Science Development
2022; 3(3): 98-103
http://www.sciencepublishinggroup.com/j/scidev
doi: 10.11648/j.scidev.20220303.13

Effect of Wheat Rust Diseases on Grain Yield and Yield Components of Bread Wheat Genotypes at Low to Mid Altitude in Ethiopia

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To cite this article:
Tafesse Solomon. Effect of Wheat Rust Diseases on Grain Yield and Yield Components of Bread Wheat Genotypes at Low to Mid Altitude in Ethiopia. *Science Development*. Vol. 3, No. 3, 2022, pp. 98-103. doi: 10.11648/j.scidev.20220303.13

Received: June 10, 2022; **Accepted**: July 6, 2022; **Published**: July 13, 2022

Abstract: Bread wheat production is reduced by wheat fungal wheat rust diseases: Stem rust, Yellow rust, and Leaf rust. In Ethiopia, stem rust and yellow rust are the two major wheat rusts in occurrence and importance. Through evaluation and selection for years, noble bread wheat varieties can be developed and released. The National Wheat Research Program Introduced the 21 Spring Bread Wheat Trial from International Center for Agricultural Research in the Dry Areas (ICARDA) in 2021. The trial had a total of fifty entries: forty seven genotype, two checks, and one empty room for the local check. The design was alpha lattice design with two replications. A rep had five sub-blocks; the sub-block had ten plots. The plot size was 2.5m in length by 1.2m in width. The total area of the plot was $3m^2$ and planted with six rows. Genotypic and phenotypic correlations between wheat rust diseases and other trait computed to see the relationship. The top six highly susceptible genotypes for yellow rust were: EBW214106, EBW214090, EBW214089, EBW214074, EBW214099, and EBW214097. Some genotypes were susceptible to both diseases; others were resistant to one of the diseases. ETBW EBW214113 had the highest CI for stem rust and the lowest CI for yellow rust. At Kulumsa, negative genotypic correlations were obtained between yellow rust and DTH r = -0.17; between yellow rust and DTM r = -0.23; between yellow rust and PHT r = -0.67***; SRCI, r = -0.33*; TKW, r = -0.79***; HLW, r = -0.57***; and GYLD, r= -0.85. Ethiopia is one of the hotspot areas for these diseases. Thus, selections for resistance genotypes are a precondition in releasing wheat variety for the farmers.

Keywords: Wheat, Stem Rust, Yellow Rust, Correlation

1. Introduction

Wheat is one of the staple crops for the peoples in the world; and also the staple crop for people in Ethiopia. They used it as for food, cash crop, feed, etc. It is an ancient crop and grows all over the world; Human makes bread, cakes, pastries, pasta, and other goods from wheat and feed their families. There are many health benefits of eating; these are: Fiber, antioxidants, vitamins, and minerals [1].

Wheat rusts are among the fungal diseases which affect wheat production. They are challenges for wheat-producing society due to their worldwide distribution, breaking resistance genes in previously resistant varieties, ability to move long distances, capability to destroy the whole crop, and rapid development under favorable conditions [2, 3].

Ethiopia is the highest wheat-producing country in sub-Saharan Africa. About 1.8 million hectares are covered with wheat in the 2021/2022 cropping season with the expectation of 5.18 million metric tons [16]. The country took different measures, including more areas under wheat production from pastoral and semi-pastoral, to increase wheat production and productivity.

Bread wheat production is reduced by wheat fungal wheat rust diseases: Stem rust, Yellow rust, and Leaf rust. In Ethiopia, stem rust and yellow rust are the two major wheat rusts in occurrence and importance [15]. The country encountered sever loss of production many times by these disease outbreaks that caused significant economic losses [4]. Stem rust is caused by the fungus Puccinia graminis f.sp.tritici. This disease also known as black rust. Occurrence and severity are high at low altitude drought-prone areas; however, it is equally challenge at mid-altitude when the environment favors the pathogen; Also, at high altitudes, the pressure in productioon of the crop is very low. Yellow rust is caused by Puccinia striiformis f.sp.tritici. Yellow rust mainly occurs in mid to high land altitude wheat-producing areas. It is not much significant at low altitude wheat-producing areas; in some wheat growing season the disease doesn't exist at low altitudes.

