Original Research Article

PHENOLOGY and HEAT UNIT REQUIREMENT of WHEAT VARIETIES UNDER DIFFERENT THERMAL ENVIRONMENTS and IW: CPE RATIO-BASED IRRIGATION SCHEDULING

ABSTRACT

A field experiment was conducted during *rabi* seasons of 2020-21 and 2021-2022 to study the heat unit indices viz; accumulated growing degree days (GDD), helio-thermal unit (HTU), photo-thermal unit (PTU), phenothermal index, helio-thermal use efficiency (HTUE), photothermal use efficiency (PTUE)andheat use efficiencies (HUE) at different phenological stages of two wheat (*Triticum aestivum*L.) varieties (Lok 1 and MP 3336) grown under different thermal environments (3rd December, 18thDecember and 2nd January) and irrigation schedules (IW: CPE= 1.0, IW: CPE= 0.9, IW: CPE= 0.8 and IW: CPE= 0.7). Results of present study reveals that the crop sown on thermal environment of 3rd December took maximum duration (113), GDD (1595.7 °C days), HTU (11,146.3 °C days hours), PTU (16,628.6 °C days hours), HUE (2.97 kgha^{-1}°C^{-1} day), HTUE (0.43 kgha^{-1}°C^{-1} day), and PTUE (0.28 kgha^{-1}°C^{-1} day). Among irrigation schedule I_1 (IW: CPE= 1.0) attained maximum crop duration (103 days), GDD (1513.8 °C days), HTU (10,550.0 °C days hours), PTU (15,461.3 °C days hours), HUE (2.96kgha^{-1}°C^{-1} day), HTUE (0.43 kgha^{-1}°C^{-1}day) and PTUE (0.29 kgha^{-1}°C^{-1} day). As regards varieties, MP 3336 took maximum duration (104), GDD (1548.1°C days), HTU (10818.9 °C days hours), PTU (15863.5 °C days hours), HUE (2.84kgha^{-1}°C^{-1} day), HTUE (0.41 kgha^{-1}°C^{-1} day) and PTUE (0.28 kgha^{-1}°C^{-1} day). The heat unit indices decrease during vegetative stages but increases during reproductive phase. The crop duration, heat indices (GDD, HTU, PTU and PTI), HUE, HTUE, PTUE and grain yield was higher under thermal environment of 3rd December sown crop with irrigation schedule I_1 (IW: CPE= 1.0) and wheat variety MP 3336.

Keywords:Grain yield, Biological yield, Thermal environments, Irrigation schedules, IW: CPE ratio, Temperature, Wheat

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is the second most crucial cereal crop of India and performs an essential role in food and nutritional security of the country. It is also one of the most nutrient dense cereals that has contributed to human diet puts it in the top for feeding the planet. India is the world's second largest wheat producer after China. Worldwide, wheat accounts for 215 million hectares (mha) area, 765 million metric tonnes (mt) with the productivity of 3420 kg ha^{-1}[1]. It is grown as the second-largest crop in India after rice in terms of acreage and production with an area of 29 mha and production of 109.1 mt [2].Madhya Pradeshhas a land area of 5.52 million hectares, a production capacity of 15.47 million tonnes, and a productivity of 3198 kg ha^{-1}[3].

Wheat development is influenced by several factors such as nutrients, water, photoperiod and temperature. As wheat crop is thermo-sensitive crop, the ideal sowing timing and selection of improved cultivars have a significant influence in maximizing the yield potential of the crop under certain agro-climatic conditions. The timing of wheat sowing determines the duration of different phenological stages and conversion efficiency of biomass into the sink i.e., grain yield. Crops sown under an optimal thermal environment have a longer growth duration, which allows them to accumulate more biomass than late-sown crops, resulting in a higher grain yield [4]. Temperature is a key climatic factor in determining sowing time and consequently the duration of various phenophases, which affect crop productivity [5]. As a result, optimization of sowing time is a crucial component for achieving maximum yield and efficient conversion of biological yield into economic yield. Crop is exposed to a range of seasonal changes during its different phenophases of growth, resulting in significant variations in growth rate and yield.The thermal units approach is widely used for quantifying the thermal relationship of crops [6] and has been further modified to include photothermal units and heliothermal units [7].

