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Statistical Modeling for Analysis of Growth and Trend Pattern of Wheat Production in Selected States of India

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Authors' contributions

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

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ABSTRACT

In the present paper, the time series analysis of wheat production in some selected states of India has been carried out by fitting well-known statistical models, viz. linear, exponential and cubic models. The selection of wheat growing states has been made on the basis of criteria of higher production and consistent growth pattern. The secondary time series data on wheat production have been utilized for the analysis. The trend values have been computed on fitting the concerned models, and the validity of the models has been tested on using the chi-square test statistic. Moreover, the coefficient of determination (R^2), root mean square error (RMSE), and relative mean absolute percentage error (RMAPE) have been computed to reveal the suitability of the concerned models for exploring the trend patterns of wheat production in the concerned states of India. The findings of the investigation reveal that the above mentioned models are appropriate for forecasting of future trend of wheat production in the concerned states.

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Keywords: Time series; linear model; exponential model; cubic model; chi-square test; coefficient of determination.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most significant cereal crops, and the second most important staple food crop in India after rice. It belongs to Gramineae (or Poaceae) family, and is a rich source of carbohydrate, protein, multi-vitamins and other vital nutrients. Wheat is mainly consumed in processed form, for instance, bread, biscuits, cookies, noodles, porridge, pudding, pasta, vermicelli, and so on. In India, mostly three species of wheat are cultivated i.e., *Triticum aestivum* (common wheat or bread wheat), *Triticum durum* (macroni or durum wheat) and *Triticum dicoccum* (emmer wheat).

In India, the largest area under coverage of wheat species is *Triticum aestivum* (common wheat or bread wheat), followed by *Triticum durum* (macaroni or durum wheat) and *Triticum dicoccum* (emmer wheat). The wheat species *Triticum aestivum is* commonly grown in all six agro-climatic zones of the country viz., Northern Hill Zone (NHZ), North West Plain Zone (NWPZ), North East Plain Zone (NEPZ), Central Zone (CZ), Peninsular Zone (PZ) and Southern Hill Zone (SHZ) (Joshi et al*.* [1]).

India is the second largest producer of wheat after China. In India, the leading state in the production of wheat was Uttar Pradesh (35.50 million tons) during the year 2020-21, followed by Madhya Pradesh (17.62 million tons), Punjab (17.14 million tons), Haryana (12.36 million tons), Rajasthan (11.04 million tons), and Bihar (6.34 million tons). In India, the overall production of wheat was 109.52 million tons, and the wheat yield was 3.464 tons per hectare (Source: Directorate of Economics & Statistics, DAC&FW, Govt. of India [2]).

The agriculture sector is deemed to be a significant sector as it contributes towards the economic development of a nation. In recent years, there is significant rise in food grain production due to noteworthy developments in agriculture sector and evolution of high-yielding variety of seeds. Cheboi and Mungabe [3] conducted an experiment to determine the effect of different pre-treatments on germination of wheat seeds. Oktem and Oktem [4] conducted a field trial experiment using randomized complete block design to determine climatic effects on quality parameters of bread wheat genotypes grown under semi-arid region. Moniruzzaman et al*.* [5] carried out a field experimentation to assess the effects of organic and inorganic nitrogen fertilizers on the growth and yield of wheat. Alemu et al. [6] conducted an experiment to identify and promote the best adapted, high yielding, and heat tolerance bread wheat varieties for irrigated areas of different agro-ecology regions.

The time series analysis of agricultural crops is of utmost importance for exploring the long-term trend pattern of the crops, and policy formulation regarding inventory management, price fixation, and transportation of the crops. Considering this fact, the trend analysis of crops has been dealt by various authors. Boken [7] applied time series analysis to forecast yield of spring wheat for Saskatchewan, Canada by using well-known statistical models (viz. linear trend, quadratic trend, simple exponential smoothing, double exponential smoothing, simple moving averaging, and double moving averaging). Arunachalam and Balakrishnan [8] investigated the trends in area, production and productivity of wheat in India by utilizing non-linear as well as non-parametric regression models. Michel and Makowski [9] presented eight statistical models for analyzing wheat yield time series and predicted wheat yield at the national and regional scales, on utilizing data obtained through the Food and Agriculture Organization of the United Nations and the French Ministry of Agriculture. Dasyam et al*.* [10] modeled and forecasted the production of wheat in India by using parametric regression, exponential smoothing and Auto Regressive Integrated Moving Average (ARIMA) models. Ray et al*.* [11] proposed a hybrid model by combining Autoregressive Integrated Moving Average (ARIMA) and Wavelet Neural Network (WNN). Polisetty and Paidipati [12] examined the change point and trend analysis of wheat production in India using non-parametric methods viz. Pettitt’s, standard normal homogeneity (SNH) and Buishand’s range tests. Yonar et al. [13] modeled and forecasted the production of wheat in South Asian region countries, viz. Afghanistan, Bangladesh, Bhutan, China, India, Nepal, and Pakistan, on utilizing ARIMA and Holt’s linear trend models. Rao and Naidu [14] applied various non-linear models to forecast the area, production and productivity of wheat crop in India. Madhukar et al. [15]