Development and release of resistance Bread wheat varieties for this disease are efficient and environmentally the safest management option. The emergence of new races of these rust fungi, overcome the resistance present in bread wheat varieties under production. Thus, sustainably delivering more alternative new resistance wheat varieties is the primary goal of every wheat research center in the country. To ensure this, The National Wheat Research Program introduces genotypes from CIMMYT and ICARDA in addition to its crosses. Introduced trials from CGIAR centers are those originally crossed for wheat rusts and other merits by CGIAR centers. Through evaluation and selection for years, noble bread wheat varieties can be developed and released.

2. Material and Method

2.1. Study Material, Locations, and Design

The National Wheat Research Program Introduced the 21 Spring Bread Wheat Trial from International Center for Agricultural Research in the Dry Areas (ICARDA) in 2021. The trial had a total of fifty entries: forty seven genotype, two checks, and one empty room for the local check. The two checks were Tesfa and Atlas; and the local check was bread wheat variety ETBW 9396 (Abay). The plot size was 2.5m in length by 1.2m in width. The total area of the plot was $3m^2$ and planted with six rows. The distance between rows, sub-blocks, and reps were 20cm, 1m, and 1.5m.

The trial was carried out at Kulumsa Agricultural Research Center (KARC) and Melkasa Agricultural Research Center (MARC)) by the national wheat research program. Kulumsa Agricultural Research Center found at 8°02′N 39°10′E latitude and longitude with an Altitude of 2200 m.a.s.l; Melkasa Agricultural Research Center found at 8°24′N 39°12′E latitude and longitude with an Altitude of 550 m.a.s.l.

The design was alpha lattice design with two replications. A rep had five sub-blocks; the sub-block had ten plots. A total of hundred plots had the trial at both locations. Nitrogen fertilizer, Urea, and phosphorous fertilizer, NPS were applied as per recommendation for the test areas 150kg/ha and 121kg/ha. All other management practices, like weeding done on time.

2.2. Data Collection and Analysis

2.2.1. Grain Yield and Yield Component Data's

Date to heading (DTH) was computed from the difference between the planting and heading day of the trial. Date to Maturity (DTM) was obtained from the difference between the sowing and physiologically matureing days of the trial. Five random measurements of plant height were taken from a plot, and averaged to get plant height (PHT).

All six rows were harvested from a plot using the Zurn-150 plot combiner. Grain yield (GYLD) weighs in grams per 3 m^2; Later, for statistical purposes changed to tone/ha. Thousand Kernel Weight (TKW) and Hectoliter weight (HLW) were captured in Kulumsa bread wheat laboratory using electronic equipment, including a barcode reader, Sensitive balance, and laptop. The laptop uses for this purpose only.

2.2.2. Stem Rust and Yellow Rust Diseases Data's

Stem and yellow rust diseases have taken two rounds on the field using a modified cobb scale, a combination of disease reaction and severity. The first score was taken a week after the symptom had seen on the plot. The second was taken at the pick time of the disease's pressure on the trial. The severity of the rust was taken in percent using the multiple five from 5% to 100%. The reaction of the host for the pathogen designates using the English letters rust where: 0= No visible infection on the plant; R= Resistant: visible chlorosis or necrosis, no uredia are present; MR= Moderately Resistant: small uredia are present and surrounded by either chlorotic or necrotic areas; M=Intermediate: variable-sized uredia are present; some with chlorosis, necrosis, or both; MS= Moderately Susceptible: medium-sized uredia are present and possible surrounded by chlorotic areas; S= Susceptible: Large uredia are present, generally with little or no chlorosis and no necrosis [8, 9].

Severity and field response readings are usually combined. For example, tR = Trace severity with a resistant field response. 20MS= 20% severity with moderately susceptible field response.

For this study the diseases data changed to Coefficient of infection (CI) as outlined by [7, 10] in which the host reaction changed to numeric and then multiplied by severity. Immunity (O) = 0.05, resistant (R) =0.1, moderately resistant (MR) = 0.2, intermediate (M) =0.4, moderately susceptible (MS) =0.6, and susceptible (S) =1.

For example: CI for 20MS= 20*0.6= 12; CI=12.

