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YIELD AND PHENOLOGICAL RESPONSES OF BT COTTON TO DIFFERENT SOWING DATES IN SEMI-ARID CLIMATE

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With the inclusion of BT cotton in the existing cotton-wheat cropping system of South Punjab, Pakistan; farmers are interested to sow early BT cotton to obtain its full production potential. There is a problem of sub and supra optimum temperature due to early and late sowing of BT cotton. Little efforts have been done to optimize the best sowing date of BT cotton in cotton-wheat cropping system. In this study, popular BT cotton cultivar MNH-886 was sown from February 14 till May 15, with two weeks interval, in soil filled earthen pots kept under natural conditions. Early sown (planted on February 14 and March 01) crop took more days to start emergence, complete 50% emergence and mean emergence time, and had minimum plant emergence. However, late sown (30th April and 15th May) took less time to germinate, with better and uniform seedling establishment. Although early planted crop took more days to start emergence, squaring, flowering, boll formation and boll opening but growing degree days to start emergence, squaring, flowering, boll formation and boll opening were high in late sown crop. However, BT cotton sown on 16th March yielded better than all other sowing dates owing to increase in yield related traits like number of sympodial branches, bolls per plant and boll weight; while crop sown on 15th May didn't perform well. Likewise sowing of BT cotton on 16th March had better fiber quality in terms of ginning out turn, fiber length, strength, fineness and uniformity. There was a positive correlation of phenological events like days to start squaring, flowering, boll formation and boll opening with seed cotton and lint yield of BT cotton; and cotton yield and boll weight were also positively linked with fiber quality traits. In conclusion, planting of BT cotton on 16th March is the best option to harvest higher seed cotton and lint yield of better quality fiber under arid to semi–arid conditions of South Punjab, Pakistan.
Keywords: BT cotton, sowing dates, phenology, seed cotton yield, fiber quality.

INTRODUCTION

Transgenically modified cotton (BT cotton) expressing insecticidal protein derived from *Bacillus thuringiensis* Berliner, has recently been added in the existing cotton-wheat cropping system of Southern Punjab, Pakistan. It is worth noting that in 2005 cotton growing season, adoption of BT cotton has increased to an area of 2.4 million hectares in China. Similar trend followed is being by the farmers of Punjab, Pakistan from 4% in 2005 to 70% in 2010 (Sabir *et al*., 2011). The addition of BT cotton reduced the number of spray operations on crop that cause the reduction of 40% pesticide usage with yield advantages of 30-40% (Men *et al*., 2003; Sadashivappa and Qaim, 2009).
In BT cotton based cotton–wheat cropping system, farmers are intended to sow BT cotton earlier to get the maximum production of BT genotypes which are relatively fast growing and give better yield. Optimum sowing time ensures higher productivity of cotton which differs in divergent agro-climatic zones (Wrather *et al*., 2008). Early planted cotton initiates reproductive growth earlier and produces more blooms and set more number of bolls utilizing the beneficial rains and sunlight that typically occur in June and July (Pettigrew, 2002). However, sowing too early leads to poor stand establishment and poor early growth due to prevailing cold weather, and also caused the seedling diseases (Bange and Milroy, 2001). Sowing time can play a vital role in achieving maximum seed cotton yield in a country like Pakistan where the climatic conditions varies in various agro-ecological zones (Ali *et al*., 2009; Deho *et al*., 2012). However, choosing the best time of sowing of cotton in a particular region can often be difficult, as it is a decision that must strike a balance between sowing too early and enduring problems associated with cold weather or sowing too late and losing potential yield.
Information about the entire growing season and comparative duration of key growth phases is imperative as both are vital determinants of final output of a crop under

divergent growing conditions (Kantolic and Slafer, 2005). Existing weather conditions has strong influence on crop performance; temperature and solar radiation are amid the major driving forces to regulate assimilates accretion and development rate of crop plants (Reynolds *et al*., 2002). Temperature plays a major role in deciding the sowing time and accordingly the length of critical phenophases to manipulate the crop production (Tewari and Singh, 1993; Hussain *et al*., 2012a). Correct timing of different phenological events and their link with yield related traits is pre–requisite to augment crop productivity under given set of climatic conditions (Gbmez-Macpherson and Richards, 1997; Hussain *et al*., 2012a,b; Awan *et al*., 2016).