analyzed the temperature and precipitation trends and their impact on wheat yield across 29 Indian states using statistical methods. Some other noteworthy contributions towards time series analysis of crops have been made by Rajarathinam et al. [16], Tripathi et al. [17], Joshi et al. [18], Kumar and Menon [19], Paudel et al. [20], and Rana and Kumar [21].

In this paper, an attempt is made to explore the trend of wheat production in some selected states of India. The analysis is done using well-known statistical models viz. linear, exponential and cubic models. The accuracy of the concerned models has been evaluated using coefficient of determination (R^2), root mean square error (RMSE) and relative mean absolute percentage error (RMAPE). Moreover, the validity of models has been examined through chi-square (χ^2) test of "Goodness of Fit".

2. MATERIALS AND METHODS

2.1 Source of Data

The present paper deals with the analysis of secondary time series data on wheat production pertaining to the period (2011-2020) in some selected states of India. The time series data is obtained from the records of Directorate of Economics & Statistics, DAC&FW, Govt. of India.

2.2 Terminologies and Notations

In the present analysis, three wheat growing states of India, viz. Uttar Pradesh (S1), Haryana (S2), and Bihar (S3) are considered. These states exhibit various trends of wheat production during the concerned period of study.

2.3 Fitting of Statistical Models to the Data

In order to analyze the growth and trend pattern of wheat production in the concerned states S1, S2 and S3, the trend values are computed by fitting linear, exponential and cubic models to the time series data on wheat production as follows:

(a) Linear Model:

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

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

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

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

where 'n' represents the number of observed values.

(b) Exponential Model:

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

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

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

i.e., $Y_t = A + bt \qquad (5)$

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

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

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

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

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

$$a = antilog\ (A)$$

(c) Cubic Model:

$$y_t = a + bt + ct^2 + dt^3 \qquad (8)$$

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

$$\sum y_t = na + b\sum t + c\sum t^2 + d\sum t^3 \qquad (9)$$

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

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

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

3. RESULTS AND DISCUSSION

The secondary time series data on wheat production in states S1, S2 and S3 of India is presented in Table 1. The trend values are obtained on fitting linear, exponential and cubic models to the data in the concerned states, and are depicted 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 wheat production in selected states of India

Year	*Production (in million tons) for the states		
	S1	S2	S3
2011	30.29	12.68	4.79
2012	30.30	11.12	5.36
2013	30.25	11.80	5.08
2014	22.42	10.35	3.99
2015	25.43	11.35	4.74
2016	30.06	11.55	5.11
2017	31.88	11.16	5.74
2018	32.74	12.57	6.47
2019	33.82	11.88	5.58
2020	35.50	12.36	6.34

*(*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	30.29	27.08	29.91	31.80
2012	30.30	27.79	30.61	28.49
2013	30.25	28.50	31.32	26.84
2014	22.42	29.21	32.05	26.54
2015	25.43	29.91	32.80	27.27
2016	30.06	30.62	33.57	28.72
2017	31.88	31.33	34.35	30.59
2018	32.74	32.04	35.16	32.56
2019	33.82	32.75	35.98	34.32
2020	35.50	33.46	36.82	35.56

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)	Cubic model (C_t)
2011	12.68	11.44	10.90	12.54
2012	11.12	11.49	10.95	11.60
2013	11.80	11.55	11.00	11.11
2014	10.35	11.60	11.05	10.96
2015	11.35	11.66	11.11	11.07
2016	11.55	11.71	11.16	11.34
2017	11.16	11.76	11.21	11.69
2018	12.57	11.82	11.27	12.02
2019	11.88	11.87	11.32	12.23
2020	12.36	11.93	11.38	12.25