2.2.3. Data Analysis

Genotypic and phenotypic correlations between wheat rust diseases and other trait computed to see the association using a method suggested by Singh and Fehr et al [11, 12].

$$rg=\frac{gcovx-y}{d\sqrt{\delta^2gx\delta^2gy}} \text{ and } rp=\frac{pcov-y}{d\sqrt{\delta^2px\delta^2py}}$$

Where rg and rp are genotypic and phenotypic correlation coefficients, respectively; g cov x·y and pcovx · y are genotypic and phenotypic covariances between variables x and y, respectively; δ^2gx and δ^2px are genotypic and phenotypic variances, respectively, for variable x; and δ^2gy and δ^2py are genotypic and phenotypic variances, respectively, for variable y.

All statistics computed using META-R Statistical software [13].

3. Result and Discussion

Wheat rusts are the major production constraint of wheat farming. At the time of stem rust and yellow rust outbreak in Ethiopia, the farming community fall in danger and put in significant economic losses. To develop and release resistance genotypes, the National Wheat Research Program introduces bread wheat trials from International Center for Agricultural Research in the Dry Areas (ICARDA). Genotypes selected here are evaluated and selected under different national trials set to low altitude, mid-altitude, and high altitude.

Wheat rust pressure reduces the grain yield and the quality of the grain. Susceptible genotypes had low Grain Yield (GYLD), Thousand Kernel Weight (TKW), and Hectoliter Weight (HLW). High coefficient values (CI) for rusts told us the genotype is highly susceptible to the disease (Table 1). The top six highly susceptible genotypes for yellow rust were: EBW214106, EBW214090, EBW214089, EBW214074, EBW214099, and EBW214097. The grain yields for the above genotypes were: 1.32, 2.28, 1.83, 1.78, 2.72, and 2.28. These were very low and below the average mean grain yield except for ETBW214099 (Table 1). On the other hand, Resistance genotypes with very low coefficients of infection for yellow rust had moderate to high scores for GYLD, TKW, and HLW. EBW214113 3.01, 30.55, and 42.44; ETBW9396 (ABAY) 4.35, 32.80, and 48.06; EBW214071 4.11, 35.93, 47.29; EBW214110 3.56, 25.19, and 44.16; and EBW214075 4.29, 32.68, and48.17 (Table 1). Hence, the yellow rust disease effect on the traits tested genotype is high.

Some genotypes were susceptible to both diseases; others were resistant to one of the diseases. ETBW EBW214113 had the highest CI for stem rust and the lowest CI for yellow rust. Thus, this genotype is highly susceptible to stem rust but resistant to yellow rust. It is effective to select and test further this genotype for a trial which will set by wheat breeding program to areas not prone to stem rust disease or high altitude.

Top five genotypes that were susceptible for stem rust diseases: EBW214113 CISR=69.58, GYLD=3.01; EBW214086 CISR=55.97, GYLD=1.23; EBW214082 CISR=55.09, GYLD=2.33; EBW214105 CISR=46.16, GYLD=1.85; and EBW214087 CISR=45.75, GYLD=1.8 revealed lowest grain yield except EBW214113 which was resistance for yellow rust. Additionally, five genotypes that Rank the least for grain yield (1St rank in grain yield means the highest in yield): EBW214083, EBW214086, EBW214081, EBW214106, and EBW214091 were susceptible to stem rust and yellow rust, and, had lower values for the thousand kernel weight and hectoliter weight. The reason was the disease pressures influenced the grain yield, thousand kernel weight, and hectoliter weight [14] (table 1).

Table 1. *Mean values of eight traits of bread wheat genotypes and ranks for yellow rust coefficient of infection, Stem rust coefficient of infection, and Grain Yield.*