Water is required at every developmental stage of crop growth, from seed germination to crop maturity, in order to harvest the maximum potential yield of wheat. At the critical phases, there is a positive correlation between grain yield and irrigation frequency. Irrigation losing during some critical growth stage can significantly reduce grain yield [8]. Moisture stress has also been found to shorten the number of days required to achieve any phenological stage and the crop growth indices [9]. Therefore, an experiment was planned to determine the phenology and heat unit requirement of wheat varieties under different thermal environments and IW: CPE ratio-based irrigation schedules.

2. MATERIAL AND METHODS

A field investigation was conducted at the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) during the *rabi* season of 2020-2021 and 2021-2022. It is situated at 23º09’ N latitude and 79º58’ E longitude and an altitude of 411 above mean sea level. The soil of the experimental site was sandy clay loam with pH 7.1, EC 0.25 ds/m and 0.54 % organic carbon. Total rainfall received was 22 mm and 51.5 mm distributed in 2 and 7 rainy days during first and second year respectively. The experiment was laid out in splitplot design with three thermal environments (3rd December, 18th December and 2nd January) in main plots, four IW: CPE ratio-based irrigation schedules (I_1= 1.0, I_2= 0.9, I_3= 0.8 and I_4= 0.7) in sub-plots and two wheat varieties (V_1= Lok 1 and V_2= MP 3336) in sub-sub plots with three replications. The crop was sown at recommended seed rate i.e., @ 125 kg ha^{-1} at the depth of 5 cm. The crop was grown with all recommended package of practices of the region. Irrigation schedules was followed as per the treatments, based on climatological data, a known amount of irrigation water was applied when CPE reached a predetermined level. When it reaches in a particular level then irrigation is scheduled. Depth of irrigation was 5 cm for each irrigation schedule. Weather data were collected from the Agrometeorological Observatory, JNKVV, Jabalpur. Agro-meteorological indices were computed for different phenophases by adopting procedure laid out by different workers. Various heat units were calculated as follows:

Growing degree days

The growing degree-days (GDD) were determined by Nuttonson[10].

$$GDD = (Tmax, + Tmin)/2 - Tt$$

Where, Tmax and Tmin are the daily maximum and minimum temperature (°C) and Tt is the base temperature taken as 5 °C for the wheat crop.

Helio-thermal unit

The HTU is the product of heat unit (HU) and daily hours of bright sunshine. The HTU worked using the formulaRajput [11].

$$HTU\ (°C\ day\ hours) = \sum (GDD \times SSH)$$

Where, (SSH = Bright Sunshine Hours)

Photo thermal units

Photo thermal units (PTU) was calculated by using the equation given by Wilsie[12].

$$PTU = GDD \times L$$

Where, GDD = Growing degree days, L = Maximum possible day length (hrs)

Heat use efficiency

The HUE worked using the formulaRao et al., [4].

$$HUE = (Seed\ yield/GDD) * 100$$

Phenothermal Index (PTI)

Phenothermal index (PTI) for each phenophase was calculated as per following formula given by Sastry and Chakravarty [13].

$$PTI=\frac{GDD}{Growth\ days}$$

Helio-thermal use efficiency (HTUE)

The helio-thermal use efficiency (HTUE) represented the efficiency of crop to make use of the available maximum possible bright sunshine hours.

$$HTUE = \frac{Total\ grain\ yield}{Accumulated\ HTU}$$

Photothermal use efficiency (PHUE)

The photothermal use efficiency (PTUE) represented the efficiency of crop to make use of the available maximum possible day length.

$$PTUE = \frac{\text{Total grain yield}}{\text{Accumulated PTU}}$$

Statistical Analysis

In the present study the data analysis for split plot design has been performed using OP stat software.

3. RESULTS AND DISCUSSION

Phenological development: The days required to attain different growth stages was more in 3rd December thermal environment and it gradually decreased as the sowing was delayed. The crop sown on 3rd December took longest period (113days) for maturity than 18th December (102 days) and 2nd January (91 days) also reported that due to late sowing, low temperatures during the early vegetative phase and high temperatures during the reproductive phase of wheat reduced the number of days required to reach different phenological stages. The same findings were reported by Jain *et al*. [14]. Irrespective of irrigation schedule or wheat variety, there was minimal or no difference in maturity period. Thorat*et al.*[15] concluded with the similar results.

