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Full Length Research Paper

Agro-morphological and phenological attributes under irrigated and rain-fed conditions in bread wheat genotypes

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Drought is a wide-spread problem seriously influencing wheat production and quality, but development of resistant cultivars is hampered by lack of effective selection criteria. Based on recent rates of increase, the world population is expected to double from 6 billion in the next 50 years. Proper management of input using modern technology, particularly irrigation water management, is essential to maximize crop production and return for the farmers. Fourteen wheat genotypes (*Triticum aestivum* L.) were grown under two environments (irrigated and rain-fed) to determine morphological and phenological responses to drought. The results of combined analysis of variance for spike length, awn length, peduncle length, plant height, days to heading, grains/spike and grain yield indicated that genotypic differences were significant (P<0.01). No significant effect was observed for spike length under each of stress and non-stress conditions. The highest peduncle length was observed for Marvdasht followed by M-83-6 and M-81-13 under rain-fed conditions. Grain yield was positively correlated with spike length, peduncle length and grain/spike, but negatively correlated with plant height in the both environments. Average grain yield in rain-fed conditions was 11.26% lower than that in irrigated conditions. Marvdasht cultivar (G13) had the highest grain yield in both conditions, while the lowest grain yield belonged to accessions 1 and 4 (Hamam-4). Marvdasht, M-81-13, WS-82-9, PYN and Shiraz were the most productive genotypes in irrigated conditions but in rain-fed site, Marvdasht followed by M-81-13, M-83-6, STAR, M-79-7 and TEVEES had the highest grain yield. Marvdasht was the superior wheat genotype under both rain-fed and irrigated conditions.

Key words: Awn length, drought, peduncle length, spike length, wheat genotypes.

INTRODUCTION

Wheat (*Triticum aestivum* L.), is one of the most important food crop which is cultivated in the large scale semi-arid areas; in this areas the rainfall is varying in different years (Kirigwi et al., 2004). Insufficient water is the primary limitation to wheat production world-wide (Ashraf and Harris, 2005). The performance of wheat under drought is correlated with yield potential and thus this has become a priority area of research (Foulkes et al., 2007; Reynolds et al., 2009). Wheat is widely grown as a rain-fed crop in semi-arid areas, where large fluctuations occur in the amount and frequency of rainfall events. The development of drought-tolerant cultivars, however, has been limited by low heritability for drought resistance and lack of effective selection strategies (Kirigwi et al., 2004). Changes have been made in the architecture towards a plant with a robust stem, long head, multiple spikelets and florets, large leaf area, and broad leaves, with the final aim of increasing seed set abilities through higher harvest index (Rajaram and Borlaug, 1997). The increase of world wheat production is attributed to the enlargement of harvested area,

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Table 1. Accession code, accession number and origin of 14 bread wheat accessions used in the experiment.

Accession code	Accession number (Name/Pedigree)	Origin
1	OR F1.158/FDL//BLO/3/SHI4414/CROW/4/C ICWH99381-0AP-0AP-0AP-OMAR-6MAR	DARSI
2	PYN/BAU//VORONA/HD2402	DARSI
3	TEVEE'S'//CROW/VEE'S'	DARSI
4	Hamam-4	DARSI
5	STAR/SHUHA-4	DARSI
6	M-83-6	**ANRRC
7	M-79-7	ANRRC
8	M-81-13	ANRRC
9	M-83-17	ANRRC
10	WS-82-9	ANRRC
11	Pishtaz	ANRRC
12	Shiraz	ANRRC
13	Marvdasht	ANRRC
14	Bolani	ANRRC

*DARSI: Dry Land Agricultural Research Sub-Institute; **ANRRC: Agricultural and Natural Resources Research Center.

optimization of crop management and development of high yielding cultivars (Feil, 1992). Depending on water availability, small amounts of irrigation water applied at strategic periods could achieve substantial increases in yield and water use efficiency of rain-fed crops (Bouthiba et al., 2008).

There are several approaches to the investigation of morphological traits for the purpose of increasing yield under water-limited conditions (Bogale et al., 2011). Peduncle length has been suggested as a useful indicator of yield capacity in dry environments. Several indices have been proposed to describe yield performance. For example put genotypes under stress and non-stress conditions or in comparison with the average yield or the yield of a superior genotype (Fischer and Maurer, 1978; Fernandez, 1992; Gavuzzi et al., 1997; Yadav and Bhatnagar, 2001). The usefulness of the indices seems to depend on the objective of selection and target environment.

