# Assessment of Trend Pattern of Rice Production in Some Rice Growing States of India


**ABSTRACT**

In this paper, the trend pattern of rice production has been examined for some rice growing states of India viz., Punjab, Andhra Pradesh and Uttar Pradesh. The analysis has been carried out by collecting secondary time series data on rice production during the period 2011-2020, and fitting some well-known models viz., linear model, exponential model and cubic model. The trend values have been estimated by fitting the respective models to the concerned time series data. Moreover, the accuracy of the models has been examined using coefficient of determination ($R^2$), root mean square error (RMSE), and relative mean absolute percentage error (RMAPE). Furthermore, Chi-square test of “goodness of fit” has been applied in the empirical investigation for validation of the concerned fitted models. The results of the investigation reveal the suitability of the models for exploring the scenario of trend patterns of rice production in the concerned states of India.



**Keywords:** *Linear model; exponential model; cubic model; coefficient of determination; root mean square error; chi-square test.*


## 1. INTRODUCTION

Rice (*Oryza sativa L.*) is a significant and widely consumed staple food grain crop, which is rich in carbohydrates, and several vital nutrients. It holds an eminent position in the diet of Indian subcontinent.

India is the second largest producer of rice in the world, witnessing a production of 127.93 million tons in the year 2021. In India, the leading state in the production of rice is West Bengal (16.65 million tons), followed by Uttar Pradesh (15.66 million tons), Punjab (12.18 million tons), Odisha (8.77 million tons), and Andhra Pradesh (7.89 million tons) [Directorate of Economics & Statistics, DAC&FW, Govt. of India, 2021].

A bundle of research works have been carried out by several scientists and researchers for exploring the scenario of rice in various geographical regions. For instance, Tripathi *et al.* (2014) forecasted area, production, and productivity of rice in Odisha on utilizing the historical data of 1950-51 to 2008-09 by using univariate autoregressive integrated moving average (ARIMA) models. The performances of models were validated by comparing with percentage deviation from the actual values and mean absolute percent error (MAPE). Dhakal (2018) fitted a multiple regression model for forecasting rice production in Nepal. Ramakrishna and Kumari (2018) considered autoregressive integrated moving average (ARIMA) approach for modeling and forecasting of rice production in India. The autocorrelation function (ACF) and partial autocorrelation function (PACF) were estimated.

Miah (2019) utilized ARIMA time series model to forecast the rice production of Bangladesh. The study was based on three types of rice cultivated in Bangladesh, namely, Aus, Aman, and Boro. Chaudhuri *et al.* (2020) fitted ARIMA models for forecasting rice production in major states of India. Lekshmi and Venkataramana (2020) studied growth and instability analysis of area, production and productivity of paddy in Kerala. The exponential growth model was utilized in the study for forecasting. Sunandini *et al.* (2020) examined the trends, growth pattern and instability in area, production and productivity of rice in Andhra Pradesh. Some other significant works towards statistical analysis of rice and other crops have been made by Kumar and Menon (2022), Rana and Kumar (2022), Zwan *et al.* (2022) Kumar *et al.* (2024), and Prakash et al. (2025).

The objective of the present investigation is to examine the scenario of rice production for some rice growing states of India. The analysis is done using secondary time series data on rice production during the period 2011-2020, and fitting some well-known models viz., linear model, exponential model and cubic model. The trend values have been estimated by fitting the respective models, and the accuracy of the models has been examined using coefficient of determination ($R^2$), root mean square error (RMSE), and relative mean absolute percentage error (RMAPE). Finally, Chi-square test of "goodness of fit" has been applied in the empirical investigation for validation of the concerned fitted models.

## 2. MATERIALS AND METHODS

### 2.1 Source of Data

The secondary time series data on rice production pertaining to the period 2011-2020 is utilized from the records of Directorate of Economics & Statistics, DAC&FW, Govt. of India.

### 2.2 Terminologies and Notations

In the present investigation, three rice growing states of India viz., Punjab (S1), Andhra Pradesh (S2) and Uttar Pradesh (S3) are selected.

