80	8.80	8.80	8.75	8.75	8.80	8.75
60	8.50	8.60	8.70	8.65	8.70	8.75	8.80	8.75	8.80
80	8.35	8.45	8.70	8.60	8.65	8.70	8.75	8.75	8.75
100	8.15	8.30	8.65	8.65	8.60	8.65	8.75	8.70	8.75
$LSD_{0.05}$	0.012	0.014	ns	ns	ns	ns	ns	ns	ns

ns= non-significant

4. Conclusions

From the current study results, stem rust infection levels (from zero to 100%) in Misr-1 variety significantly decreased the yield, thousand kernel weight (g), hectoliter weight, yield/feddan (ardab), and flour extraction rate. Grain yield decrease mainly attributed to the effect of the infection on the kernels weight and the number of kernels/spikes. A positive correlation was found between infection levels and actual loss (%) of both 1000 kernel weight and yield/feddan (ardab) of stem rust. Furthermore, there were significant differences in the moisture, protein, fat, and total carbohydrate contents of the wheat flour (82% extraction rate). Moreover, there was a significant decrease in wet gluten, dry gluten, gluten index, and hydration ratio as well as the infection level increased from zero to 100%. Regarding the rheological properties, the stem rust infection significantly lowered the water absorption, the dough development time, and dough stability time of the wheat flour. Finally, no significant difference in the sensory evaluation scores of the balady bread, except of the appearance and layer separation scores, which significantly declined as the infection levels increased which may be a result of the lower gluten content and hydration ratio.

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