To improve yield of wheat in different environments, it is necessary to identify selection criteria that can identify high-yielding genotypes in variable environments. The objectives of the present study were to assess fourteen bread wheat genotypes that had good yield potential, for investigating morphological and phenological responses to water stress.

MATERIALS AND METHODS

Site description and plant material

The experiment was carried out in 2009 to 2010 at the Research Farm of Kermanshah Azad University (latitude 34° 20' N, longitude 46°20' E, altitude 1351.6 m above sea level). Kermanshah is located in west of Iran and has a mean annual temperature of 13.8°C and annual rainfall of 478 mm. The amount of rainfall during the growing season was 387.2 mm. The soil texture of the research area was sandy-loam. Fourteen wheat genotypes that had good yield potential were planted. List and pedigree of the wheat accessions are presented in Table 1.

Experimental procedure

The experiment was performed, based on randomized complete block design (RCBD) with three replications, in two environments (irrigated and rain-fed). The genotypes were sown in six rows of 3 m length, spaced 25 cm apart in early November. The final stand density was 400 plants per m^2. All of phosphorus (50 kg ha^{-1}, P_2O_5) and half of total nitrogen (45 kg ha^{-1}, N) was applied at sowing time. The other half of the N was split and given at tillering (as urea) and booting (as ammonium nitrate) stages, respectively. To minimize the probability of seed- and soil-borne diseases, seeds were pretreated with Mancozeb as a fungicide. Experimental plots were hand weeded. Plants in rain-fed plots did not receive any water except rainfall during the experiment. In irrigated plots, three supplement irrigations were applied during flowering and grain filling period. Spike length, awn length, peduncle length, plant height, grains/spike, days to heading, days to anthesis and grain yield were measured.

Peduncle length (cm) was determined as average height of peduncle from the last node of the main stem to the initial tip of the spike. Plant height (cm) was measured from soil surface to the end of spike without considering awn length. Stress intensity (SI) was calculated using the relationship $1-\left(\frac{\overline{Ys}}{\overline{Yp}}\right)$ where $\overline{Ys}$ and $\overline{Yp}$ are the mean yields of all genotypes under stress and irrigated conditions, respectively (Fischer and Maurer, 1978). To avoid border effects, central three rows were used to measuring the traits. At maturity, plants in 1 m^2 of middle part of each plot were hand

Table 2. Combined analysis of variance for morphological and phonological traits.

Source of variation	df	Mean square							
		Spike length	Awn length	Plant height	Peduncle length	Days to heading	Days to anthesis	Grains/spike	Grain yield
Environment (E)	1	0.005	0.046	108.22	4.86	0.64	25.78	1.01	2738.2
Error (R/P)	2	0.054	2.42**	68.56	4.98	0.89	2.32	8.04	3107.1
Genotype (G)	13	1.86**	10.1**	726.9**	58.3**	13.1**	5.17	177.8**	5817.6**
E×G	13	0.33	0.2	41.06	8.38	1.33	2.13	24.96	2585.7
Error (R×G/E)	26	0.47	0.31	54.11	10.47	0.89	1.85	24.98	2295.7
CV (%)		7.76	9.49	7.31	10.12	0.67	0.88	14.28	19.25

*, ** Significant at 0.05 and 0.01, respectively.

harvested and oven dried at 80°C for 48 h. Grain yield per unit area for each treatment at each replicate was determined.

Statistical analyses

Combined analyses of variance appropriate to RCBD was carried out using SAS (version 9.1). Environments (rain-fed and irrigated) were considered as fixed effects. Duncan test was used for mean comparisons. Correlation among characters was performed by SPSS software.

RESULTS

Combined analysis of variance

Combined analysis of variance (Table 2) showed that the environment was not significant source of variation of the measured traits. Stress intensity (SI) was estimated to be 0.112, indicating a moderate water deficit stress. The results of combined analysis of variance for spike length, awn length, peduncle length, plant height, days to heading, grains/spike and grain yield indicated that genotypic differences were significant ($P<0.01$). Two-way interaction of environment × genotype was not significant for the measured traits. No significant effects were detected for days to anthesis (Table 2).