### 2.3 Fitting of Statistical Models to the Data

In order to analyze the trend patterns of rice production in the states S1, S2, and S3, the trend values are obtained on fitting linear, exponential, and cubic models to the time series data as follows:

**(a) Linear Model:**

$$y_t = a + bt \ldots (1)$$

where $y_t$ denotes the time series value at time $t$.The values of constants '$a$' and '$b$' are obtained on using the principle of least squares by solving the following normal equations:

$$\sum y_t = na + b\sum t \ldots (2)$$

$$\sum ty_t = a\sum t + b\sum t^2 \ldots (3)$$

where '$n$' represents the number of observed values.

**(b) Exponential Model:**

$$y_t = ae^{bt} \ldots (4)$$

Taking natural log on both sides of above equation, we have

$$log_e\, y_t = log_e\, a + bt\, log_e\, e$$

$$\text{i.e., } Y_t = A + bt \quad \ldots(5)$$

$$\text{where } Y_t = log_e y_t\,,\ A = log_e\, a\,, \text{ and } log_e\, e = 1$$

The normal equations for estimating the values of '$A$' and '$b$' are as follows:

$$\sum Y_t = nA + b\sum t \ldots (6)$$

$$\sum tY_t = A\sum t + b\sum t^2 \ldots (7)$$

Finally, the value of '$a$' is obtained on using

$$a = antilog\,(A)$$

**(c) Cubic Model:**

$$y_t = \mathrm{a} + \mathrm{bt} + ct^2 + \mathrm{dt}^3 \ldots (8)$$

The values of constants '$a$', '$b$','$c$' and '$d$' are obtained on solving the following normal equations.

$$\sum y_t = na + b\sum t + c\sum t^2 + \mathrm{d}\sum t^3 \ldots (9)$$

$$\sum ty_t = a\sum t + b\sum t^2 + c\sum t^3 + d\sum t^4 \ldots (10)$$

$$\sum t^2 y_t = a\sum t^2 + b\sum t^3 + c\sum t^4 + d\sum t^5 \ldots (11)$$

$$\sum t^3 y_t = a\sum t^3 + b\sum t^4 + c\sum t^5 + d\sum t^6 \ldots (12)$$

In order to test the precision of the various fitted models, the values of statistical measures viz., $R^2$, RMSE and RMAPE are computed using the following formulae:

$$R^2 = 1 - \frac{\sum_{t=1}^{n}(y_t - \hat{y}_t)^2}{\sum_{t=1}^{n}(y_t - \bar{y})^2}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(y_t - \hat{y}_t)^2}$$

and

$$RMAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{y_t - \hat{y}_t}{y_t}\right| \times 100$$

where $y_t$ denotes the observed value of rice production ($Y$), and $\bar{y}$ is the mean value of the variable $Y$. Also, $\hat{y}_t$ is the trend value of the variable $Y$, which is obtained on fitting the respective statistical model (such as linear model, or exponential model or cubic model, as the case may be) to the variable $Y$.

## 3. RESULTS AND DISCUSSION

The time series data on rice production in the states S1, S2 and S3, is summarized in Table 1. Also, the trend values on fitting linear, exponential and cubic models to the data pertaining to states S1, S2 and S3 are computed, and the findings are presented in Tables 2, 3, and 4, respectively. Moreover, the model equations for linear, exponential and cubic trends in the respective states are elaborated in Table 5.

**Table 1.**Time series data on rice production in selected states of India

| **Year** | ***Production (in million tons) for the states** | | |
|---|---|---|---|
| | **S1** | **S2** | **S3** |
| 2011 | 10.54 | 12.9 | 14.02 |
| 2012 | 11.37 | 11.51 | 14.42 |
| 2013 | 11.27 | 12.72 | 14.64 |
| 2014 | 11.11 | 7.23 | 12.17 |
| 2015 | 11.82 | 7.49 | 12.5 |
| 2016 | 11.59 | 7.45 | 13.75 |
| 2017 | 13.28 | 8.17 | 13.27 |
| 2018 | 12.82 | 8.23 | 15.55 |
| 2019 | 11.78 | 8.66 | 15.52 |
| 2020 | 12.18 | 7.89 | 15.66 |

(***Source:** Directorate of Economics & Statistics, DAC&FW, Govt. of India)

