Research Article

Shifted Multiplicative Model Clustering of Environments for Synthetic-Derived Bread Wheat

Fida Mohammad[1], O.S. Abdalla[2], Sheraz Ahmed[1*], Fakharuddin[1] and S. Rajaram[2]

[1]Department of Plant Breeding and Genetics, The University of Agriculture, Peshawar, 25130, Khyber Pakhtunkhwa-Pakistan; [2]International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria.

Abstract | Synthetic derived bread wheat is considered to be a rich source of resistant genes for stresses including drought and rusts. To evaluate the grain yield and related yield components of synthetic derived bread wheat lines under different moisture levels, this research was conducted during 2006-07 in the field conditions of Tel Hadya and Breda i.e. the leading research venues of International Center for Agricultural Research in the Dry Areas (ICARDA), Syria. The experimental material comprised of forty synthetic derived wheat lines along with eight check cultivars was planted in alpha lattice design with three replications. Genotypes exhibited significant ($p \leq 0.01$) variations for all the studied traits excluding biomass. Genotype by environment interactions (GEI) were significant for all the characters except for thousand kernel weight. The influences of yield components on grain yield were explained by the cluster analysis of environments. Clustering of five test environments based on Shifted Multiplicative Model (SHMM) exposed the major role of grains spike^{-1} and harvest index in production of grain yield. Though the rate and distribution of rainfall during the cropping season were the main contributing factors in the varied performance across years, however, the grain yield of synthetic derived wheat lines across different environments was not significantly disturbed within each year and hence, are suitable for areas of prolonged drought. Some lines of synthetic derived wheat especially those carrying blood from *T. tauschii* germplasm were equivalent in performance to superior cultivars used in the study, thus can be utilized in breeding for drought stress by wheat breeders.

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Correspondence | Sheraz Ahmed, Department of Plant Breeding and Genetics, The University of Agriculture, Peshawar, 25130, Pakistan; **Email:** sheraazahmed@yahoo.com

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Keywords | Cluster analysis, Shifted multiplicative model, ICARDA, Bread wheat, GxE Interaction

Introduction

The prime objective of International Center for Agricultural Research in the Dry Areas (ICARDA) is to broaden genetic base of wheat germplasm for drought prone areas of the world. World resources institute (WRI) already has identified a list of countries confronting extremely high water stress in 2040 which means they may be more susceptible to scarcity of food than they are today as there would be extremely adverse effects on agriculture sector (Figure 1). Resistance to diseases, insect pressures and unpredictable environmental stresses are believed to be the foremost hindrances in achieving the goal of high crop yields. Cluster analyses of environments and genotypes could help in the assessment of genotype by environment interactions. Cluster analysis is exercised to predict the performance of genotypes in varying environmental conditions and sub-grouping genotypes and environments into more homogeneous categories (Sabaghnia et al., 2012).

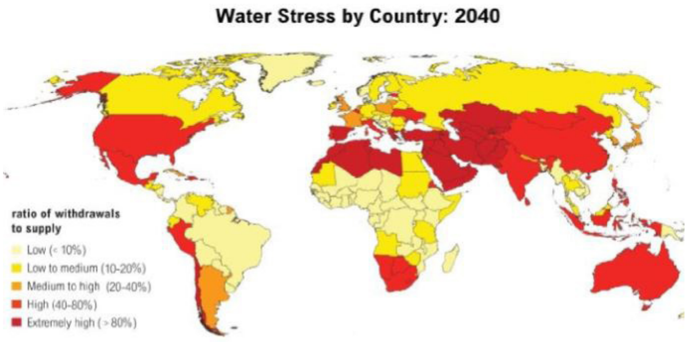

Figure 1: *Map showing the ranking of countries facing severe water stress by 2040*
Note: *Projections are based on a nusiness-as-usual acenario using SSP2 and RCP8.5*

Assessment of environments and genotypes remain to be the critical factors in plant breeding (Tonk et al., 2011). Clustering of environments based on the shifted multiplicative model (SHMM) of field data has ascertained successfully to squeeze down the number of testing sites for evaluation of genotypes. (Crossa, 2012). Correlation or regression analyses are the basis of SHMM method which link the scores of genotypes and environments obtained from the principal component analysis of the genotype by environment interaction (GEI). The degree of sensitivity of genotypes to ever changing environments can be achieved through the knowledge of GE interaction. Currently, ICARDA is scrutinizing some synthetic-derived wheat lines and identifying lines of superior performance especially for developing countries through its wheat improvement program.

