

# EFFECT OF CLIMATE VARIABILITY ON POTATO YIELD UNDER DIFFERENT AGROCLIMATIC ZONES OF PUNJAB

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**ABSTRACT:** A study was conducted to determine the role of meteorological parameters on year to year variability in potato yield in two different agroclimatic zones of Punjab viz. Central Zone (Ludhiana) and Western Zone (Bathinda) using last 17 years (2003-04 to 2019-20) data. The meteorological data of different months from October to January was used to conduct this study. The meteorological data of October and November month did not show any significance for locations. Whereas, meteorological data of December and January month significantly influenced potato yield at both locations. Potato yield showed highly significant positive correlation with minimum temperature and evening relative humidity for both locations whereas yield showed significant negative correlation with sunshine hours at Ludhiana. After studying the deviation of meteorological parameters from respective normals during highest and lowest yield years and the correlation of meteorological parameters with potato yield it can be concluded that in the Punjab minimum temperature along with sunshine hours play a major role in determining the potato yield. Regression model based on maximum and minimum temperature, morning relative humidity and sunshine hours gave good results. Validation of the regression models for prediction of potato yield proved the efficiency of the targeted predictions at both locations.

**KEYWORDS:** Potato, Agroclimatic Zones, Meteorological Parameters, Regression Models, Validation

## INTRODUCTION

Potato (*Solanum tuberosum* L.) was originated in the Andean hills of South America. It belongs to the genus *Solanum* of the *Solanaceae* family. It was first introduced in the Europe by the Spanish conquerors in the end of 16<sup>th</sup> century. In India, it was introduced in early 17<sup>th</sup> century by Portuguese traders. At world level, potato is the third-largest food crop after wheat and rice and is cultivated in numerous countries, including China, India and Iran (Arab *et al.*, 2012). Total area under potato in India is ~2.16 million ha (m ha) with the production of 51.3 million tonnes (mt) and average productivity of 23.8 t ha<sup>-1</sup> far behind China (Choudhary *et al.*, 2021). The Indo-Gangetic plains (IGP) are the main potato growing region accounting for almost 85 per cent of the area under the crop in India, where it is grown as an irrigated crop during the winter season and

contributes more than 80 per cent to the total potato production of the country (Pandey and Kang, 2003). In Punjab, during 2020-21, 1.07 thousand ha area was under potato with production of 2.95 mt (Anonymous, 2021).

Potato requires long days and low temperature for its flowering and is restricted to its temperature requirement for tuber formation. Optimum tuber formation takes place at 20°C. Increase in temperature above 21°C cause sharp reduction in the tuber yield and at 30°C complete inhibition of tuber formation occurs. Temperature dependent planting time is major factor in determining growth and yield in the major potato growing regions of IGP (Haris *et al.*, 2015). The entire phase from emergence to tuber initiation is photosensitive. Short photoperiods favour early tuber initiation. However, under drought stress conditions tuber initiation and maturity is hastened (Beukema and Van

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der Zaag, 1990; Paul *et al.*, 2016). Various studies have projected a 10-40 per cent loss in potato production in India by 2080-2100 due to climate change unless farmers adapt to climate change (IPCC, 2007). Its growing duration in the IGP is projected to decrease due to climate change. The effect of climate change on potato production in India has been studied by Singh *et al.* (2009) and they revealed that under the warming scenarios, potato productivity is expected to decline in all potato growing states of India. The radiation use efficiency (RUE) is suppressed under high temperatures (Allen and Scott, 1992; Rajpoot *et al.*, 2021). It requires cool night temperature to induce tuberization (Ewing, 1997). Potato is very sensitive to frost. Severe damage of foliage occurs when temperature falls below 0°C (Hijmans *et al.*, 2003). Temperature less than 1°C for more than 4-5 hours can cause 50 per cent loss of foliage even in one night. Frost causes burning and leaf withering. Prolonged cold can cause a purplish discolouration of edges of leaflets. The frozen part of tuber become soft and blackens from inside. Frost can cause high reduction in yield. However, the reduction of yield depends on stage of crop when frost occurs. If frost occurs at 80-90 days after planting then 10-15 per cent yield loss occur while at 50-60 days after planting then 30-40 per cent yield loss occur. In Punjab, frost is the very dangerous for potato growth and yield. When planting is delayed beyond third week of October then severe damage can occur due to frost. This can be avoided by timely planting of crop. Frost can cause reduction of leaf area and can cause decrease in photosynthesis and yield. Potato is well known for its specific temperature and day length requirement for tuber formation as well as flowering, so it becomes the most vulnerable crop for climate change. As potato is the major food crop at global scale, thus

evaluating the effect of climate change on its productivity is the need of hour, so keeping this in view, the effect of climate variability on potato yield under two agro-climatic zones of Punjab have been analyzed and discussed in this paper.