Heat units during crop growth period

Growing degree days (GDD)

The GDD was estimated from initial emergence to harvest maturity. The GDD dropped significantly with delay in sowing. The results reveals that the agrometeorological indices i.e., growing degree day (GDD) from date of emergence to harvest maturity accounted higher with 3rd December sown environment as compared to 18th December and 2nd January sown environment. Analysis of the data (Table 1) confirmed that delay in sowing resulted in reduction of GDD requirement khandee*t al*. [16] noted the similar results. This concisely explains how temperature affects crops.Lower consumption of heat units under delayed sowing. The result showed that highest GDD i.e., 1595.7, 1513.8and 1548.1 °C days was recorded at maturity when crop sown on 3rd December thermal environment with IW: CPE=1.0 irrigation schedule and wheat variety MP 3336 respectively. The reduction in GDD accumulation was due to a decrease in the number of days required to reach any phenological stage under water stress conditions, as also reported by Thorat*et al*. [15] and Bist*et al*. [17].

Helio-thermal units (HTU)

The accumulated HTU required to attain different phenological stages of wheat are presented in Table 1. Data shows that the highest Helio thermal unit 11,146.3°C day hours were required for maturity under 3rd December thermal environment with IW: CPE=1.0 irrigation schedule (10,550.0 °C day hours) and wheat variety MP 3336 (10818.9 °C day hours) as compared to delay sowing on 18th December and 2nd January thermal environment. This could be because early sown wheat crops mature later than late sown wheat crops. According to Masoni*et al*. [18] and Agrawal *et al*. [19], HTU for various phenological phases decreased with delay in sowing.

Photo-thermal units (PTU)

The variations in PTU under different treatments at various pheno-phases of wheat are presented in Table 1, revealed that delay of sowing date decreased the PTU consumption. The result indicated that the crop sown on 3rd December required maximum PTU with IW: CPE=1.0 irrigation schedule and wheat variety MP 3336 (16,628.6, 15,461.3 and 15863.5 °C day hours) respectively for maturity as compared to late sown crop environment, Thorat*et al*. [15] found similar results. While lowest value of heat unit was in delay sowing on 2nd January with IW: CPE=0.7 irrigation schedule and wheat variety Lok 1. The higher PTU value in early sown crop may be due to fact that crop took longer duration to reach phenological stages. The PTU was lowest under late sown crop i.e., 2nd January thermal environment Prasad *et al*. [20] also noted the similar findings.

Pheno-thermal Index (PTI)

The accumulated growth stage unit required per growth day between each two consecutive phenophases for different combination called pheno-thermal index (PTI) were particularize and it was presented in Table 2. The pheno-thermal index is expressed as degree day per growth day Sastry and Chakravarty, [13]. It is clear from the Table 2, the value of PTI during the milk stage to physiological maturity showed an increasing trend, whereas the early vegetative phases revealed a complex relationship between the length of crop time and the permissible ambient temperature, independent of the sowing environment, irrigation schedule, and variety. The PTI value was highest (15.7) in late sown wheat on 2nd January environment as compared to rest of the sowing times at harvest maturity. The highest PTI value (15.3) was noted under IW: CPE= 0.7 with MP 3336 (15.6). The PTI for the whole crop cycle (from emergence to maturity) showed very few differences between the different thermal environments but the irrigation schedules and varieties were remarkably similar. The duration and GDD dynamics supported the PTI values under various thermal environments. Agrawal *et al*. [21] and Khande*et al*. [16] revealed similar results.

Table 1. Crop duration, Accumulated heat units (GDD), helio-thermal unit (HTU) and photo-thermal unit (PTU) of wheat varieties sown under different thermal environments and irrigation schedules (Mean of two years)