With the inclusion of BT cotton in the cotton–wheat cropping system, most of the farmers sow cotton early to achieve its maximum production potential, however, research on optimization of the best sowing tome of BT cotton is lacking. Moreover, knowledge of correct timing of various phenological events of BT cotton and their link with yield related traits is not known. This study was, therefore, conducted to optimize the planting time of BT cotton. It was hypothesized that optimum sowing date may help enhancing the productivity of BT cotton.

MATERIALS AND METHODS

***Description of experimental site and plant material*:** The experiment was conducted at Wire House of Agronomy Department, Bahauddin Zakariya University Multan, Pakistan (71.43° E, 30.2° N and altitude of 122 meters) in 2013. Seed of BT cotton genotype MNH-886 was obtained from sale point of Punjab seed Corporation, Bahawalpur Road Multan, Pakistan with initial moisture contents of 11% and germination over 95%.

***Experimental details*:** Ten seeds of BT cotton genotype MNH-886 were sown in earthen pots (50 cm length and 36 cm internal diameter) of 25 kg capacity filled with well pulverized soil from February 14 to May 15 with two weeks interval. The experiment was laid out in completely randomized design with five replications. When the crop attained the height of 15 cm, thinning was done to maintain one plant per pot. Nitrogen (N) and phosphorus (P) were applied at 10 and 7 g per pot using urea and di-ammonium phosphate (DAP) as sources, respectively. Half amount of N and whole of P was thoroughly mixed in soil at the time of sowing while remaining N was applied after one month of sowing in each pot. All other agronomic practices like watering and plant protection measures were adopted to keep crop free from water stress and insect-pest attack. The experiment was harvested on October 15 by taking final picking. Total duration was 243, 228, 213, 198, 183, 168 and 153 days of crop sown on Feb 14, March 1, March 16, March 31, April 15, April 30 and May 15, respectively.

***Seedling emergence and early stand establishment*:** Each pot was visited daily to record number of seedlings emerged following the seedling evaluation Handbook of Association of Official Seed Analysts (AOSA, 1983) until a constant count was achieved. Time taken for the 1st seedling in emergence was taken as days to start emergence. Mean emergence time (MET) was recorded following Ellis and Robert (1981). The time to 50% emergence (E_{50}) was calculated as described by Farooq *et al*. (2005). Final emergence percentage was computed as a ratio of total emerged seeds to total seeds sown expressed in percentage. Coefficient of uniformity of emergence (CUE) was calculated by following formula of Bewley and Black (1985). Emergence index (EI) was calculated as described in the Association of Official Seed Analysts (1983).

***Crop phenology*:** Time taken in appearance of 1st square, flower and boll was recorded as days to start squaring, flowering and boll formation. Likewise, days to boll opening were also recorded. For recording growing degree days (GDDs) of each phenophase, daily GDDs (°C days) were calculated as under:

$$\text{Daily GDD} = [(T_{max} + T_{min})/2] - T_b$$

Where, T_{max} and T_{min} represents the maximum and minimum temperatures in °C and T_b indicates the base temperature of cotton i.e. minimum temperature at which growth ceases; and 12°C was used as base temperature for cotton (Yeates *et al*., 2013). Accumulated GDDs for each phenophase were taken by summing up daily GDDs of each phenophase (Hussain *et al*., 2012a).

***Morphological and yield traits*:** Plant height (cm) of each plant in every pot was measured with meter rod from base to tip of plant on 15th October. Number of monopodial and sympodial branches per plant, and number of bolls per plant were counted. To record boll weight (g), five mature bolls from each plant were used and averaged. Mature bolls were picked on regular intervals up to 15th October and total weight was expressed as seed cotton yield (g per plant). To estimate lint yield (g per plant), 50 g of dry and clean sample from each pot ginned through single roller electrical gin machine and its value was noted. To calculate biological yield, plants in all pots were cut from the base, sundried for seven days and then weighed; this weight was added to seed cotton yield to record biological yield. Harvest index (%) were calculated as a ratio between seed cotton yield and biological yield, and was expressed in percentage. Seed cotton was randomly selected from each treatment and ginned with a single roller electrical gin to separate the lint. Ginning out turn (GOT) was calculated as ratio of total lint to seed cotton and was expressed in percentage.