Analysis of variance

The results of analysis of variance (Table 3) showed significant genotypic differences for awn length, peduncle length and days to heading ($P<0.01$) and for plant height, days to anthesis, grains/spike and grain yield ($P<0.05$) in irrigated conditions. Significant variation among genotypes was observed for grain yield ($P<0.05$) and for awn length, plant height, days to heading and grains/spike ($P<0.01$) in the stress conditions. No significant effects were observed for spike length under stress and non-stress conditions (Table 3).

Mean comparisons

Phenological and morphological traits and grain yield were calculated for all genotypes and are presented in Table 4. The low-yielding genotypes in the present study were tall, sensitive to lodging and had fewer grains/spike (Table 4). Mean comparison of eight traits under rain-fed and irrigated conditions are shown in Table 5. All the measured traits values recorded under water stress conditions were slightly lower than those under non-stress conditions. Peduncle length under irrigated conditions ranged from 41.52 (Marvdasht) to 25.18 (Bolani), with an average of 32.25. The highest peduncle length was recorded for Marvdasht (G13) followed by M-81-13 (G8), PYN (G2), M-83-6 (G6) and STAR (G5) under irrigated conditions. Under water stress conditions, ORF1.158 (G1) and WS-82-9 (G10) had the shortest peduncle. The highest peduncle length was observed for Marvdasht followed by M-83-6 and M-81-13 in the environment (Table 5). Grain yield was positively correlated with peduncle length (r=0.599** and r=.698**) in the irrigated and rain-fed environments, respectively (Tables 6 and 7).

The highest spike length under both irrigated and rain-fed conditions was recorded for M-81-13 followed by Marvdasht (Table 5). Spike length was positively correlated with grains/spike ($r = 0.544$, $P < 0.05$) and grain yield ($r = 0.505$, $P < 0.05$) under irrigated conditions. In the rain-fed site, spike length had positive correlation with grains/spike ($r = 502$, $P < 0.05$), grain yield ($r = 0.511$, $P <0.05$), length of awn ($r = 520$*, $P< 0.05$)

Table 3. Analysis of variance for some morphological and phenological characters of wheat genotypes in irrigated and rain-fed conditions.

		Mean of squares							
Irrigated conditions	**df**	**Spike length (cm)**	**Awn length (cm)**	**Plant height (cm)**	**Peduncle length (cm)**	**Days to heading**	**Days to anthesis**	**Grains/spike**	**Grain yield (gm^{-2})**
Replication	1	0.099	3.64	108.82	6.89	0.035	0.321	3.18	4282.98
Genotype (G)	13	1.35	4.93**	287.4*	49.74**	8.035**	4.826*	96.6*	5108.40*
Error	13	0.319	0.367	95.22	8.72	0.80	1.09	27.07	2770.36
Rain-fed conditions									
Replication	1	0.008	1.21*	28.30	3.08	18.5	4.32	12.89	1931.24
Genotype (G)	13	0.84	5.32**	480.6**	43.96	6.36**	2.47	116.2**	3295.01*
Error	13	0.626	0.253	13.1	12.21	0.98	2.62	26.88	1821.05

Table 4. Some agro-morphological and phonological attributes of the wheat genotypes based on combined analysis of irrigated and non-irrigated environments.

Genotype	Days to anthesis	Days to heading	Peduncle length (cm)	Plant height (cm)	Awn length (cm)	Spike length (cm)	Grains/spike	Grain yield
ORF1.158	152.5	142	34.57	110.7	5.2	8.9	27.07	224.3
PYN	155.8	142.7	26.18	102.2	0.7	7.7	34.20	226.7
TEVEES	154.5	142.7	39.13	131.7	6.1	9.4	32.35	176.3
Hamaam-4	156.3	142.5	39.55	116.2	6.6	8.5	27.80	220.2
STAR	153.8	141.3	31.10	79.85	6.2	8.1	35.65	267.1
M-83-6	153.8	139.3	29.53	100.8	5.3	8.3	45.70	283.8
M-79-7	154	142	34.25	101.8	7.1	10	41.62	271.4
M-81-13	154.8	141.5	30.02	92.77	6.2	9.1	48.05	299.2
M-83-17	152.3	139.8	29.85	88.17	6.3	8.5	36.82	262.7
WS-82-9	152.8	137.3	37.93	112.6	6.3	10	40.20	243.2
Pishtaz	153.5	138.5	32.20	89.75	7.2	8.9	32.72	273.5
Shiraz	154.3	140	28.16	88.80	5.8	8.4	39.00	261.1
Marvdasht	153.3	141.3	30.40	91.20	7.1	9.3	41.00	291.6
Bolani	153.8	138.3	24.51	103.7	5.9	8.5	26.88	183.2
Mean	153.9	140.6	31.95	100.5	5.8	8.8	36.36	248.8
LSD0.05	1.98	1.37	4.70	10.6	0.8	0.99	7.54	69.6