Modern hexaploid bread wheat is believed to be the result of natural hybridization of tetraploid cultivated emmer wheat (*Triticum turgidum*) subsp. *dicoccum* (2n=28, genomes AABB) and a diploid goat grass *Aegilops tauschii* (2n=14, genome DD) (Dreisigacker et al., 2008). Ladizinsky (1985) cogitated that there were fewer cases of development of hexaploid bread wheat through natural hybridization, which is why the present population of bread wheat represents only a fraction of variation presented in their parental population. However, existence of sufficient genetic variability in the breeding population is pre-requisite for crop improvement. One of the newest ways to bring genetic diversity into the gene pool of bread wheat is to reconstitute hexaploid bread wheat through interspecific crosses. Even though, synthetic hexaploid wheat (SHW) have been used as a rich source for some important mono- and oligo-genic traits, yet the available data is insufficient for their successful involvement in breeding program for improvement of quantitative traits such as yield etc. This study was initiated with the exclusive objectives to; i) examine the associations among different test environments and identify mega-environments, ii) to ascertain relationship of various plant traits with grain yield.

MATERIALS AND METHODS

Experimental germplasm, design and growing conditions

The experimental material comprised of forty synthetic-derived bread wheat lines along with eight check cultivars (Table 1). The research was conducted in alpha lattice design with three replications during 2006-07. Five test environments were used in the study, where, experiment 1 was planted under irrigated conditions of Tel Hadya on March 23rd, 2006 while experiment 2 was planted on February 2nd, 2006 at Tel Hadya under rainfed conditions. Likewise, experiment 3 and 4 were planted at Tel Hadya on December 3rd, 2006 under irrigated and rainfed conditions, respectively. Experiment 5 was grown at Breda under rainfed conditions on November 14th, 2006. Henceforth, experiments conducted in 2006 and 2006-07 will be seemed as year-1 and year-2, respectively. A Seed rate of 130 kg ha^{-1} was maintained. The soil of Tel Hadya and Breda is clay type, low in organic matter, with a pH of 7.8 and 8.2 respectively and when the soil dries up, it gets cracked. Each experimental line comprised of 8 rows, which were 2.5 m long and 20 cm apart. The field was fertilized with 45 kg ha^{-1} of Nitrogen before plantation, while additional 45 kg ha^{-1} was side dressed. As per soil tests no other nutrients were recommended for crop production. Broad leaf weeds were controlled by Weedex when needed.

Locations and climate

A 2-year experiment was carried out at the International Center for Agricultural Research in the Dry Areas (ICARDA), Tel Hadya and 1 year at Breda, Syria. The elevation of Tel Hadya is 284 m above sea level which is located between 36°01'N and 36°56'E. Breda is 300 m above sea level and located between 35°56'N and 37°10'E. These regions are classified as semiarid. The magnitude of average rainfall is 254 mm which generally distributes during winter season. Precipitation in spring is very unreliable while summer months usually receive no rainfall.

Table 1: *Synthetic-derived wheat populations and check cultivars across 5 environments, 2006-07*