Genotype	DTH	DTM	PHT	CIYR	CISR	TKW	HLW	GYLD	YRR	SRR	GYLDR
Atlas	57.75	108.75	81.25	29.75	25.76	27.00	45.89	2.05	27	19	35
EBW214069	60.50	108.25	79.25	9.00	16.01	30.00	47.71	3.84	42	39	6
EBW214070	54.00	106.50	70.00	43.75	19.76	25.50	48.75	2.62	9	32	17
EBW214071	63.25	108.75	76.00	3.00	10.01	36.00	47.47	4.11	48	47	4
EBW214072	62.75	106.50	82.50	9.00	24.50	31.00	47.08	3.85	43	21	5
EBW214073	61.75	106.50	88.75	10.50	10.61	27.50	44.65	3.18	39	44	11
EBW214074	53.75	106.50	75.75	45.00	27.53	21.00	41.02	1.77	4	14	40
EBW214075	59.75	106.50	80.50	6.50	5.50	33.00	48.34	4.29	46	49	2
EBW214076	57.25	106.50	75.50	19.75	26.01	33.50	45.87	2.36	35	15	23
EBW214077	65.00	105.75	75.75	22.50	14.51	22.50	42.62	2.27	34	42	28
EBW214078	64.00	106.75	82.50	7.85	24.50	25.00	42.68	3.15	45	23	12
EBW214079	61.25	105.75	80.00	24.50	40.00	26.50	42.83	2.50	32	7	22
EBW214080	53.00	106.25	70.75	34.25	32.61	18.00	43.67	1.78	24	11	39
EBW214081	67.75	107.00	81.75	36.25	15.11	19.00	43.7	1.32	21	41	48
EBW214082	53.75	106.75	84.75	42.50	55.00	22.50	43.27	2.33	11	3	24
EBW214083	67.00	107.50	82.50	42.50	18.60	16.00	41.46	1.16	11	34	50
EBW214084	61.25	105.75	81.25	42.00	15.85	20.50	47.07	1.58	14	40	43
EBW214085	61.00	109.50	85.50	42.50	33.00	20.00	41.45	1.50	10	10	45
EBW214086	56.00	107.50	71.25	37.50	55.75	17.00	34.58	1.24	18	2	49
EBW214087	51.50	106.50	72.25	30.75	45.75	25.00	41.71	1.80	26	5	38
EBW214088	60.50	106.25	75.00	36.25	19.03	22.50	43.13	2.14	20	33	32
EBW214089	56.25	106.00	64.75	46.00	17.03	22.00	65.76	1.83	3	35	37
EBW214090	56.00	104.75	68.75	47.50	3.51	20.00	52.78	2.28	2	50	27
EBW214091	58.50	106.50	72.00	42.50	16.70	26.50	49.01	1.50	13	36	46
EBW214092	63.25	107.00	79.75	19.50	21.60	21.00	43.74	2.53	36	31	21
EBW214093	56.25	106.75	66.75	36.25	32.01	22.50	45.09	1.68	22	12	41
EBW214094	56.25	105.50	69.25	26.50	25.76	25.50	45.34	2.20	31	17	30
EBW214095	63.75	104.75	71.25	27.25	10.00	22.50	44.02	2.54	30	46	19
EBW214096	61.00	108.25	73.25	45.00	16.53	25.00	42.67	1.61	8	37	42
EBW214097	59.25	107.75	75.00	45.00	25.25	28.00	46.04	2.28	4	20	26
EBW214098	56.75	106.50	80.25	40.00	25.25	24.50	43.11	2.20	15	22	29

Genotype	DTH	DTM	PHT	CIYR	CISR	TKW	HLW	GYLD	YRR	SRR	GYLDR
EBW214099	60.00	105.75	68.75	45.00	22.61	26.00	45.20	2.72	4	28	16
EBW214100	60.00	105.75	78.00	28.75	15.00	23.00	45.88	3.55	28	43	8
EBW214101	54.25	105.75	69.50	45.00	33.75	27.50	45.24	2.30	7	9	25
EBW214102	51.25	107.50	74.50	34.50	31.50	26.00	42.56	1.55	23	13	44
EBW214103	55.25	105.50	77.75	10.50	41.00	22.50	40.98	2.59	39	6	18
EBW214104	59.00	106.50	84.00	8.25	25.00	32.50	47.36	4.20	44	24	3
EBW214105	56.50	106.75	68.25	38.75	46.50	22.50	43.34	1.85	17	4	36
EBW214106	68.00	109.75	73.75	47.50	16.53	22.00	45.61	1.32	1	38	47
EBW214107	61.75	106.75	75.00	9.10	24.50	25.50	43.31	3.19	41	25	10
EBW214108	69.25	109.25	83.50	37.50	24.00	21.50	43.30	2.15	19	26	31
EBW214109	65.75	108.00	75.75	16.50	10.70	30.00	48.88	3.13	38	45	13
EBW214110	65.50	109.50	76.75	5.10	26.50	25.00	44.12	3.57	47	16	7
EBW214111	59.25	105.75	63.75	39.25	26.01	25.00	45.14	2.53	16	18	20
EBW214112	66.50	109.00	82.50	28.00	22.00	23.00	45.00	2.97	29	30	15
EBW214113	57.25	105.75	80.00	0.40	70.00	30.50	42.46	3.01	50	1	14
EBW214114	61.25	108.50	80.25	18.75	23.50	30.00	47.41	3.47	37	27	9
EBW214115	65.25	105.25	55.50	31.50	39.00	21.00	41.56	2.08	25	8	34
ETBW9396 (ABAY)	63.70	108.50	72.49	1.90	21.72	32.80	48.06	4.35	49	29	1
Tesfa	67.00	108.00	73.75	24.50	9.53	23.50	46.03	2.10	32	48	33
Mean	63.75	108.50	72.50	1.90	22.01	33.00	48.07	4.35			