## MATERIALS AND METHODS

The impact of meteorological parameters on potato yield was analysed by conducting analysis of historical data. The historical data (2003-04 to 2019-20) of potato yield was collected for Ludhiana and Bathinda from "Statistical Abstracts of Punjab". The data of different meteorological parameters *viz.* temperature, relative humidity, rainfall, rainy days, sunshine hours for both locations was collected from Department of Climate Change and Agricultural Meteorology. The normal weekly meteorological data of Ludhiana was calculated by using data of 1970-2017 and for Bathinda was calculated by using data of 1977-2015. The potato yield data was analyzed and year with highest and lowest yield were identified. The deviations of different parameters were calculated for Ludhiana and Bathinda for highest and lowest yield year. Correlation and regression analysis was conducted to study the relation between potato yield and different meteorological parameters. The validation of developed regression models for Ludhiana and Bathinda was done by using data of 2004-05 and 2009-10 and 2005-06 and 2018-19 (that was not used in development of model) respectively. These years' data was used for predicting the potato yield.

## RESULTS AND DISCUSSION

### Meteorological parameters and potato yield at Ludhiana

The perusal of weekly maximum and minimum temperature during highest (2019-20) and lowest (2005-06) potato yield

year at Ludhiana revealed that maximum temperature was mostly below normal during highest yield year. The deviations of temperatures were calculated for both highest and lowest yield year and it was observed that during 2019-20 i.e. highest yield year, deviation of maximum temperature was in range of  $-7.9^{\circ}\text{C}$  to  $0.0^{\circ}\text{C}$  as shown in Table 1. This data showed that during crop duration period in 2019-20, maximum temperature was not above normal even for a single week. Whereas, for lowest yield year deviation of maximum temperature was in range of  $-0.2^{\circ}\text{C}$  to  $+3.7^{\circ}\text{C}$ . Out of 18 weeks, 14 weeks recorded above normal maximum temperature and resulted in lower potato yield. Comparison of weekly minimum temperature, during these two years indicate that during highest yield year only 3 weeks out of 18 weeks observed below normal minimum temperature and

on the other hand during lowest potato yield year 11 weeks recorded below normal temperature during crop duration period. Similarly, Singh *et al.*, (2010) revealed that lower yield is most common problem in areas where night temperatures fall below optimum during winter season.

The analysis of rainfall and sunshine hours prevailed during highest and lowest potato yield year is presented in Table 2. The highest yield year recorded 68.7 mm above normal rainfall whereas lowest yield year recorded 36.3 mm below normal rainfall. The comparison of sunshine hours indicate that lower sunshine hours favoured potato yield as more sunshine hours lead to more frost days. So, it was observed that, highest yield year recorded very low sunshine hours than normal as compared to lowest yield year which recorded more sunshine hours than highest

**Table 1. Weekly maximum and minimum temperature deviation from normal during highest and lowest potato yield year at Ludhiana**