***Fiber quality*:** Cleaned and ginned lint samples were used for testing fiber quality parameters. Lint was conditioned at 20±2°C with 65% relative humidity in a conditioned chamber. High Volume Instrument (HIV 900 SA) was used to determine fiber length (mm), fiber uniformity (%), fiber fineness (µg $inch^{-1}$), and fiber strength (g tex^{-1}).

***Statistical analysis*:** Data collected, on various parameters, were analyzed by Fisher's analysis of variance technique. Least significant difference test was used for mean separation at $p \leq 0.01$ (Steel *et al*., 1997). Correlation coefficients between different phenological, seed and fiber quality parameters were computed by Microsoft Excel Program.

RESULTS

Sowing dates had significant effect on seedling emergence and stand establishment of BT cotton (Table 2). BT cotton sown on May 15 took less time to start emergence, days to complete 50% emergence (E_{50}) and mean emergence time (MET) but it was statistically at par with April sown crop. However, early planted crop (February 14) took more time to start emergence, E_{50} and MET (Table 2). However, crop sown after March 16 had higher emergence index (EI) than early planted crop. Nonetheless, higher coefficient of uniform emergence (CUE) was noted in late sown crop (April 30 and May 15) than all other sowing dates (Table 2). More final emergence percentage (FEP) was noted in with delay in planting until April 15 after which, decreasing trend was noted. Crop sown on March 16, March 31 and April 15 had 100% FEP while it was only 35% in crop planted on February 14 (Table 2).

Sowing dates had significant effect on all phenological events of BT cotton with respect to calendar days and growing degree days (GDDs) (Table 3). The crop sown on February 14 took more time to start emergence, to start squaring and flowering, and boll formation and boll opening against delayed sown crop but it was at par with the crop sown on March 01 (Table 3). On the other hand, late (May 15 and April 30) planted crop had minimum days to squaring, flowering, boll formation and boll opening (Table 3).

However, early sowing (February 14) took the least GDDs to start emergence and squaring compared with rest of sowing dates while late sown crop (May 15 and April 30) took more GDDs to start emergence and squaring, which was similar to all other sowing dates except February 14 for GDDs to start emergence (Table 3). Similarly, early sowing (February 14) had the least GDDs to start flowering and boll formation than late planted crop while the crop sown April on 15 and April 30 took more days to start flowering and boll formation, respectively than other sowing dates (Table

Table 1. Weather data of experimental site during the course of study (year 2013).

Months	Mean monthly Maximum temperature (°C)	Mean monthly Minimum temperature (°C)	Mean monthly temperature (°C)	Mean relative humidity (%)	Total monthly rainfall (mm)	Mean sunshine hours
February	20.6	11.4	16.00	87.37	72.93	5.74
March	28.1	15.9	22.00	75.65	16.73	8.43
April	33.4	20.5	26.95	60.95	1.33	7.78
May	40.3	25.5	32.90	54.92	0.00	9.86
June	38.8	29.2	34.06	67.85	50.70	8.19
July	38.1	29.8	33.97	64.51	16.91	7.92
August	35.2	27.9	31.55	72.22	74.23	7.17
September	33.9	28.0	30.90	61.87	3.22	7.87
October	32.7	24.9	28.75	71.82	2.19	8.11

Source: Central Cotton Research Station (CCRI) Multan, Pakistan

Table 2. Effect of sowing dates on stand establishment of BT cotton.

Sowing dates	Time to start emergence (days)	Time to 50% emergence (days)	Mean emergence time (days)	Emergence index	Coefficient of uniform emergence	Final emergence (%)
14 February	8.25 a	10.00 a	10.59 a	0.97 b	0.48 b	35.00 d
01 March	6.50 b	7.81 b	9.06 b	1.94 b	0.69 b	62.50 c
16 March	4.25 c	5.50 c	6.88 c	4.89 a	0.69 b	100.00 a
31March	4.00 cd	4.50 d	6.22 c	4.51 a	0.87 b	100.00 a
15 April	3.00 de	3.38 e	4.44 d	5.74 a	0.86 b	100.00 a
30 April	2.00 e	3.05 e	3.80 d	4.63 a	1.82 a	80.00 b
15 May	2.00 e	2.17 f	3.25 d	4.27 a	1.80 a	57.50 c
LSD ($p \leq 0.01$)	1.11	0.87	1.36	1.54	0.75	11.56

Means sharing the same letter, within a column, don't differ significantly from each other at $p \leq 0.01$

Table 3. Effect of sowing dates on phenology of BT cotton.