**Table 2.** Trend values for linear, exponential and cubic models in state S1

| Year (t) | Production($y_t$) | Trend Values | | |
|---|---|---|---|---|
| | | Linear Model($L_t$) | Exponential Model ($E_t$) | Cubic model ($C_t$) |
| 2011 | 10.54 | 10.91 | 10.52 | 10.80 |
| 2012 | 11.37 | 11.10 | 10.69 | 10.88 |
| 2013 | 11.27 | 11.29 | 10.87 | 11.13 |
| 2014 | 11.11 | 11.48 | 11.05 | 11.47 |
| 2015 | 11.82 | 11.68 | 11.23 | 11.85 |
| 2016 | 11.59 | 11.87 | 11.42 | 12.20 |
| 2017 | 13.28 | 12.06 | 11.61 | 12.45 |
| 2018 | 12.82 | 12.25 | 11.80 | 12.54 |
| 2019 | 11.78 | 12.44 | 11.99 | 12.41 |
| 2020 | 12.18 | 12.63 | 12.19 | 11.99 |

**Table 3.** Trend values for linear, exponential and cubic models in state S2

| Year (t) | Production ($y_t$) | Trend Values | | |
|---|---|---|---|---|
| | | Linear Model ($L_t$) | Exponential Model ($E_t$) | CubicModel ($C_t$) |
| 2011 | 12.9 | 11.53 | 8.58 | 13.47 |
| 2012 | 11.51 | 11.02 | 8.16 | 11.53 |
| 2013 | 12.72 | 10.50 | 7.76 | 10.04 |
| 2014 | 7.23 | 9.99 | 7.38 | 8.97 |
| 2015 | 7.49 | 9.48 | 7.02 | 8.26 |
| 2016 | 7.45 | 8.96 | 6.68 | 7.87 |
| 2017 | 8.17 | 8.45 | 6.36 | 7.73 |
| 2018 | 8.23 | 7.94 | 6.04 | 7.82 |
| 2019 | 8.66 | 7.42 | 5.75 | 8.07 |
| 2020 | 7.89 | 6.91 | 5.47 | 8.44 |

**Table 4.** Trend values for linear, exponential and cubic models in state S3

| Year (t) | Production ($y_t$) | Trend Values | | |
|---|---|---|---|---|
| | | Linear Model ($L_t$) | Exponential Model ($E_t$) | Cubic Model ($C_t$) |
| 2011 | 14.02 | 13.28 | 13.80 | 14.62 |
| 2012 | 14.42 | 13.48 | 13.98 | 13.83 |
| 2013 | 14.64 | 13.67 | 14.17 | 13.35 |
| 2014 | 12.17 | 13.86 | 14.35 | 13.16 |
| 2015 | 12.5 | 14.05 | 14.54 | 13.21 |

| | | | | |
|---|---|---|---|---|
| 2016 | 13.75 | 14.24 | 14.74 | 13.48 |
| 2017 | 13.27 | 14.43 | 14.93 | 13.93 |
| 2018 | 15.55 | 14.62 | 15.13 | 14.54 |
| 2019 | 15.52 | 14.81 | 15.33 | 15.26 |
| 2020 | 15.66 | 15.01 | 15.53 | 16.08 |

In Tables 2, 3 and 4, the term '$y_t$' denotes the observed value of rice production (in million tonnes) at time t ($t = 2011, 2012, \ldots, 2020$), '$L_t$'denotes the linear trend value of rice production at time t, '$E_t$'denotes the exponential trend value of rice production at time t, and '$C_t$'denotes the cubic trend value of rice production at time t.

**Table 5.** Model equations for linear, exponential and cubic trends in selected states of India

| **States** | **Linear Model** | **Exponential Model** | **Cubic Model** |
|---|---|---|---|
| S1 | $y_t = 11.87 + 0.19t$ | $y_t = 5\text{E} - 14e^{0.016t}$ | $y_t = 12.2 + 0.31t - 0.05t^2 - 0.01t^3$ |
| S2 | $y_t = 8.96 - 0.51t$ | $y_t = 4\text{E} + 44e^{-0.05t}$ | $y_t = 7.87 + 0.25t + 0.13t^2 - 0.008t^3$ |
| S3 | $y_t = 14.24 + 0.19t$ | $y_t = 5\text{E} - 11e^{0.013t}$ | $y_t = 13.48 + 0.36t + 0.09t^2 - 0.005t^3$ |

In order to illustrate the relative influence of linear, exponential and cubic trend values on the observed values of rice production for the states S1, S2, and S3, the graphical plots are obtained and demonstrated in Figs. 1 to 9.