Treatments	Emergence	CRI	Tillering initiation	Jointing	Earhead emergence	Milk stage	Dough stage	Physiological maturity	Harvest maturity
Duration (days)									
Thermal environments									
E_1= 3rdDecember	7	19	29	46	70	86	96	108	113
E_2= 18thDecember	6	18	27	43	67	79	90	97	102
E_3= 2ndJanuary	6	14	21	39	60	71	82	87	91
Irrigation schedules (IW: CPE Ratio)									
I_1= 1.0	6	18	26	43	67	79	90	98	103
I_2= 0.9	6	17	25	43	66	78	89	97	102
I_3= 0.8	5	16	24	41	65	76	87	96	100
I_4= 0.7	5	17	25	41	64	75	85	95	98
Varieties									
V_1= Lok 1	5	15	24	41	63	76	87	94	98
V_2= MP 3336	6	18	27	44	69	79	91	98	104
GDD (°C day)									
Thermal environments									
E_1= 3rdDecember	88.6	245.4	343.0	549.6	832.6	1067.1	1214.8	1427.8	1595.7
E_2= 18thDecember	78.5	236.1	321.6	520.7	805.9	956.2	1102.7	1271.8	1497.0
E_3= 2ndJanuary	64.0	196.1	259.6	481.0	717.6	845.4	979.1	1118.9	1416.6
Irrigation schedules (IW: CPE Ratio)									
I_1= 1.0	88.5	231.0	318.1	523.7	796.6	964.1	1110.0	1286.0	1513.8
I_2= 0.9	75.5	225.5	306.5	522.1	790.9	961.9	1108.5	1276.3	1511.2

I_3= 0.8	73.4	222.0	304.9	511.8	781.4	950.6	1092.1	1267.4	1497.2
I_4= 0.7	70.7	225.1	302.7	510.8	772.5	948.3	1084.8	1261.7	1490.3
Varieties									
V_1= Lok 1	70.3	213.6	294.7	499.6	742.3	938.3	1073.9	1232.5	1458.1
V_2= MP 3336	83.8	238.2	321.3	534.6	828.4	974.2	1123.8	1313.2	1548.1
HTU (°C day hours)									
Thermal environments									
E_1= 3rdDecember	605.9	1366.0	2090.9	3090.7	5283.0	7,122.4	8,702.8	10,284.1	11,146.3
E_2= 18thDecember	538.1	1315.1	1945.6	2914.4	4951.0	6,298.9	7,737.9	9,498.9	10,586.6
E_3= 2ndJanuary	444.3	1035.5	1514.7	2717.8	4195.0	5,341.7	6,588.5	8,145.3	9,652.7
Irrigation schedules (IW: CPE Ratio)									
I_1= 1.0	605.9	1287.2	1901.5	2940.1	4914.4	6,350.2	7,770.2	9,413.4	10,550.0
I_2= 0.9	513.9	1242.5	1833.0	2933.5	4866.5	6,297.7	7,754.7	9,330.8	10,535.5
I_3= 0.8	503.8	1221.8	1834.9	2882.9	4762.5	6,194.5	7,613.4	9,268.0	10,408.5
I_4= 0.7	494.1	1204.0	1832.4	2874.0	4695.4	6,174.9	7,567.4	9,225.4	10,353.4
Varieties									
V_1= Lok 1	483.7	1150.4	1766.7	2810.7	4432.1	6115.0	7459.4	8974.6	10104.8
V_2= MP 3336	575.2	1327.3	1934.2	3004.5	5187.2	6393.6	7893.4	9644.3	10818.9
PTU (°C day hours)									
Thermal environments									
E_1= 3rdDecember	959.5	2541.2	3602.8	5753.0	8593.1	10,918.7	12,652.4	15,192.3	16,628.6
E_2= 18thDecember	822.5	2457.6	3360.0	5445.1	8287.1	10,217.9	12,298.1	14,141.1	15,362.2
E_3= 2ndJanuary	670.1	2050.7	2712.9	5028.9	7347.6	9,026.0	10,992.5	12,979.2	14,041.1
Irrigation schedules (IW: CPE Ratio)									
I_1= 1.0	941.0	2414.9	3323.6	5484.9	8204.9	10,152.8	12,132.4	14,257.6	15,461.3
I_2= 0.9	786.3	2357.3	3206.9	5464.9	8139.7	10,121.0	12,095.0	14,144.7	15,438.7
I_3= 0.8	777.4	2320.6	3195.0	5350.6	8003.4	9,994.1	11,893.8	14,041.2	15,254.0
I_4= 0.7	764.7	2306.5	3175.4	5335.6	7955.8	9,948.9	11,802.7	13,973.1	15,221.7
Varieties									
V_1= Lok 1	741.6	2226.4	3080.0	5237.5	7608.7	9864.1	11702.8	13637.3	14824.3
V_2= MP 3336	893.1	2473.3	3370.5	5580.5	8543.1	10244.3	12259.2	14571.0	15863.5