1	ALTAR 84/AEGILOPS SQUARROSA (TAUS)//OPATA
2	DVERD-2/AE.SQUARROSA (214)//2*ESDA
3	CROC-1/AE.SQUARROSA (224)//OPATA
4	CROC-1/AE.SQUARROSA (205)//2*BCN
5	CROC-1/AE.SQUARROSA (205)//2*BCN
6	**HUBARA-9 (check)**
7	REBWAH-3
8	REBWAH-7
9	REBWAH-11
10	REBWAH-13
11	REBWAH-17
12	**ATTILA-7 (check)**
13	REBWAH-21
14	QIMMA-2
15	QIMMA-3
16	QIMMA-4
17	QIMMA-6
18	**CHAM-6 (check)**
19	QIMMA-8
20	QIMMA-12
21	CHEN/AEGILOPS SQUARROSA (TAUS)//FCT/3/STAR
22	QAFZAH-8
23	QAFZAH-11
24	**DEBEIRA (check)**
25	QAFZAH-13
26	QAFZAH-18
27	QAFZAH-23
28	QAFZAH-26
29	QAFZAH-32
30	**GIRWILL-7 (check)**
31	QAFZAH-33
32	QAFZAH-35
33	CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/KAUZ
34	CROC-1/AE.SQUARROSA (205)//KAUZ/3/SASIA
35	CROC-1/AE.SQUARROSA (205)//KAUZ/3/SASIA
36	**GIRWILL-9 (check)**
37	CROC-1/AE.SQUARROSA (205)//KAUZ/3/ATTILA
38	CROC-1/AE.SQUARROSA (205)//KAUZ/3/ATTILA
39	PASTOR/KAUZ/3/CROC-1/AE.SQUARROSA (224)//OPATA
40	MUNIA/CHTO/3/PFAU/BOW//VEE#9/4/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN
41	CROC-1/AE.SQUARROSA (224)//OPATA/3/PASTOR
42	**KATILA-13 (check)**
43	CROC-1/AE.SQUARROSA (224)//OPATA/3/PASTOR
44	CROC-1/AE.SQUARROSA (224)//OPATA/3/PASTOR
45	SKAUZ/BAV92/3/CROC-1/AE.SQUARROSA (224)//OPATA
46	MILAN/KAUZ/3/URES/JUN//KAUZ/4/CROC-1/AE.SQUARROSA (224)//OPATA
47	TAM200/TUI//MILAN/KAUZ/3/CROC-1/AE.SQUARROSA (224)//OPATA
48	**HUBARA-5 (check)**

Data collection

Days to heading were calculated as the number of days from planting to 50% spike emergence. The number of days counted from sowing to when 50% of the peduncles turned yellow were recorded as days to physiological maturity. Data on plant height was taken as average distance recorded from the ground level to spike tips, awns not included. Grain yield was acquired as the total grain yield from each plot. Thousand kernel weight (TKW) was recorded by weighing 1000 kernels. The procedures of Sayre et al. (1997) were used to estimate yield components from a sub sample of 50 fertile tillers from each plot. Biomass production was calculated as above ground biomass. Grain filling days were counted from heading to physiological maturity. Field reaction of plants to yellow rust (YR), caused by *Puccinia striiformis* was transformed into average coefficient of infection (ACI) as described by Stubbs et al. (1986).

Statistical analyses

Separate analyses of variance were carried out for all traits. The combined analysis of variance over 5 environments showed a significant genotype by environment interaction for all traits except 1000-kernel weight and biomass. Therefore, main effects of genotype were analyzed against the mean square values of genotype by environment interaction. Cluster analysis on 5 environments for grain yield was conducted using shifted multiplicative model as suggested by Crossa et al. (1993). All the analyses were performed using SAS (Statistical Analysis System) (Anon., 2009) procedures.

Results and Discussion

SHMM clustering of environments

The environments included in this experiment had wider variation for grain yield production. Mean

Table 2: *Mean of agronomic data with ranges in parenthesis and disease reaction of shifted multiplicative model grouping of 48 synthetic wheat genotypes in 5 environments at various group levels, 2006-07 at Tel Hadya and Breda*

Cluster Grouping of Environments											
Groups	**Heading**	**Maturity**	**GFD§**	**P. height**	**Spikes**	**Grains**	**TKW ¶**	**Yield**	**Biomass**	**HI‡**	**YR***
	____days____			cm	ha^{-1}	spike^{-1}	g	kg ha^{-1}	kg ha^{-1}	%	ACI#
Two group level											
A	133	157	23	64	4083730	15	31	1500	10185	25	4
	(131-135)	(153-159)	(21-26)	(56-75)	(2977930-6915973)	(9-20)	(25-38)	(757-2198)	(7115-12874)	(14-42)	(1-15)
B	58	84	25	68	3272203	26	30	2412	22148	32	2
	(51-63)	(81-86)	(22-32)	(53-85)	(1575081-5149200)	(21-31)	(20-37)	(1449-3165)	(8116-37453)	(23-40)	(0-9)
Three group level											
A1	125	148	22	66	3642852	19	30	1704	13409	28	2
	(124-127)	(145-150)	(20-25)	(59-77)	(2216534-5373792)	(14-24)	(23-35)	(1210-2456)	(5229-18842)	(18-59)	(0-9)
A2	141	166	24	63	4524609	12	32	1296	6961	22	6
	(138-144)	(161-168)	(22-28)	(52-73)	(2793111-9189689)	(1-21)	(25-42)	(185-1997)	(4829-11957)	(3-34)	(2-30)
B	58	84	25	68	3272203	26	30	2412	22148	32	2
	(51-63)	(81-86)	(22-32)	(53-85)	(1575081-5149200)	(21-31)	(20-37)	(1449-3165)	(8116-37453)	(23-40)	(0-9)