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	4.79	4.55	5.31	5.16
2012	5.36	4.72	5.47	4.78
2013	5.08	4.89	5.65	4.65
2014	3.99	5.06	5.83	4.71
2015	4.74	5.24	6.02	4.91
2016	5.11	5.41	6.21	5.21
2017	5.74	5.58	6.41	5.55
2018	6.47	5.75	6.61	5.87
2019	5.58	5.92	6.82	6.12
2020	6.34	6.09	7.04	6.25

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

State	Linear model	Exponential model	Cubic model
S1	$y_t = 29.914 + 0.709\,t$	$y_t = 2\text{E} - 19e^{0.0231\,t}$	$y_t = 27.265 + 1.144\text{ t} + 0.362\,t^2 - 0.052\,t^3$
S2	$y_t = 11.655 + 0.054\,t$	$y_t = 7\text{E} - 4e^{0.0048\,t}$	$y_t = 11.068 + 0.207\text{ t} + 0.083\,t^2 - 0.015\,t^3$
S3	$y_t = 5.235 + 0.170\,t$	$y_t = 2\text{E} - 27e^{0.0314\,t}$	$y_t = 4.913 + 0.260\text{ t} + 0.046\,t^2 - 0.009\,t^3$

In Tables 2, 3 and 4, the term 'y_t' denotes the observed value of wheat production (in million **tons**) for the year 't' ($t = 2011,\ 2012,\ \ldots\ , 2020$). Moreover, '$L_t$' denotes the linear trend value of wheat production for the year 't'. In a similar manner, 'E_t' denotes the exponential trend value of wheat production, and 'C_t' denotes the cubic trend value of wheat production.