Table 2. Pheno-thermal index (PTI) of wheat varieties under different thermal environment and irrigation schedules at different phenological stage

Treatments	Emergence	CRI	Tillering initiation	Jointing	Earhead emergence	Milk stage	Dough stage	Physiological maturity	Harvest maturity
Thermal environments									
E_1= 3rdDecember	13.6	12.9	11.8	12.1	11.9	12.5	12.6	13.3	14.1
E_2= 18thDecember	14.3	13.1	12.1	12.2	12.0	12.1	12.3	13.2	14.9
E_3= 2ndJanuary	10.7	14.0	12.7	12.3	12.0	12.0	11.9	12.9	15.7
Irrigation schedules (IW: CPE Ratio)									
I_1= 1.0	14.8	13.2	12.5	12.3	11.9	12.2	12.4	13.1	14.8
I_2= 0.9	14.0	13.2	12.3	12.3	11.9	12.3	12.5	13.1	14.9
I_3= 0.8	14.7	13.8	12.7	12.5	12.0	12.5	12.6	13.3	15.0
I_4= 0.7	14.1	13.6	12.3	12.4	12.2	12.6	12.8	13.3	15.3
Varieties									
V_1= Lok 1	14.1	13.2	12.1	12.3	11.4	12.2	12.4	13.4	14.4
V_2= MP 3336	15.2	14.2	12.5	12.3	12.4	12.5	12.3	13.2	15.6

Heat use efficiency (HUE)

GDD accumulated to produce a unit amount of grain yield was used to calculate HUE. The HUE for grain yield was 2.97 kgha^{-1}°C^{-1} days and for biological yield was 7.09 kgha^{-1}°C^{-1} days under 3rd December, whereas lowest HUE was on 2nd January thermal environment for grain yield (2.58 kgha^{-1}°C^{-1} days) and biological yield (6.15 kgha^{-1}°C^{-1} days). The highest HUE on the 3rd December crop could be attributed to increasing dry matter proportionately per each heat unit assimilated. The accumulation of comparable GDD to that of early sowing at later crop growth stages results in the lowest HUE in delayed sowing. This could be due to higher temperature remaining during the reproductive phase, which has a negative effect on dry matter accumulation and grain yield. HUE was recorded significantly superior on 3rd December thermal environment (2.97 kgha^{-1}°C^{-1} days) with irrigation schedule I_1 (2.96 kgha^{-1}°C^{-1} days) and wheat variety MP 3336 (2.84 kgha^{-1}°C^{-1} days) over rest of the treatments. These results were supported by finding at Jabalpur by Gajbhiye[22] at Jabalpur condition.

Helio-thermal use efficiency (HTUE)

The highest HTUE for grain yield was 0.43 kg ha^{-1} °C^{-1} day and for biological yield was 1.02 kg ha^{-1} °C^{-1} day under 3rd December thermal environment, whereas lowest HTUE was on 2nd January for grain yield and biological yield was 0.38 kg ha^{-1} °C^{-1} day, 0.91 kg ha^{-1} °C^{-1} day respectively. Irrigation schedule I_1 (IW: CPE= 1.0) was higher value of HTUE (0.43 kg ha^{-1} °C^{-1} day) for grain yield and biological yield (1.03 kg ha^{-1} °C^{-1} day) as compared to rest of the treatments. Wheat variety MP 3336 exhibited maximum value of HTUE for grain yield and biomass yield (0.41 kg ha^{-1} °C^{-1} day and biological yield 0.96 kg ha^{-1} °C^{-1} day) respectively also noted by Jain *et al*. [14].