Sowing dates	DS (days)	DF (days)	DBF (days)	DBO (days)	GDDE (days)	GDDS (days)	GDDF (days)	GDDBF (days)	GDDBO (days)
14 February	16.00a	49.25a	72.50a	107.25a	38.36b	70.20d	583.68d	790.97f	1672.3c
01 March	15.25a	47.00b	71.00ab	102.25b	59.70a	156.21c	729.18c	972.01e	1746.0c
16 March	14.75a	45.00c	69.00b	100.25bc	56.51a	159.22c	692.38c	1085.8d	1863.0b
31 March	13.25b	42.75d	68.75b	98.50cd	54.38ab	181.39b	839.07b	1174.3c	1976.0a
15 April	12.25bc	40.25e	66.00c	96.00de	59.26a	196.18b	937.75a	1268.4b	2019.1a
30 April	11.50cd	38.25f	65.00cd	92.75e	52.38ab	233.98a	869.71b	1356.4a	2016.4a
15 May	10.50d	35.00g	63.25d	88.50f	50.25ab	241.37a	704.76c	1215.5c	1935.7ab
LSD ($p \leq 0.01$)	1.31	1.80	2.33	3.36	17.73	19.36	49.71	52.42	102.11

Means sharing the same letter, within a column, don't differ significantly at $p \leq 0.01$

DS = days to squaring, DF = days to flowering, DBF = days to boll formation, DBO = days to boll opening, GDDE = growing degree days to emergence, GDDS = growing degree days to squaring, GDDF = growing degree days to flowering, GDDBF = growing degree days to boll formation; GDDBO = growing degree days to boll opening

Table 4. Effect of sowing dates on the yield and yield components of BT cotton.

Sowing dates	Plant height (cm)	Number of monopodial branches per plant	Number of sympodial branches per plant	Number of bolls per plant	Boll weight (g)	Seed cotton yield (g per plant)	Lint yield (g per plant)	Biological yield (g per plant)	Harvest index (%)
14 February	106.0c	2.75ab	47.25a	41.25abc	3.98b	189.77b	79.20c	674.75b	28.12bc
01 March	107.0b	2.75ab	45.00b	44.00ab	3.95b	195.70b	82.86b	671.75b	29.14ab
16 March	112.0a	3.00a	48.00a	47.25a	4.10a	207.79a	88.10a	702.50a	29.58a
31 March	105.0c	2.25abc	41.75c	37.25bc	3.81c	173.84c	74.03d	648.75c	27.55c
15 April	102.0d	1.75bc	38.25d	33.25cd	3.66d	138.01d	57.53e	509.00d	27.12c
30 April	99.0e	1.50c	36.75de	26.50de	3.59d	115.63e	47.95f	466.00e	25.41d
15 May	96.0f	1.25c	35.50e	21.50e	3.49e	93.67f	38.71g	333.00f	28.14bc
LSD ($p \leq 0.01$)	1.0	1.14	2.05	7.67	0.08	7.12	1.49	13.78	1.17

Means sharing the same letter, within a column, don't differ significantly at $p \leq 0.01$

Table 5. Effect of sowing dates on ginning out turn (GOT) and fiber quality parameters of BT cotton.

Sowing dates	GOT (%)	Fiber length (mm)	Fiber uniformity (%)	Fiber fineness (µg $inch^{-1}$)	Fiber strength (g tex^{-1})
14 February	40.62 b	28.14 b	81.73 c	4.48 de	27.92 bc
01 March	40.92 a	28.18 b	82.01 b	4.85 bc	27.94 bc
16 March	41.08 a	28.51 a	82.55 a	5.45 a	28.71 a
31 March	40.97 a	28.26 ab	82.08 b	5.05 b	28.20 b
15 April	40.24 c	27.98 b	81.55 c	4.65 cd	27.77 c
30 April	39.81 d	27.66 c	81.30 d	4.48 de	27.11 d
15 May	39.45 e	27.46 c	80.96 e	4.30 e	26.84 d
LSD ($p \leq 0.01$)	0.22	0.30	0.23	0.25	0.29

Means sharing the same letter, within a column, don't differ significantly at $p \leq 0.01$

3). The crop sown on February 14 and March 01 took less GDDs to start boll opening while crop sown on March 31 and had more GDDs to start boll opening (Table 3).