| Month    | SMW | Normal T <sub>max</sub> | 2019-20 (H) | 2005-06 (L) | Normal T <sub>min</sub> | 2019-20 (H) | 2005-06 (L) |
|----------|-----|-------------------------|-------------|-------------|-------------------------|-------------|-------------|
| October  | 40  | 33.3                    | -3.1        | +0.7        | 19.7                    | +0.8        | +1.1        |
|          | 41  | 32.8                    | -1.6        | +0.7        | 18.2                    | +1.0        | +0.7        |
|          | 42  | 31.6                    | -1.1        | +0.2        | 16.1                    | +2.4        | 0.0         |
|          | 43  | 30.5                    | 0.0         | +0.6        | 14.6                    | +1.2        | -0.9        |
| November | 44  | 29.3                    | -0.3        | -0.4        | 13.5                    | +2.7        | +0.2        |
|          | 45  | 28.1                    | -0.7        | -0.2        | 12.2                    | +1.4        | -1.4        |
|          | 46  | 26.8                    | -1.7        | +0.6        | 10.8                    | +2.8        | -1.4        |
|          | 47  | 25.3                    | -0.5        | +2.0        | 9.5                     | +1.7        | -1.3        |
| December | 48  | 23.8                    | -1.4        | -0.9        | 8.1                     | +3.9        | -0.7        |
|          | 49  | 22.9                    | -0.5        | +0.1        | 7.3                     | -0.1        | -2.5        |
|          | 50  | 20.8                    | -4.6        | +0.5        | 6.9                     | +2.5        | -3.3        |
|          | 51  | 19.6                    | -6.0        | +0.1        | 6.2                     | +1.9        | -2.3        |
| January  | 52  | 18.2                    | -7.9        | +1.5        | 5.6                     | -0.2        | -0.2        |
|          | 1   | 17.6                    | -1.3        | -0.8        | 5.4                     | +0.3        | +0.3        |
|          | 2   | 17.9                    | -2.8        | +1.8        | 5.4                     | +1.7        | -2.3        |
|          | 3   | 17.7                    | -1.6        | +1.8        | 5.8                     | +1.6        | +4.5        |
|          | 4   | 18.5                    | -0.2        | +0.3        | 5.8                     | +0.4        | -1.5        |
|          | 5   | 19.4                    | -1.9        | +3.7        | 6.3                     | -0.6        | +1.5        |

Where, T<sub>max</sub>: Maximum Temperature T<sub>min</sub>: Minimum Temperature H: Highest yield year L: Lowest yield year

**Table 2. Weekly rainfall and sunshine hour's deviation from normal during highest and lowest potato yield year at Ludhiana**

| Month    | SMW | Normal Rainfall | 2019-20 (H) | 2005-06 (L) | Normal Sunshine hours | 2019-20 (H) | 2005-06 (L) |
|----------|-----|-----------------|-------------|-------------|-----------------------|-------------|-------------|
| October  | 40  | 3.1             | -3.1        | -3.1        | 9.2                   | -2.0        | 1.2         |
|          | 41  | 1.8             | -1.8        | -1.8        | 8.9                   | 0.1         | 0.1         |
|          | 42  | 4.6             | -4.6        | -4.6        | 8.6                   | -3.1        | -0.8        |
|          | 43  | 0.5             | -0.5        | -0.5        | 8.4                   | -2.1        | -0.7        |
| November | 44  | 2.4             | -2.4        | -2.4        | 7.4                   | -6.2        | -1.4        |
|          | 45  | 0.6             | -0.6        | -0.6        | 9.1                   | -3.2        | -0.7        |
|          | 46  | 0.6             | -0.6        | -0.6        | 9.0                   | -4.9        | 0.9         |
|          | 47  | 1.7             | -1.7        | -1.7        | 8.8                   | -3.7        | 0           |
| December | 48  | 1.1             | +34.1       | -1.1        | 8.5                   | -3.5        | -1.7        |
|          | 49  | 2.9             | -2.9        | -2.9        | 8.2                   | -2.0        | 0.2         |
|          | 50  | 3.0             | +43.8       | -3.0        | 7.6                   | -5.3        | 0.4         |
|          | 51  | 4.7             | -4.7        | -4.7        | 7.0                   | -6.1        | -3.5        |
|          | 52  | 3.8             | -3.8        | -3.8        | 6.9                   | -6.0        | -2.4        |
| January  | 1   | 4.3             | +9.1        | 1.9         | 7.3                   | -4.5        | -1.6        |
|          | 2   | 4.3             | +15.7       | -4.3        | 6.8                   | -2.7        | 0.7         |
|          | 3   | 5.5             | -5.5        | 5.1         | 7.1                   | -3.3        | -2.8        |
|          | 4   | 8.2             | -1.8        | -8.2        | 6.8                   | -0.5        | 2.4         |
|          | 5   | 3.1             | -3.1        | -3.1        | 7.5                   | -0.3        | 0           |
| Total    |     | 53.1            | +68.7       | -36.3       | 143.1                 | -59.3       | -9.7        |

yield year. Comparison of the number of frost days between highest and lowest potato yield years at Ludhiana is shown in Fig. 1. In the year 2005-06, highest number of frost days (17 and 12 days) was recorded in month of December and January respectively, whereas in 2019-20 very few days (1 and 4) observed frost during December and January. Hijmans *et al.*, (2003) also revealed that potato is highly sensitive to frost and severe damage may occur when temperature drops below 0°C.