Photothermal use efficiency (PHUE)

The highest PTUE for grain yield was 0.28 kg ha^{-1} °C^{-1} day and for biological yield was 0.68 kg ha^{-1} °C^{-1} day under 3rd December, whereas lowest PTUE was on 2nd January for grain yield and biological yield was (0.26 kg ha^{-1} ºC^{-1} day and 0.62 kg ha^{-1} ^{o}C^{-1} day) respectively. Irrigation schedule I_1 recorded higher value of PTUE for grain yield 0.29 kg ha^{-1} ºC^{-1} day and for biological yield was 0.70 kg ha^{-1o}C^{-1} day whereas lowest PTUE value was under I_4 irrigation schedule (0.25 kg ha^{-1o}C^{-1} day and 0.59 kg ha^{-1} °C^{-1} day) for grain yield and biological yield respectively. Among variety, MP 3336 recorded maximum value of PTUE for grain yield and biomass yield (0.28 kg ha^{-1} °C^{-1} day and 0.66 kg ha^{-1}°C^{-1} day) respectively. This could be due to higher temperature during the reproductive phase having a negative impact on dry matter accumulation and grain yield, as suggested by Khande*et al*.[16].

Grain yield and biological yield

The data given in table 3 revealed that grain and biological yield of wheat were significantly superior on 3rd December thermal environment (4,735and 11,315kgha^{-1}) than 18th December (4,244and 9,838kgha^{-1}) and 2nd January (3,660and 8,717kgha^{-1}) sown crop. The higher grain yield may be due to higher GDD, HTU, PTU, HUE, PTUE and PTUE as compare to other sowing environments. Temperature at later stages of crop development had a detrimental impact on grain yield in early and delayed sowing. When sowing was delayed beyond the 20th of November, grain yield of timely sown wheat was significantly reduced. Delayed sowing accelerated the crop phenological development, resulting in a significant decrease in yield. Similar findings were reported by Pal *et al*. [23], Amravat*et al*. [24], and Pathania*et al*. [25]. Hundal[26] discovered that a 2 ^{o}C increase in temperature in wheat or rice resulted in a 15-17 percent drop in grain yield in both crops, but the decrease in wheat was much greater.

Table 3. Yields and HUE, HTUE, PTUE of wheat varieties under different thermal environments and irrigation schedules

Treatments	Yield (kg ha^{-1})		HUE (kg ha^{-1}°C^{-1} day)		HTUE (kg ha^{-1}°C^{-1} day)		PTUE (kg ha^{-1}°C^{-1} day)	
	Grain yield	Biological yield	Grain yield	Biological yield	Grain yield	Biological yield	Grain yield	Biological yield
Thermal environments								
E_1= 3rd December	4,735	11,315	2.97	7.09	0.43	1.02	0.28	0.68
E_2= 18th December	4,244	9,838	2.80	6.49	0.40	0.93	0.28	0.64
E_3= 2nd January	3,660	8,717	2.58	6.15	0.38	0.91	0.26	0.62
Irrigation schedules (IW: CPE Ratio)								
I_1= 1.0	4,496	10,840	2.96	7.13	0.43	1.03	0.29	0.70
I_2= 0.9	4,342	10,319	2.86	6.80	0.41	0.98	0.28	0.67
I_3= 0.8	4,146	9,724	2.76	6.46	0.40	0.94	0.27	0.64
I_4= 0.7	3,868	8,943	2.58	5.97	0.38	0.87	0.25	0.59
Varieties								
V_1= Lok 1	4,085.02	9,727.79	2.74	6.53	0.40	0.95	0.27	0.64
V_2= MP 3336	4,340.73	10,185.36	2.84	6.66	0.41	0.96	0.28	0.66

4. CONCLUSION

On the basis of findings of this study, it is possible to conclude that heat unit indices provided a scientific foundation for assessing the effect of temperature at various phenological stages of the wheat crop. The crop sown on 3rd December thermal environment maximum calendar days resulting in higher growing degree days, photo-thermal units, helio-thermal units, Helio-thermal use efficiency, Photothermal use efficiency and heat use efficiency for all the stages were significantly reduced as a result of the subsequent delay in sowing. Thus, wheat crop sown on 3rd December recorded the highest grain yield as compare to 18th and 2nd January sown crop. Irrigation schedule I_1 (IW: CPE= 1.0) noted maximum heat indices amongst all the irrigation schedules during the study. As regards with the varieties the timely sown wheat varieties MP 3336 acquired maximum thermal units and produced maximum yield because of longer duration.It has the potential to convert heat units into economic yield and biomass in an efficient manner. The crop sown on 3rd December with IW: CPE= 1.0 and variety MP 3336 attained maximum heat unit indices as compared to rest of the treatment combinations.

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