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

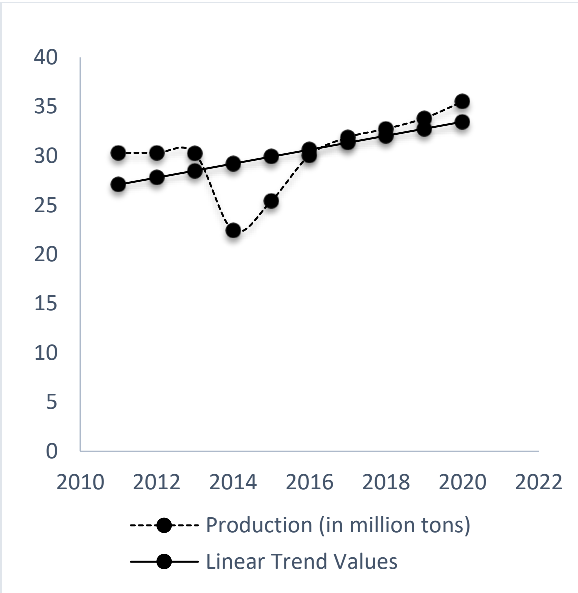

Fig. 1. Trend values for linear model in state S1

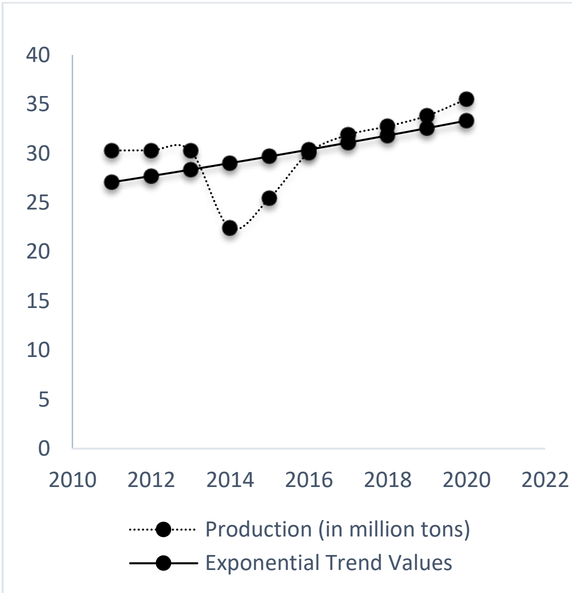

Fig. 2. Trend values for exponential model in state S1

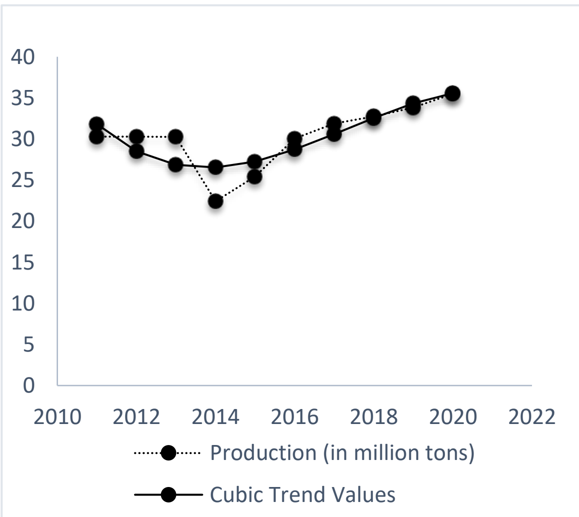

Fig. 3. Trend values for cubic model in state S1

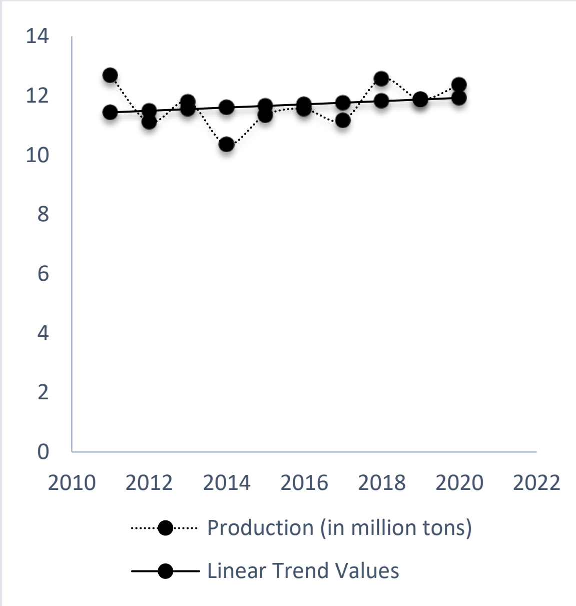

Fig. 4. Trend values for linear model in state S2

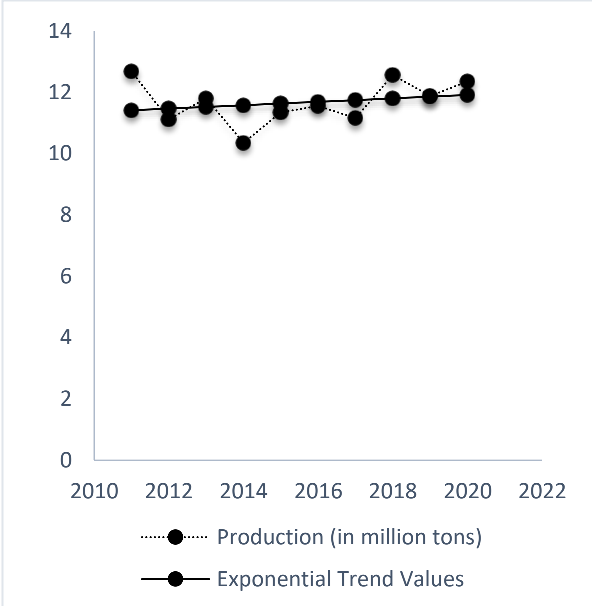

Fig. 5. Trend values for exponential model in state S2

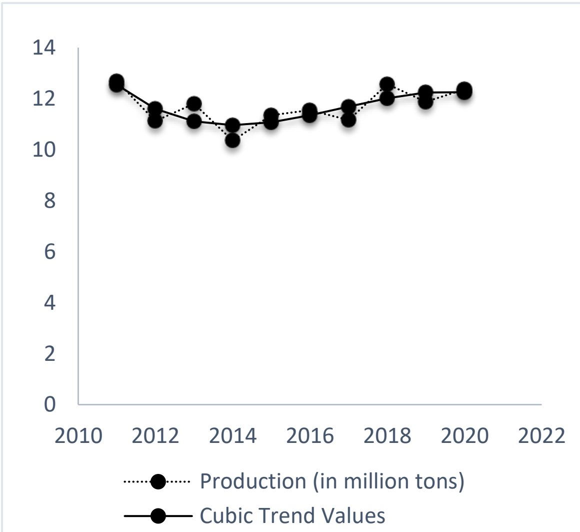

Fig. 6. Trend values for cubic model in state S2

In order to test the suitability of various fitted models, the statistical measures, viz. coefficient of determination (R^2), root mean square error (RMSE) and relative mean absolute percentage error (RMAPE) are computed for the selected states on 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 wheat 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.