DTH= Date to heading; DTM; Date to maturity; PHT= plat height; CIYR= Coefficient of infection for Yellow rust; CISR= Coefficient of infection for Stem rust; TKW= Thousand kernel weight; HLW= Hectoliter weight; GYLD= Grain yield; YRR= Yellow rust rank; SRR= stem rust rank; GYLDR= grain yield rank.

Genetic and phenotypic correlations were used to detect the degree and direction of the relationship between wheat rusts and other traits on the tested genotypes. To see the association, They were computed for each location separately. Yellow rust diseases didn't occur at Melkasa during the crop season. Thus, the correlations were not computed between the yellow rust coefficient of infection and the traits for Melkasa. At Kulumsa, negative genotypic correlations were obtained between yellow rust and DTH r = -0.17; between yellow rust and DTM r = -0.23; between yellow rust and PHT r = -0.67***; SRCI, r = -0.33*; TKW, r = -0.79***; HLW, r = -0.57***; and GYLD, r = -0.85. Moreover, the relation between TKW, HLW, and GYLD was highly significant (Table 2). The same result was reported at kulumsa by Wondwesen et a [6]. These indicated that the susceptibility of the genotypes and effects on the traits were associated genetically. Therefore, selections for resistance genotypes for yellow rust at Kulumsa enable us to get genetically potential genotypes for this Disease.

Table 2. *Estimate of genotypic correlations coefficient at Melkasa (above diagonal) at Kulumsa (below diagonal) in fifty bread wheat genotypes.*

Traits	DTH	DTM	PHT	YRCI	SRCI	TKW	HLW	GYLD
DTH	1.00	-076***	0.24	-	-0.64***	-0.47***	-0.59***	-0.31*
DTM	0.63***	1.00	0.99***	-	0.53***	0.56***	0.25	0.24
PHT	0.15	0.51***	1.00	-	0.50***	-0.50***	-0.99***	-0.99***
YR	-0.17	-0.23	-0.67***	1.00	-	-	-	-
SR	-0.24	-0.29*	0.19	-0.33*	1.00	0.01	-0.14	-0.55***
TKW	0.09	0.38**	0.65***	-0.79***	0.16	1.00	0.54***	0.27
HLW	0.43**	0.56***	0.46***	-0.57***	-0.27	0.76***	1.00	0.77***
GYLD	0.16	0.31*	0.67***	-0.85***	0.17	0.94***	0.77***	1.00

DTH= Date to heading; DTM; Date to maturity; PHT= plat height; CIYR= Coefficient of infection for Yellow rust; CISR= Coefficient of infection for Stem rust.

As of result the study, negative genotypic correlations were observed between SRCI and DTH r = -0.64***; Between SRCI and HLW r = -0.14; Between SRCI and GYLD r = -0.55*** at Melkasa, and Between SRCI and DTH r = -0.24; Between SRCI and DTM r = -0.29*; Between SRCI and YRCI r = -0.33*; Between SRCI and HLW r = -0.27 at Kulumsa. Besides, significant negative correlations were observed Between SRCI and DTH; and SRCI and GYLD at Melkasa. However, small non-significant positive correlations were obtained unexpectedly between stem rust coefficient and grain yield at Kulumsa, r = 0.17. Most probably, this was due to Yellow rust diseases occurring at kulumsa earlier than stem rust, and those susceptible genotypes already died before the existence of stem rust. At Melkasa, there was no Yellow rust disease occurrence. Also, a negative significant correlation existed between SRCI and GYLD. Generally, the genotypic relationship in the genotypes between grain yield and stem rust was more expressed at Melkasa than at Kulumsa. Melkasa is a drought-prone area that favors the existence of stem rust pressure. Hence, it is better to use Melkasa stem rust response of genotypes to select genetically resistant genotypes for stem rust.