*§ GFD = Grain filling days, ¶ TKW = Thousand-kernel weight, ‡ HI = Harvest index, * YR = Yellow rust, A2-2** = Range not given as it contains one element, and # ACI = Average coefficient of infection*

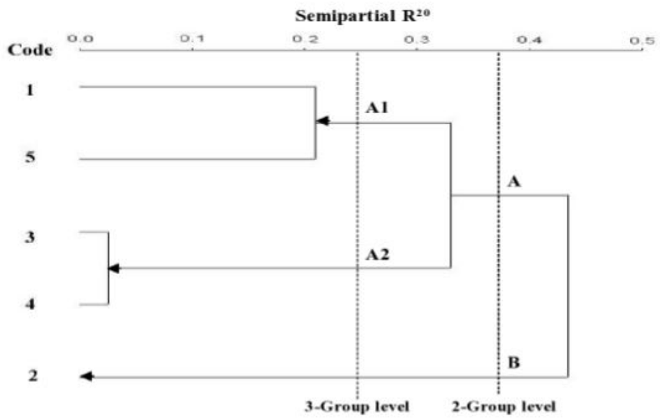

Figure 2: *Dendrogram resulting from shifted multiplicative model cluster method on 5 environments. Final groups of environments are marked with arrows*

grain yield across 5 environments ranged between 891 kg ha^{-1} and 2517 kg ha^{-1}, which reflected the diversity of test environments (Table 3). The dendrogram from cluster analysis of test environments is shown in Figure 2. Five test environments partitioned into two major groups A and B. The dry environment of year-1 appeared independent as cluster B while the other four environments formed the same cluster A (Figure 2). At two group level, the group B (dry environment in year-1) expressed higher mean grain yield than group A (Table 2). The group B possessed higher mean values for harvest index, biomass, grains spike^{-1}, plant height and grain filling duration compared to group A (Table 2). However, group B had lower mean values for yellow rust reaction, thousand-kernel weight spikes per hectare, days to maturity and days to heading compared to group A (Table 2). At three group level, group A split into two sub groups A1 and A2 (Figure 2). The group A1 included irrigated environment (Tel Hadya) of year-1 and dry environment (Breda) of year-2. Group A2 comprised dry and irrigated environments (Tel Hadya) of year-2. The possible reason could be the similar rainfall at Breda in year-2 and Tel Hadya in year-1 (Table 3) which provided same amount of moisture to experiments. Likewise, the experiments at Tel Hadya in year-2 received 314 mm of rainfall (Table 3), higher than year-1, generated sufficient amount of moisture that did not exhaust for long time, thus provided an edge to the overall mean of dry experiment. Consequently, it narrowed down the gap between irrigated and dry environments and both experiments expressed

Table 3: *Environmental and agronomic data with yellow rust disease rating for 5 environments (2006-07)*

Cluster	Code	Year	Site	Precipitation Mm	Heading	Maturity	GFD§	P. height cm	Spikes ha^{-1}	Grains spike^{-1}	TKW ¶ g	Yield kgha^{-1}	Biomass kgha^{-1}	HI‡ %	YR** ACI#
					days										
A1	1	1	Tel Hadya	290 + IR*	89	112	24	86	2920909	29	32	2517	22246	35	2
A1	5	2	Breda	290	162	183	21	45	4364794	9	28	891	4571	20	NA
A2	3	2	Tel Hadya	314 + IR*	141	166	24	63	3960139	12	33	1246	6285	23	6
A2	4	2	Tel Hadya	314	141	165	24	63	5089079	11	31	1346	7637	21	6
B	2	1	Tel Hadya	267	58	84	25	68	3272203	26	30	2412	22148	32	2