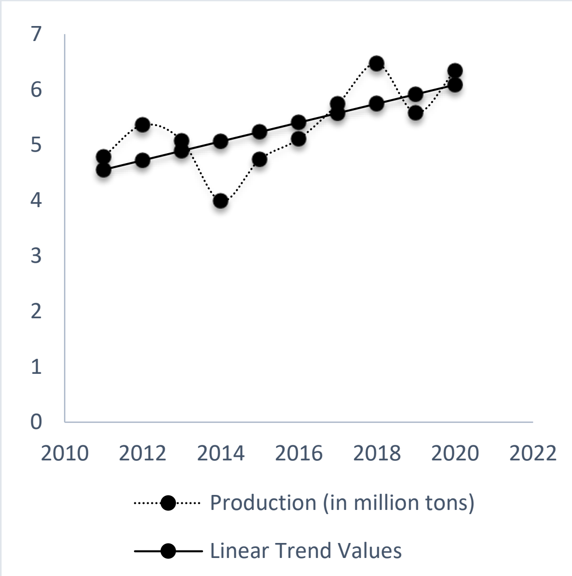

Fig. 7. Trend values for linear model in state S3

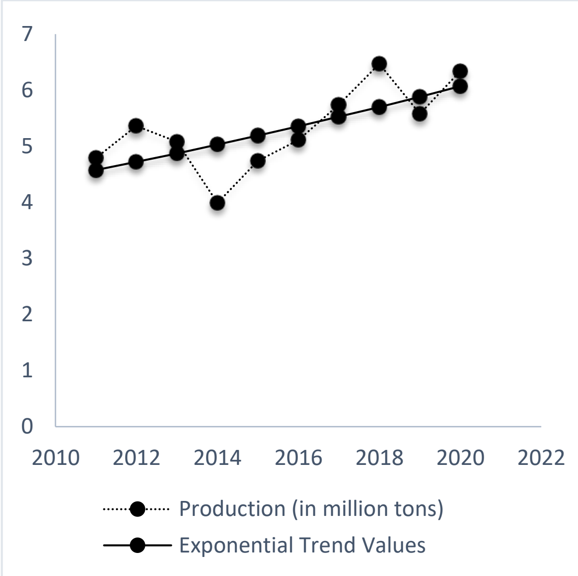

Fig. 8. Trend values for exponential model in state S3

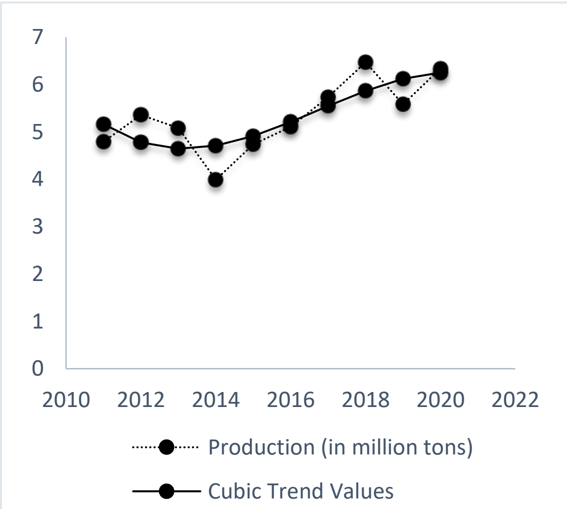

Fig. 9. Trend values for cubic model in state S3

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

State	Model	R^2	RMSE	RMAPE
S1	Linear	0.31	3.04	8.72
	Exponential	0.33	3.00	8.79
	Cubic	0.69	2.03	5.85
S2	Linear	0.05	0.67	4.64
	Exponential	0.05	0.67	4.62
	Cubic	0.59	0.44	3.45
S3	Linear	0.47	0.52	8.77
	Exponential	0.49	0.51	8.60
	Cubic	0.62	0.44	7.46

The values of R^2, RMSE and RMAPE for the concerned states are obtained on fitting linear, exponential and cubic models, and are presented in Table 6.