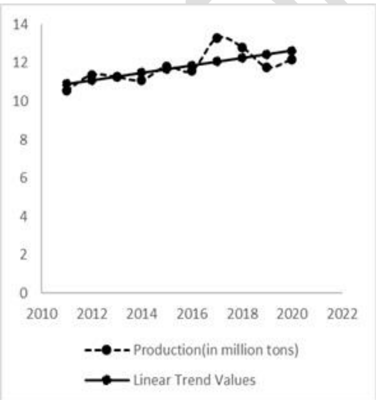


**Fig. 1.** Trend values for Linear Model in state S1

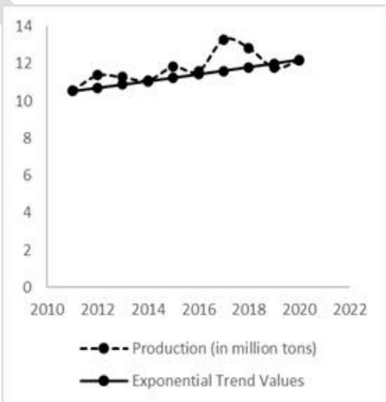


**Fig. 2.** Trend values for Exponential Model in state S1

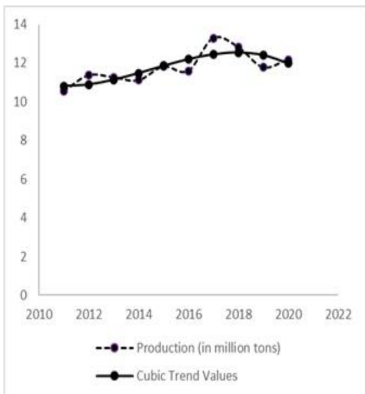


**Fig. 3.** Trend values for Cubic Model in state S1

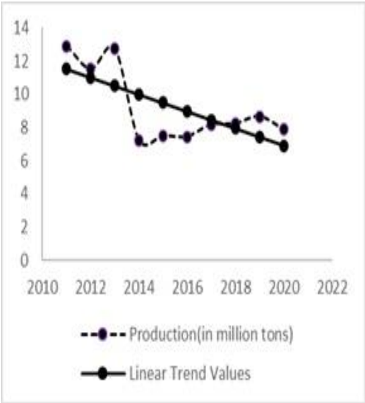


**Fig. 4.** Trend values for Linear Model in state S2

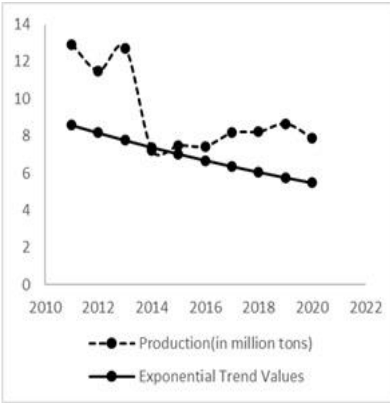


**Fig. 5.** Trend values for Exponential Model in state S2

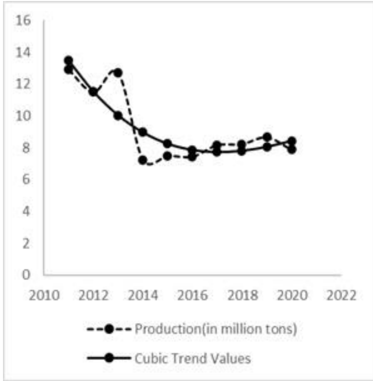


**Fig. 6.** Trend values for Cubic Model in state S2

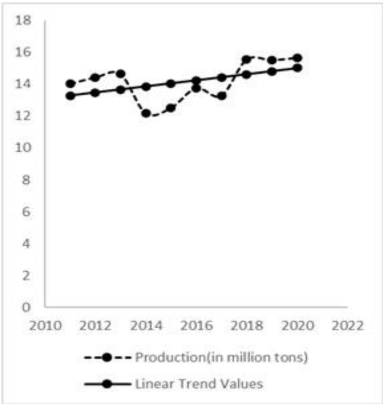


**Fig. 7.** Trend values for Linear Model in state S3

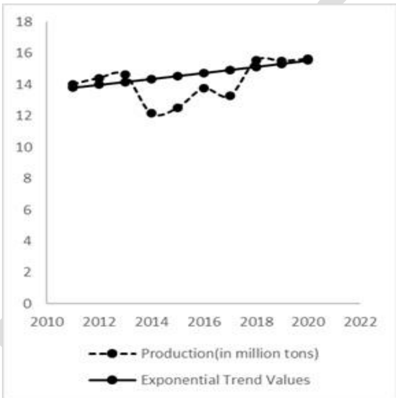


**Fig. 8.** Trend values for Exponential Model in state S3

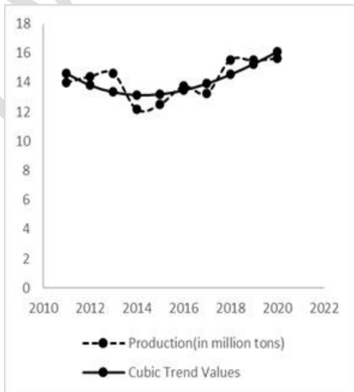


**Fig. 9.** Trend values for Cubic Model in state S3

The values of $R^2$, RMSE and RMAPE for the concerned fitted models in the respective states are obtained, and presented in Table 6.

**Table 6.** Model evaluation for rice production in selected states of India

| States | Models | $R^2$ | RMSE | RMAPE |
|---|---|---|---|---|
| S1 | Linear | 0.51 | 0.54 | 3.61 |
| | Exponential | 0.50 | 0.70 | 3.89 |
| | Cubic | 0.66 | 0.45 | 3.21 |
| S2 | Linear | 0.48 | 1.53 | 15.19 |
| | Exponential | 0.52 | 2.78 | 23.28 |
| | Cubic | 0.73 | 1.11 | 8.98 |
| S3 | Linear | 0.22 | 1.05 | 7.17 |
| | Exponential | 0.22 | 1.16 | 6.66 |
| | Cubic | 0.60 | 0.75 | 4.88 |

From Table 6, the following results are obtained:

i) In each of the three states S1, S2 and S3, the values of $R^2$ are more for the cubic model as compared to the linear and exponential models. Moreover, the values of $R^2$ are nearly the same for the both linear and exponential models in each state.

ii) In all the three statesS1, S2 and S3, the values of RMSE are least for cubic model as compared to the linear and exponential models. Furthermore, the values of RMSEare nearly the same for the both linear and exponential models in state S1 and S3.

iii) In the statesS1, S2 and S3, the values of MAPE are least for cubic model as compared to the linear and exponential models. Furthermore, the values of MAPE are nearly the same for the both linear and exponential models in state S1 and S3.

iv) On the basis of values of $R^2$, RMSE and MAPE, we conclude that the cubic model is the best fitted model, as compared to the linear and exponential models, for analyzing the growth and trend pattern of rice production in concerned states of India.

### 3.1 Formulation of Hypotheses

The following null hypotheses are tested:

$H_{0L}$: Linear model fits the data on rice production.

$H_{0E}$: Exponential model fits the data on rice production.

$H_{0C}$: Cubic model fits the data on rice production.

against the following respective alternative hypotheses:

$H_{1L}$: Linear model does not fit the data on rice production.

$H_{1E}$: Exponential model does not fit the data on rice production.

$H_{1C}$: Cubic model does not fit the data on rice production.

The above mentioned hypotheses are tested in the concerned states S1, S2 and S3 of India, using chi-square test of "goodness of fit".