### Meteorological parameters and potato yield at Bathinda

The analysis of weekly maximum and minimum temperature during highest (2003-04) and lowest (2007-08) potato yield year at Bathinda showed that maximum temperature was mostly below normal during highest yield year. The deviations of temperatures

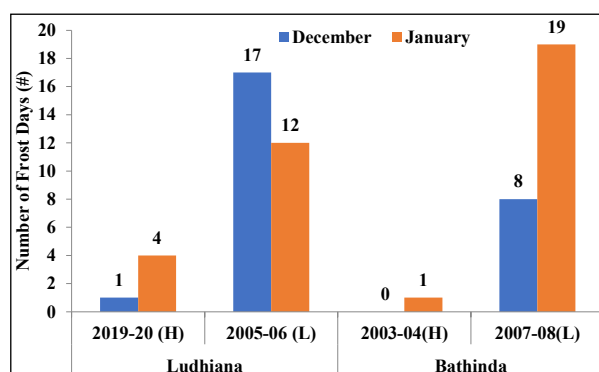


Fig. 1. Frost days variability during highest and lowest potato yield year

revealed that during highest yield year (2003-04), deviation of maximum temperature was in range of -5.5°C to +1.3°C as shown in Table 3. Whereas, for lowest yield year deviation of maximum temperature was in range of -0.2°C to +1.4°C. The comparison of weekly minimum temperature, during these

**Table 3. Weekly maximum and minimum temperature deviation from normal during highest and lowest potato yield year at Bathinda**

| Month    | SMW | Normal T <sub>max</sub> | 2003-04 (H) | 2007-08 (L) | Normal T <sub>min</sub> | 2003-04 (H) | 2007-08 (L) |
|----------|-----|-------------------------|-------------|-------------|-------------------------|-------------|-------------|
| October  | 40  | 34.6                    | -2.8        | +0.7        | 19.7                    | -0.5        | -0.9        |
|          | 41  | 34.0                    | -2.7        | +0.4        | 18.5                    | -0.1        | +0.2        |
|          | 42  | 32.7                    | -1.1        | +0.6        | 16.4                    | +1.0        | -0.8        |
|          | 43  | 31.8                    | -1.4        | +0.9        | 14.8                    | +0.2        | +0.2        |
| November | 44  | 30.9                    | -2.3        | +0.5        | 13.4                    | +1.3        | -0.3        |
|          | 45  | 29.7                    | +1.3        | -0.2        | 12.0                    | +0.8        | -1.9        |
|          | 46  | 28.5                    | -0.9        | -3.1        | 10.9                    | +1.4        | +1.4        |
|          | 47  | 26.8                    | -2.7        | -3.9        | 9.3                     | -0.2        | -2.9        |
| December | 48  | 25.2                    | -2.0        | -2.0        | 7.7                     | -1.6        | -2.9        |
|          | 49  | 24.3                    | -4.8        | -1.2        | 6.9                     | -1.2        | +2.8        |
|          | 50  | 22.6                    | -1.8        | -1.6        | 6.5                     | -0.7        | +3.6        |
|          | 51  | 21.1                    | +1.3        | -3.4        | 5.7                     | +0.8        | -0.4        |
|          | 52  | 19.5                    | -0.6        | -2.8        | 4.9                     | -0.1        | -1.3        |
| January  | 1   | 18.3                    | +0.1        | -3.7        | 4.5                     | -1.5        | +0.3        |
|          | 2   | 18.6                    | -1.3        | +1.4        | 4.5                     | +2.1        | +1.8        |
|          | 3   | 18.5                    | -1.1        | -1.1        | 4.9                     | -0.5        | +2.5        |
|          | 4   | 20.1                    | -5.5        | -3.1        | 5.5                     | -6.6        | +1.1        |
|          | 5   | 20.6                    | -4.9        | -4.5        | 5.8                     | -4.5        | -0.8        |

two years indicate that during highest yield year deviation of minimum temperature was in range of -6.6°C to +2.1°C and on the other hand during lowest potato yield year, range of deviation was -2.9°C to +2.5°C. Dua *et al.* (2018) revealed that increase in temperature can lower potato yield by 10-11.4 per cent.