Sowing dates also had significant effect on seed cotton yield and its related traits (Table 4). The crop sown on March 16 had more plant height than early and late sown crop; and the minimum plant height was noted in late (May 15) sown cotton (Table 4). The crop sown from February 14 to March 16 had more number of sympodial branches per plant than late sown crop (Table 4). The crop sown on March 16 had more sympodial branches and bolls per plant, which was at par with early sown cotton. However, late sowing (April 30 and May 15) had less sympodial branches and bolls per plant (Table 4). However, the crop sown on March 16 had more boll weight, seed cotton and lint yield, and biological yield per plant and late sown (May 15) crop performed poor in this regard (Table 4). Moreover crop sown on March 01 and March 16 recorded higher harvest index while the crop sown on April 30 had the minimum harvest index (Table 4). The

BT cotton sown during March had higher ginning out turn (GOT) than early and late planted crop (Table 5).

Sowing dates had significant effect on fiber quality traits of BT cotton as well (Table 5). Higher fiber length and uniformity was recorded in BT cotton sown on March 16 than both early and late sown crop while the late sown crop noted the minimum fiber length and uniformity (Table 5). Similarly, higher fiber strength and fiber fineness were recorded in BT cotton sown on March 16 compared with early and late sown crop while the crop sown on April 30 and May 16 observed the least fiber strength and fiber fineness (Table 5).

Correlation analysis indicated a strong positive link of phenological events like days to start squaring, flowering, boll formation and boll opening with seed cotton and lint yield of BT cotton sown under different sowing dates (Table 6). Moreover, seed cotton and lint yield, and boll weight were also positively correlated with GOT, and fiber quality characters like fiber length and fiber uniformity of BT cotton sown under various sowing dates (Table 7).

Table 6. Correlation coefficients of different phenological parameters with seed cotton and lint yield of BT cotton sown under different sowing dates (n = 5).

Variables	Seed cotton yield	Lint yield
Days to boll opening	0.89*	0.88*
Days to boll formation	0.90*	0.89*
Days to squaring	0.94*	0.92*
Days to flowering	0.93*	0.92*

* = Significant at $p \leq 0.05$

Table 7. Correlation coefficients of seed cotton yield, lint yield and boll weight with ginning out turn, fiber length and fiber uniformity of BT cotton sown under different sowing dates (n = 5).

Variables	Ginning out turn	Fiber length	Fiber uniformity
Seed cotton yield	0.96**	0.95*	0.92*
Lint yield	0.97**	0.95*	0.93*
Boll weight	0.91*	0.92*	0.90*

** = Significant at $p \leq 0.01$and * = Significant at $p \leq 0.05$

DISCUSSION

Planting time is one of the most important agronomic concerns for BT cotton growers to harvest maximum production potential. Results of this study indicated that BT cotton sown on March 16 produced more yield than too early and late sown crop (Table 4). Early sowing (compared with conventional planting during late April and May) of cotton in Pakistan had the advantage of favorable environmental conditions before the start of monsoon and high temperature during flowering and fruit development (Ali *et al*., 2009).

Temperature has significant impact on emergence and early stand establishment of crops (Hussain *et al*., 2012a). Prevalence of low temperature (Table 1) might be the key cause of poor and delayed emergence in early sown crop i.e. February 14 and March 01 leading to poor stand establishment (Table 2) as has been reported in other crops like wheat (Hussain *et al*., 2012a) and chickpea (Singh *et al*., 1997). On one hand the crop sown on April 30 and May 15 had quick and uniform emergence due to the prevalence of high temperature at that time but the FEP was less than the crop planted on March 16 to April 15 (having 100% FEP; Table 2) which might be due to high temperature-induced loss of seed viability (Table 1). So, the temperature seemed the driving motive to modulate the emergence and early stand establishment of BT cotton sown on varying dates (Siddiqui *et al*., 2004). However, late sown crop took less time to start and complete emergence; nonetheless the crop sown from mid March to mid April had higher EI and 100% FEP.