Due to the nonexistence of the yellow rust at Melkasa, the phenotypic correlation was not calculated between yellow rust and the other traits for this study. Negative phenotypic correlations existed between yellow rust and all other characters at Kulumsa. Further, a significant correlation existed between YRCI and PHT r = -0.59***; YRCI and SRCI r = -0.28*; YRCI and TKW r = -0.76***; YRCI and HLW r = -0.58***; YRCI and GYLD r= -0.83*** (table 3). This stated the significant impact of the yellow rust on the phenotypic appearance of the traits.

Table 3. *Estimate of phenotypic correlations coefficient at Melkasa (above diagonal) at Kulumsa (below diagonal) in fifty bread wheat genotypes.*

Traits	DTH	DTM	PHT	YRCI	SRCI	TKW	HLW	GYLD
DTH	1.00	0.48***	0.12	-	-0.51***	-0.39	-0.50**	-0.10
DTM	0.60***	1.00	0.03	-	0.51***	0.13	0.03	-0.41**
PHT	0.17	0.45**	1.00	-	-0.02	-0.06	-0.20	-0.04
YR	-0.18	-0.22	-0.59***	1.00	-	-	-	-
SR	-0.20	-0.21	0.21	-0.28*	1.00	-0.08	-0.15	-0.46**
TKW	0.09	0.33*	0.53***	-0.76***	0.13	1.00	0.55***	0.38**
HLW	0.39**	0.54***	0.46***	-0.58***	-0.10	0.80***	1.00	0.54***
GYLD	0.15	0.29*	0.58***	-0.83***	0.17	0.92	0.81***	1.00

DTH= Date to heading; DTM; Date to maturity; PHT= plat height; CIYR= Coefficient of infection for Yellow rust; CISR= Coefficient of infection for Stem rust.

Significant negative phenotypic correlations were found between SRCI and DTH r = -0.51***; SRCI and GYLD r = -0.46 at Melkasa. The non-significant negative phenotypic relationship got between SRCI and PHT r = -0.02; SRCI and TKW = -0.08; and SRCI and HLW r = -0.15 at Melkasa. And between SRCI and DTH r = -0.20; SRCI and DTM = -0.21; SRCI and HLW r = -0.10 at Kulumsa (table 3). Hence, the environmental impact on the relationship between stem rust and yield-related traits was lower than the genotypic association. It was an opportunity to select genetically fit genotypes for the two rusts. Negative significant, genotypic and phenotypic correlations exhibited between yellow rust and stem rust in the study population. This result is in contrast to Tehseen et al [5].

4. Conclusion

Grain yield is one of the primary traits in any wheat breeding program. Selection for these traits largely depends on the potential for wheat rust disease resistance of genotypes, especially in the area that favors the development and the incidence of wheat rusts. Ethiopia is one of the hotspot areas for yellow rust and stem rust. Thus, selections for resistance genotypes are a precondition in releasing wheat variety for the farmers. Stem rust is genetically associated with grain yield, thousand kernel weight, and hectoliter weight at both locations. Therefore, those resistance genotypes are genetically appropriate to select for advanced trials since this study was in the nursery stage of the breeding pipelines. Similarly, genotype resistance for yellow rust disease exhibited high performance for yield and its components. Generally, studying the association between wheat rust diseases and grain yield enables wheat breeders to select elite genotypes and develop noble bread wheat varieties for wheat growers.

Conflict of Interest

The author declare that the paper has no any possible conflicts of interest.

Acknowledgements

The Author are grateful to Ethiopian Institute of Agricultural Research (EIAR), Kulumsa Agricultural Research Center, Melkasa Agricultural Research Center, and AGGW project for the budget and facilities. I highly appreciate and acknowledge the staff of national wheat research program for conducting and handling the trial. I also would like to acknowledge ICARDA for the germplasms.

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