The analysis of rainfall received during highest and lowest potato yield year is presented in Table 4. The highest yield year recorded 1.1 mm below normal rainfall whereas lowest yield year recorded 22.2 mm below normal rainfall. The Comparison of the number of frost days between highest and lowest potato yield years at Bathinda is shown in Fig. 1. In the year 2007-08 highest number of frost days (8 and 19 days) was recorded in month of December and January respectively, whereas in 2003-04 very few days (0 and 1) observed frost during December and January.

### Correlation Analysis

The pooled correlation coefficients between potato yield and different meteorological parameters were calculated for Ludhiana and Bathinda on the basis of potato yield and monthly data of different meteorological parameters prevailed during crop duration period as presented in Table 1. For Ludhiana, potato yield and meteorological parameters data of 2004-05 and 2009-10 years was not used for correlation and regression analysis as these years data was used for model validation.

Similarly, for Bathinda, potato yield and meteorological parameters data of 2005-06 and 2018-19 years were not used for correlation and regression analysis as these years' data was used for model validation. Among this correlation coefficient analysis, meteorological data of October month did not show any significance for both locations.

**Table 4. Weekly rainfall deviation from normal during highest and lowest potato yield year at Bathinda**

| Month    | SMW | Normal Rainfall | 2003-04 (H) | 2007-08 (L) |
|----------|-----|-----------------|-------------|-------------|
| October  | 40  | 4.4             | -4.4        | -4.4        |
|          | 41  | 2.8             | -2.8        | -2.8        |
|          | 42  | 6.6             | 7.8         | -6.6        |
|          | 43  | 1.2             | -1.2        | -1.2        |
| November | 44  | 1.7             | -1.7        | -1.7        |
|          | 45  | 1               | -1.0        | -1.0        |
|          | 46  | 0               | 0.0         | 0.0         |
|          | 47  | 2               | 7.8         | -2.0        |
| December | 48  | 0               | 0.0         | 0.0         |
|          | 49  | 1               | 5.4         | -1.0        |
|          | 50  | 1               | -1.0        | -1.0        |
|          | 51  | 2               | -2.0        | -2.0        |
|          | 52  | 4               | 1.8         | -4.0        |
| January  | 1   | 4               | -4.0        | -4.0        |
|          | 2   | 2               | 1.4         | -2.0        |
|          | 3   | 2               | -1.0        | -2.0        |
|          | 4   | 6               | -6.0        | -1.0        |
|          | 5   | 3               | -0.2        | 14.5        |
| Total    |     | 44.7            | -1.1        | -22.2       |

Whereas, meteorological data of December and January month significantly influenced potato yield at both locations. Potato yield showed highly significant positive correlation with minimum temperature and evening relative humidity whereas yield showed significant negative correlation with sunshine hours at Ludhiana.

### Development of a regression model

On the basis of different correlation coefficients and relationships of potato yield with different meteorological parameters most influencing meteorological parameters were identified from different months. These meteorological parameters were from crop duration period. After analyzing number of regression equations best fit equation with significant  $R^2$ -value was selected as a model

for forewarning potato yield at Ludhiana and Bathinda. For Ludhiana, selected regression model includes maximum and minimum temperature, morning and evening relative humidity, rainfall and sunshine hours as independent variables and potato yield as dependent variable as dependent variable. The regression models for Ludhiana and Bathinda are as follows:

For Ludhiana:

$$Y = 50784.3 + 691.4T_{\max} - 268.9T_{\min} - 386.8RH_m + 88.1RHe + 53.8RF - 1094.0SSh$$

( $R^2 = 0.54$ )

For Bathinda:

$$Y = 10474.4 + 354.8T_{\max} + 1186.1T_{\min} - 104.7RH_m + 183.7RHe - 23.7RF$$

( $R^2 = 0.64$ )

Where,

Y= Potato Yield (Kg/ha)