Table 5. Mean comparison of eight traits under rain-fed and irrigated conditions.

	Genotypes	Days to anthesis	Days to heading	Peduncle length (cm)	Plant height (cm)	Awn length cm)	Spike length (cm)	Grains/ spike	Grain yield (g^{-2})
Irrigated conditions	ORF1.158	152.5^{a}	142.5^{a}	28.62^{de}	116.3^{b}	5.5^{c}	8.77^{c}	26.5^{d}	186.4^{d}
	PYN	156.0^{a}	142.5^{a}	37.22^{ab}	100.9^{cd}	7.11^{a}	9.22^{ab}	39.9^{abc}	299.2^{a}
	TEVEES	155.5^{a}	143^{a}	27.47^{e}	112.9^{b}	6.51^{abc}	9.10^{ab}	34.1^{bcd}	222.3^{cd}
	Hamaam-4	156.0^{a}	142^{a}	29.25^{cde}	142^{a}	6.39^{abc}	8.74^{c}	31.1^{bcd}	220.2^{cd}
	STAR	155.0^{a}	142^{a}	29.75^{cde}	81.40^{f}	6.22^{abc}	7.92^{c}	35.6^{abcd}	243^{bcd}
	M-83-6	155.0^{a}	138.5^{c}	36.38^{abc}	103^{c}	6.89^{ab}	9.11^{ab}	43^{ab}	291.6^{ab}
	M-79-7	154.5^{a}	142^{a}	35.33^{abcd}	102.2^{cd}	5.62^{bc}	8.24^{c}	41.8^{abc}	271.4^{bc}
	M-81-13	155.5^{a}	141^{ab}	39.95^{a}	95.35^{cde}	7.18^{a}	10.54^{a}	44.8^{a}	299.7^{a}
	M-83-17	153.5^{a}	139^{bc}	30.65^{bcde}	87.7^{ef}	6.23^{abc}	8.72^{c}	33.8^{bcd}	262.7^{bc}
	WS-82-9	154.5^{a}	137.5^{c}	27.90^{e}	111.2^{b}	6.35^{abc}	9.22^{ab}	41.3^{abc}	276.5^{bc}
	Pishtaz	152.5^{a}	138^{c}	32.05^{bcde}	89.7^{ef}	0.8d	7.95^{c}	29.8^{cd}	226.7^{cd}
	Shiraz	155.0^{a}	141^{ab}	30.25^{bcde}	87^{ef}	5.76^{abc}	8.12^{c}	37.7^{abcd}	261.1^{bc}
	Marvdasht	154.5^{a}	141^{ab}	41.52^{a}	94.2^{de}	7.12^{a}	10.33^{a}	47.4^{a}	319.1^{a}
	Bolani	154.5^{a}	137.5^{c}	25.18^{e}	103.2^{c}	5.83^{abc}	7.97^{c}	26.08^{d}	224.4^{cd}
	Mean	154.6	140.5	32.25	101.93	5.94	8.95	36.49	263.72
Rain-fed conditions	ORF1.158	152.5^{dc}	141.5^{abc}	23.85^{e}	109.1^{abc}	4.90^{e}	8.54^{ab}	27.65^{de}	183.1^{bc}
	PYN	155.5^{ab}	143^{a}	31.5^{abcde}	103.6^{abc}	0.70^{f}	9.26^{ab}	28.5^{cde}	195.1^{bc}
	TEVEES	153.5^{bcd}	142.5^{ab}	30.4^{abcde}	110.6^{abc}	5.71^{cde}	7.35^{b}	30.6^{bcde}	255.4^{ab}
	Hamaam-4	156.5^{a}	143^{a}	32.58^{abcd}	120.5^{a}	5.50^{de}	8.36^{ab}	24.5^{e}	194.8^{bc}
	STAR	152.5^{dc}	140.5^{bcd}	32.45^{abcd}	78.3^{d}	6.95^{ab}	9.10^{ab}	35.7b^{cde}	272.2^{ab}
	M-83-6	152.5^{dc}	140^{cd}	38.31^{a}	98.7^{abcd}	6.89^{ab}	9.21^{ab}	41.4^{ab}	273.3^{ab}
	M-79-7	153.5^{bcd}	142^{abc}	33.18^{abc}	101.5^{abcd}	6.20^{abcd}	8.25^{ab}	40.8^{abc}	267.6^{ab}
	M-81-13	154.0^{bc}	142^{abc}	37.58^{ab}	90.2^{cd}	7.05^{a}	9.75^{a}	48.4^{a}	275.1^{ab}
	M-83-17	151.0^{d}	140.5^{bcd}	29.05^{bcde}	88.65^{cd}	6.38^{abcd}	8.37^{ab}	39.8^{abcd}	249.5^{b}
	WS-82-9	151.0^{d}	137^{e}	24.46^{e}	114.1^{ab}	6.32^{abcd}	9.82^{a}	37.6^{abcd}	226.9^{b}
	Pishtaz	154.5^{abc}	139^{dc}	32.35^{abcd}	89.8^{cd}	6.68^{abcd}	8.57^{ab}	35.7^{bcde}	196.3^{bc}
	Shiraz	153.5^{bcd}	139^{dc}	26.07^{cde}	90.6^{bcd}	5.97^{bcde}	8.77^{ab}	40.2^{abcd}	222.1^{b}
	Marvdasht	152.0^{cd}	141.5^{abc}	38.63^{a}	88.2^{cd}	7.22^{a}	9.58^{a}	48.6^{a}	283.8^{a}
	Bolani	153.0^{bcd}	139^{dc}	32.76^{abcd}	104.3^{abc}	6.09^{abcd}	9.00^{ab}	27.7^{de}	204^{b}
	Mean	153.2	140.75	30.66	99.15	5.89	8.87	36.22	234.05