Although the early sown crop (February 14 and March 01) had more number of calendar days to complete its various phenophases i.e. days to start emergence, squaring, flowering, boll formation and boll opening; late sown crop (April 30 and May 15) had higher GDDs to accomplish all phenological events (Table 3). Temperature was the major driving force for this all. Early sown crop completed all its phases during the months of February, March, April and May when prevailing mean temperature was too low (Table 1). Hence the crop took more days to realize all the phenophases but accumulated lesser GDDs owing to lesser mean temperature of that time (Tables 1 and 2). While the late sown crop completed its phenological phases during the months of May, June, July and August when the existing mean temperature was too high compared with earlier months; so, the crop took less time to complete all the phenophases but accumulated more GDDs due to high mean temperature of these months (Tables 1 and 2). Cotton development between planting and squaring would stop below 11.4°C. Similarly, high temperature adversely affected on growth and development.

BT cotton sown on March 16 yielded better than too early and late sown crop due to substantial increase in yield related traits like number of monopodial and sympodial branches and bolls per plant, and average boll weight (Table 2). There was a strong positive correlation of phenological events like days to start squaring, flowering, boll formation and opening with seed cotton and lint yield (Table 6). Therefore, the number of days to start squaring, flowering, boll formation and boll opening might be the reason of curtailed seed cotton and lint yield of late season sown BT cotton (Table 6).

Late sown crop (April 30 and May 15) had poor seed cotton yield owing to less number of sympodial branches, bolls per plant and less boll weight (Tables 4–6). Late sown crop had

60 days less than the crop sown on March 16, hence had less time to boll formation and opening (Table 3) leading to less number of bolls of small size per plant. Moreover, in late sown crop, boll formation and opening took place during the hot months of July and August; so high temperature in these months accelerated boll shedding. Actually temperature beyond 30/20°C (day/night temperature regime) may result in decrease in boll retention due to enhanced abortion of squares and young bolls (Reddy *et al*., 1999). Therefore, mid-season plantation may yield more (Pettigrew, 2002). In this study, although the crop sown too early (February 14 and March 01) had more time to complete its various phenophases but low temperature during early growth cycle (Table 1) retarded crop growth, so the seed cotton yield was less than the crop sown on March 16 (Table 4). Higher lint yield in case of crop sown on March 16 was the direct result of higher seed cotton yield (Table 4).

Due to its indeterminate nature, the early sown cotton plant resulted in early initiation of squaring, flowering and boll formation, accumulates more biomass as well. Number of days taken to flowering is considered as an important determinant of earliness (Chen *et al*., 1991; Wrather *et al*., 2008). Mid-season planting provided better environmental conditions, which allowed the plant to gain more plant height and number of bolls; thus producing more seed cotton yield than late planting (Bozbek *et al*., 2006; Bange *et al*., 2008; Wrather *et al*., 2008). Reproductive stage of cotton plant just start after the initiation of first square and continued development of new fruiting branches resulting in production of fruiting sites (Deho *et al*., 2012). But in late sown crop, boll maturation period is shorter than early sowing (Bednarz *et al*., 2005). Similarly, flowering interval also performed a key role because early flowering was translated in better yield (Pettigrew, 2002; Ali *et al*., 2009).

Although the fiber quality characters are genetically linked but the impact of growing conditions like time of sowing, irrigation and fertilizer application etc. also have significant impact as observed in this study (Ali *et al*., 2009; Awan *et al*., 2011; Deho *et al*., 2012; Table 5). In later planted crop, in addition to decline in yield, fiber quality is also reduced (Tables 3–5; Misra and Malik, 1979; Cathey and Meredith, 1988). Therefore, early and mid-season planted cotton had better fiber strength than late sowing due to higher maturity of fiber (Abraham *et al*., 1991; Hallikeri *et al*., 2009) as has been noted in this study.

Conclusion: Early sown BT cotton i.e. February 14 and March 01 had poor and delayed emergence, and erratic crop stand. Planting BT cotton on March 16 (mid-season planting) is the best option to get good crop stand tied with higher seed cotton and lint yield, and good quality fiber as well under arid to semi–arid conditions of South Punjab, Pakistan.

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