$T_{\max}$ : Maximum Temperature ( $^{\circ}\text{C}$ )  $T_{\min}$ : Minimum Temperature ( $^{\circ}\text{C}$ )

$RH_m$ : Morning Relative Humidity (%)  $RHe$ : Evening Relative Humidity(%)

RF: Rainfall (mm) SSh: Sunshine Hours (hrs)

### $R^2$ : Coefficient of Determination

This model indicates that potato yield at Ludhiana as well as Bathinda is highly influenced by meteorological parameters. The significant  $R^2$ -value of 0.54 indicates that 54 per cent variability in potato yield at Ludhiana was due to different meteorological parameters. Similarly, for Bathinda district,  $R^2$ -value of 0.64 indicates that 64 per cent variability in potato yield at Bathinda was due to different meteorological parameters (Table 5).

### Validation of model

Validation of regression models for Ludhiana as well as Bathinda was done by calculating the predicted yield of two years data (2004-05 and 2009-10 for Ludhiana and 2005-06 and 2018-19 for Bathinda)

**Table 5: Correlation coefficients between meteorological parameters and potato yield at Ludhiana and Bathinda (pooled over 15 years)**

| Meteorological Parameter      | Ludhiana |             |              |              | Bathinda           |       |       |              |
|-------------------------------|----------|-------------|--------------|--------------|--------------------|-------|-------|--------------|
|                               | Oct      | Nov         | Dec          | Jan          | Oct                | Nov   | Dec   | Jan          |
| Maximum Temperature (°C)      | -0.40    | -0.22       | -0.11        | <b>-0.28</b> | 0.26               | -0.20 | -0.11 | <b>-0.29</b> |
| Minimum Temperature (°C)      | 0.54     | 0.46        | 0.48         | <b>0.58</b>  | 0.18               | 0.13  | 0.10  | <b>0.76</b>  |
| Morning Relative humidity (%) | -0.03    | -0.21       | <b>-0.57</b> | -0.26        | 0.32               | -0.21 | -0.14 | <b>0.41</b>  |
| Evening relative humidity (%) | 0.08     | 0.42        | 0.16         | <b>0.42</b>  | 0.35               | 0.15  | 0.36  | <b>0.71</b>  |
| Rainfall (mm)                 | 0.22     | <b>0.41</b> | 0.26         | 0.24         | 0.07               | 0.16  | -0.18 | <b>0.29</b>  |
| Sunshine hours (Hrs/day)      | -0.52    | -0.37       | -0.53        | <b>-0.65</b> | Data not available |       |       |              |

\*significant at 5 per cent level of significance

\*bold values were used for development of regression models

which was not used in development of the regression model. This validation indicated that developed regression model predicted yield very near to the observed yield (Fig.2).

## CONCLUSION

The analysis of meteorological data for both locations indicated that deviations were comparatively less during high yield year as compared to lowest yield years. Number of frost days was significantly higher during lowest yield years. Correlation coefficients between different meteorological parameters and potato yield showed that minimum temperature, morning relative humidity and sunshine hours during December and January period significantly influenced potato yield at Ludhiana and Bathinda. Regression equation between different meteorological parameters and potato yield indicated that potato yield

is highly dependent on weather conditions of December and January. Significant  $R^2$  values explained that more than 54 and 64 per cent variability in potato yield at Ludhiana and Bathinda respectively, was due to different meteorological parameters.

## CONFLICT OF INTEREST

The authors confirm that this manuscript has no conflict of interest

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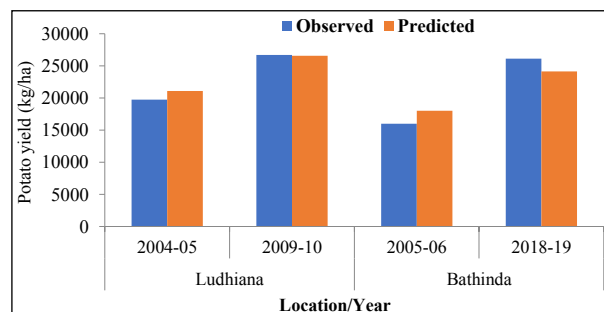


Fig. 2. Observed and predicted potato yield for Ludhiana and Bathinda

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