and length of peduncle (r = 536*, P< 0.05) (Tables 6 and 7). No significant correlation was found between awn length and grain yield under irrigated conditions. Highest awn length was observed for genotypes number 13, 8, 2 and 6. In rain-fed site, Marvdasht followed by M-81-13, STAR and M-83-6 had the highest awn length (Table 5). A positive correlation was found between awn length and grain yield (r = 0.577*, P< 0.05) under rain-fed conditions (Table 7). Plant height under irrigated conditions ranged from 142 (Hamam-4) to 81.4 (STAR), with an average of 101.93. The highest plant height was recorded for Hamam-4 followed by ORF1.158, TEVEES and WS-82-9. Under water stress conditions, plant height was reduced, and the most affected wheat genotypes were STAR, Shiraz, Pishtaz and Marvdasht with a general mean of 99.15. The relationships between plant height and peduncle length were significant (r = 0.66** and r = 0.506*) under irrigated and rain-fed, respectively. Adversely, negative significant correlations were noted among plant height with grains/spike and grain yield (r = -0.536* and r = -0.64**) under irrigated and (r = -0.553* and r = -0.578*) under rain-fed conditions (Tables 6 and 7).

The highest grains/spike under both irrigated and rain-fed conditions was recorded for Marvdasht followed by M-81-13 and M-83-6 (Table 5). Grain yields of stress conditions varied from between 183.1 to 283.8 gm^{-2} and in non stress site, ranged between 186.4 and 319.1 gm^{-2}. Mean grain yield in non-stress and stress environments was 263.72 and 234.05, respectively (Table 5). Average

Table 6. Correlation coefficients among morphological and phonological traits under irrigated (non-stress) conditions.