**IR: Fully irrigated, § GFD = Grain filling days, ¶ TKW = Thousand-kernel weight, ‡ HI = Harvest index, ** YR = Yellow rust, and # ACI = Average coefficient of infection*

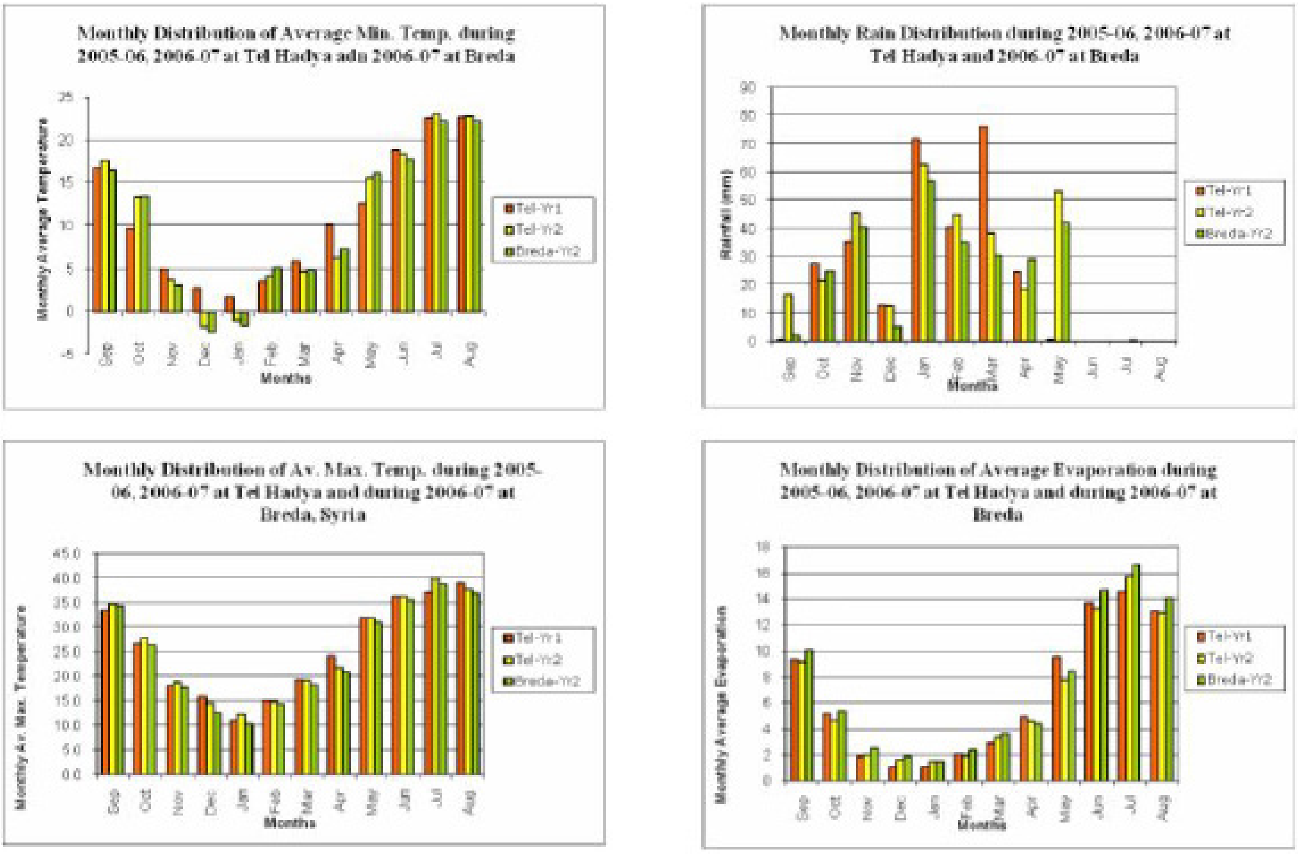

Figure 3: *Monthly average distribution of rainfall,evaporation, maximum and minimum temprature 2006-07 at tel Hadya and Breda*

similar mean but not the same trend in genotypic performance. At three group level, the group B maintained higher mean values for grain yield, harvest index, biomass, grains spike^{-1}, plant height and grain filling duration compared to other groups. However, group B was equal to one of the other groups in disease reaction rating and thousand-kernel weight (Table 2). Cluster analysis of 5 environments revealed that the differences in grain yield could be attributed to high harvest index and more grains spike^{-1}.