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 both linear and exponential models in each state.
(ii) In each of the three states S1, S2 and S3, we observe that $R^2 > 0.5$ for the cubic model, whereas $R^2 < 0.5$ for the linear and exponential models. Hence, among all the three models, cubic model is the best fitted model.
(iii) In each state, the values of RMSE are least for cubic model as compared to the linear and exponential models. Furthermore, the values of RMSE are nearly the same for both the linear and exponential models.
(iv) In each state, the values of RMAPE are least for cubic model as compared to the linear and exponential models. Also, the values of RMAPE are approximately the same for both the linear and exponential models.

Since the cubic model attains the least values of RMSE and RMAPE in each state, hence the cubic model is more precise, as compared to the linear and exponential models, for exploring the trends of wheat production in the concerned states.

3.1 Formulation of Hypotheses

We test the following null hypotheses:

H_{0L}: Linear model fits the data on wheat production.
H_{0E}: Exponential model fits the data on wheat production.
H_{0C}: Cubic model fits the data on wheat production.

against the following respective alternative hypotheses:

H_{1L}: Linear model does not fit the data on wheat production.
H_{1E}: Exponential model does not fit the data on wheat production.
H_{1C}: Cubic model does not fit the data on wheat production.

The above mentioned hypotheses for model fitting on wheat production are tested using the chi-square test statistic in the concerned states S1, S2 and S3 of India.

3.2 Hypotheses Testing and Validation

The chi-square values have been computed for the linear, exponential and cubic models (i.e., χ_L^2, χ_E^2 and χ_C^2 respectively) in the concerned states of India, and the findings are depicted in Table 7. The chi-square values, on fitting the concerned models, have been obtained 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' are obtained from Tables 2, 3 and 4, for the concerned states S1, S2 and S3 of India.

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

State	Chi-square values		
	Linear model (χ_L^2)	Exponential model (χ_E^2)	Cubic model (χ_C^2)
S1	3.1593	3.1048	1.5069
S2	0.3921	0.3925	0.1704
S3	0.5216	0.5087	0.3733

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

$\chi^2_{0.01,9} = 21.67$ and $\chi^2_{0.05,9} = 16.92$

From Table 7, the following results are obtained:

(i) $\chi^2_{L(S_i)} < \chi^2_{0.01,9}$ and $\chi^2_{L(S_i)} < \chi^2_{0.05,9}$ $(i = 1, 2, 3)$
(ii) $\chi^2_{E(S_i)} < \chi^2_{0.01,9}$ and $\chi^2_{E(S_i)} < \chi^2_{0.05,9}$ $(i = 1, 2, 3)$
(iii) $\chi^2_{C(S_i)} < \chi^2_{0.01,9}$ and $\chi^2_{C(S_i)} < \chi^2_{0.05,9}$ $(i = 1, 2, 3)$

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 time series data on wheat production in the concerned states S1, S2 and S3 of India.

4. CONCLUSION

The present paper deals with time series analysis of wheat production in some selected states of India, viz. S1 (Uttar Pradesh), S2 (Haryana), and S3 (Bihar). The secondary time series data on wheat production pertaining to the period (2011-2020) have been utilized for the analysis. The growth and trend pattern of wheat production have been examined by fitting some well-known statistical models, viz. linear model, exponential model and cubic model to the time series data in the concerned states. The states S1 and S3 exhibit slight increase in growth pattern of wheat production, whereas the state S2 reveals a constant growth pattern of wheat production. Moreover, the production of wheat in the state S1 remains the highest, as compared to the states S2 and S3, during the concerned period.

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., χ^2_L, χ^2_E and χ^2_C) 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 time series data on wheat production in the respective states during the concerned period. Hence, the above mentioned models could be effectively utilized for forecasting of future trend of wheat production in the concerned states. Moreover, it has been observed from the results of Table 6 that the cubic model is slightly more appropriate, as compared to the linear and exponential models, for exploring the trends of wheat production in the concerned states.

The present study could be enhanced further by considering the scenario of wheat production in other states of India. Moreover, considering the benefits and usefulness of wheat, the potential farmers could be encouraged for its cultivation.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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