Trait	Spike length	Awn length	Plant height	Peduncle length	Days to heading	Days to anthesis	Grains/spike
Awn length	0.508						
Plant height	0.270	-0.121					
Peduncle length	0.506*	0.349	0.66**				
Days to heading	-0.08	-0.228	0.087	0.347			
Days to anthesis	-0.209	-0.337	0.302	0.181	0.416		
Grains/spike	0.544*	-0.072	-0.536*	-0.181	-0.223	-0.223	
Grain yield	0.505*	0.245	-0.64**	0.599**	-0.163	-0.195	0.581*

Table 7. Correlation coefficients among morphological and phonological traits under rain-fed (stress) conditions.

Trait	Spike length	Awn length	Plant height	Peduncle length	Days to heading	Days to anthesis	Grains/spike
Awn length	0.520*						
Plant height	0.183	-0.035					
Peduncle length	0.536*	0.448	0.506*				
Days to heading	-0.224	-0.307	0.341	0.092			
Days to anthesis	-0.188	-0.290	0.248	0.024	0.411		
Grains/spike	0.502*	0.351	-0.553*	-0.044	-0.253	-0.071	
Grain yield	0.511*	0.577*	-0.578*	0.698**	-0.171	-0.226	0.836**

grain yield in rain-fed conditions numerically was 11.26% lower than that in irrigated conditions. Marvdasht had the highest grain yield in both conditions, while the lowest grain yield belonged to ORF1.158 and Hamam-4 (Table 5). Marvdasht, M-81-13, PYN and M-83-6 were the most productive in irrigated conditions but in rain-fed site, Marvdasht followed by M-81-13, M-83-6, STAR, M-79-7 and TEVEES had the highest grain yield.

DISCUSSION

Negative significant correlations of plant height with grains/spike and grain yield under irrigated and rain-fed conditions were in agreement with Sio-Se et al. (2006) that showed the negative relationship of plant height with grain yield and grains/spike in wheat cultivars. Several studies indicated that semi-dwarf stature is preferred in late season drought conditions (Fischer and Maurer, 1978; Richards, 1996). Van Ginkel et al. (1998) also found that many grains/spike was criteria to high grain yield only in irrigated conditions and it was negatively correlated with grain yield under late season drought condition. Bogale et al. (2011) reported a significant and positive correlation between plant height and peduncle length. Peduncle length has been suggested as a useful indicator of yield capacity in dry environments. The significant and positive correlation observed between peduncle length and grain yield in the present study. This result suggested that peduncle length could be a good indicator of grain yield for breeding purpose in areas where water is limited for an extended period of the growing season in bread wheat. This finding is in agreement with Bogale et al. (2011) and in conformity with previous reports that showed peduncle length as an indirect selection criterion in wheat under drought conditions (Kaya et al., 2002). Kaya et al. (2002) and Bogale et al. (2011) have been found as a strong positive correlation between peduncle length and grain yield.

In other cases, such relationship has been found inverse (Briggs and Aytenfisu, 1980) or no relationship (Villeagas et al., 2006) depending on environment. The positive relationship between grain yield and morphological traits (spike length, peduncle length, awn length and grains/spike) under water stress conditions indicated that low growth rate of plants is one of the limiting factors of yield under the conditions (Siman et al., 1993; Villegas et al., 2001). Therefore, genotypes with greater growth rate under such conditions would provide the highest grain yield. Favorable conditions during growth may permit an expansion of the last internodes as well as a higher yield (Gupta et al., 2001).

The positive and significant correlation between grain yield and awn length in rain-fed conditions emphasizes the role of awn photosynthesis in grain filling. The superiority of Marvdasht in producing comparatively greater grain yield as an adapted genotype could be attributed to higher grains/spike, spike length, awn length of this genotype in both irrigated (non-stress) and rain-fed (stress) environments. Grains/spike and peduncle length were positively correlated with grain yield (r = 0.836** and r = 0.698**, respectively) in water stress conditions. Therefore, grains/spike and peduncle length could be used as reliable criteria for selection of bread wheat genotypes for water stress tolerance.

Conclusion

As a result of moderate water deficit stress (according to SI), there were no significant differences between studied traits under rain-fed and irrigated conditions. Therefore, under low stress intensity and drought avoidance, there is no need for supplementary irrigation to obtain higher grain, and this can help for saving the water. Marvdasht was the superior wheat genotype under both rain-fed and irrigated conditions.

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