Mean grain yields over environments at Tel Hadya in Table 3 indicate that year-1 was more productive than year-2. Higher grain yield in year-1 at Tel Hadya was mainly the manifestation of higher grains spike^{-1}, harvest index, plant height and lower YR reaction (Table 3). However, in year-2, genotypes on average took more days to heading as well as maturity and exhibited higher number of spikes ha^{-1} with fewer heavier grains (Table 3). Based on mean grain yield of environments for both years, the experiments in year-1 expressed higher mean grain yield compared to the experiments in year-2 despite of earlier plantation and higher total rain fall during the year-2: total rainfall at Tel Hadya during year-1 was 290 mm and 314 mm during year-2 with similar tendency of maximum temperature and evaporation rate over both years (Table 3). Analysis of climatic data in Figure 3 reveals that the timing and intensity of rainfall as well as prevalence of temperature above 0°C during winter months were mainly responsible for significantly higher grain yield of year-1 versus year-2 at Tel Hadya. There had been 76 mm rain shower during March 2006 but half to this (38 mm) during March 2007 at Tel Hadya (Figure 3), tended to lower the grain yield in 2006-07. Similarly, minimum temperature during 2006 prevailed above 0°C during winter months while it went down below 0°C during December and January 2007 at Tel Hadya and Breda (Figure 3). Differences in wheat grain yield across environments could be the result of diversity in management and environmental factors such as rainfall and temperature (Nachit et al., 1992-II). Wheat becomes very sensitive to moisture level and temperature especially at late stages (Naheed and Cheema, 2015). The importance of rainfall and temperature increases many folds in areas where water holding capacity of soil is low and appropriate level of moisture is available at the time of sowing (Pratley, 2003). Thus, more rain showers during March 2006 and prevalence of temperature above 0°C during winter tended to have more favorable effects on grain yield in year-1. High rainfall during March 2006 compared to March 2007, made available more water for conservation: as a result, moisture was available to crop during year-1 for longer duration during reproductive phase compared to the crop during year-2. This is consistent with the findings of Edmeades et al. (1989), who reported that water deficit emerging in the spring resulted in a moderate stress for rainfed wheat around anthesis, increasing in severity throughout grain filling.

Conclusion

Grain yield in this study appears to be most determined by grains spike^{-1} and harvest index. Selection for these traits may contribute to important increases in grain yield, particularly in drought-prone environments. Difference in grain yield was the result of acquiring more grains rather than heavier grains. More grains in turn increased harvest index. Therefore, the character of grains spike^{-1} was the sole contributing factor towards higher yield in this study. Seed containers in plants can be determined at an early stage of development and thus can act as best criterion for screening a large number of genotypes for drought conditions. Similar grain yield of the synthetic-derived lines in irrigated and rainfed conditions within each year at Tel Hadya suggests that they can be considered best alternatives for moisture-stressed environments. This study further reveals that more rain showers during the month of March and prevalence of temperature above 0°C during winter tended to have more favorable effects on grain yield. Cluster analysis of environments was helpful in identifying associations among testing environments, their effects on yield components and phenology on grain yield formation. Our study singled out some superior lines from the experimental material particularly synthetic-derived lines 21, 32, 44 and two check cultivars ('KATILLA-13' and 'HUBARA-5'). The mentioned lines appeared stable across environments and hence can be grown in similar drought prone areas with least compromised yield. The identified lines were equivalent in yield and exceptional in some of the yield components to that of high yielding check cultivars used in the study, which could be of significant use for wheat breeders.

Authors Contributions

This research is based on the Post-Doctoral studies of the first author conducted at ICARDA Syria. Fida Mohammad and O.S Abdalla conceived the research. Fida Mohammad carried out the research in the assistance of S. Rajaram. Sheraz Ahmed and Fakharuddin wrote the first draft of the manuscript.

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