### 3.2 Hypotheses Testing and Validation

The chi-square values have been obtained by fitting the linear, exponential and cubic models (i.e., $\chi_L^2$ , $\chi_E^2$ and $\chi_C^2$) in the concerned states of India, and the findings are elaborated in Table 7. The chi-square values have been computed using the following formulae:

$$\chi_L^2 = \sum_{t=1}^{n} \frac{(y_t - L_t)^2}{L_t} = \sum_{t=1}^{10} \frac{(y_t - L_t)^2}{L_t},$$

$$\chi_E^2 = \sum_{t=1}^{n} \frac{(y_t - E_t)^2}{E_t} = \sum_{t=1}^{10} \frac{(y_t - E_t)^2}{E_t},$$

$$\chi_C^2 = \sum_{t=1}^{n} \frac{(y_t - C_t)^2}{C_t} = \sum_{t=1}^{10} \frac{(y_t - C_t)^2}{C_t},$$

where the values of the terms '$y_t$', '$L_t$', '$E_t$' and '$C_t$' have been utilized from the Tables 2, 3 and 4, for the concerned states S1, S2 and S3.

**Table 7.** Values of chi-square test statistic on fitting linear, exponential and cubic models

| States | Chi-square values | | |
|---|---|---|---|
| | **Linear Model ($\chi_L^2$)** | **Exponential Model ($\chi_E^2$)** | **Cubic Model ($\chi_C^2$)** |
| S1 | 0.24 | 0.42 | 0.16 |
| S2 | 2.45 | 10.64 | 1.29 |
| S3 | 0.78 | 0.92 | 0.40 |

The tabulated values of chi-square ($\chi^2$) at 1% and 5% levels of significance with 9 degrees of freedom are given, respectively, by

$$\chi_{0.01,9}^2 = 21.67 \text{ and } \chi_{0.05,9}^2 = 16.92$$

From Table 7, the following results are obtained:

(i) $\chi_{L(S_i)}^2 < \chi_{0.01,9}^2$ and $\chi_{L(S_i)}^2 < \chi_{0.05,9}^2$ $(i = 1,2,3)$

(ii) $\chi_{E(S_i)}^2 < \chi_{0.01,9}^2$ and $\chi_{E(S_i)}^2 < \chi_{0.05,9}^2$ $(i = 1,2,3)$

(iii) $\chi_{C(S_i)}^2 < \chi_{0.01,9}^2$ and $\chi_{C(S_i)}^2 < \chi_{0.05,9}^2$ $(i = 1,2,3)$

Hence, on the basis of above results, the null hypotheses $H_{0L}$, $H_{0E}$ and $H_{0C}$ are accepted at 1% and 5% levels of significance. So, we conclude that the linear, exponential and cubic models fit the given time series data on rice production for the concerned states S1, S2 and S3 of India.

## 4. CONCLUSION

In the present paper, trend pattern analysis of rice production is carried out in some selected states of India viz., S1 (Punjab), S2 (Andhra Pradesh) and S3 (Uttar Pradesh), using time series data pertaining to the period 2011-2020. The trend values have been estimated by fitting linear, exponential, and cubic models to the concerned time series data on rice production. Moreover, the accuracy of the fitted models have been measured using $R^2$, RMSE and RMAPE.

It has been observed from the empirical results of section 3 that the cubic model is more precise and suitable, as compared to the linear and exponential models, for exploring the trends of rice production in the concerned states. Also, Punjab and Uttar Pradesh exhibit slight increase in the growth patterns of rice production, while Andhra Pradesh exhibits a rapid decline in growth pattern. In the year 2020, the rice production in Uttar Pradesh is observed to be the highest, followed by Punjab and Andhra Pradesh.

In order to test the "Goodness of Fit" of the linear, exponential and cubic models for the states S1, S2 and S3, the chi-square test statistic values (i.e., $\chi_L^2$, $\chi_E^2$ and $\chi_C^2$) have been computed for the respective states. These values are then compared with the tabulated values of chi-square at 1% and 5% levels of significance. It has been observed that all the considered models fit the given time series data on rice production for the concerned states.

The present investigation could be enhanced further by considering the scenario of rice production in other rice growing states of India. Moreover, as rice holds a prominent position in the human diet, so the potential rice farmers could be encouraged for its cultivation.

The findings of the investigation may enable the scientists and policymakers in formulating strategies to enhance rice production for meeting global food security.

**Acknowledgment**

The authors are highly thankful to the editors and reviewers for their valuable suggestions regarding the improvement of the manuscript in the present form.

**Disclaimer (Artificial Intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

**Competing Interests**

Authors have declared that no competing interests exist.

**Authors' contributions**

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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