TRENDS IN AREA, PRODUCTION, AND PRODUCTIVITY OF COFFEE IN CHIKKAMAGALURU DISTRICT OF KARNATAKA

ABSTRACT

Coffee is a significant commodity crop worldwide, and Karnataka, an Indian state with coffee-growing regions such as Chikkamagaluru, Kodagu, and Hassan, is a major producer. Chikkamagaluru, also known as the Coffee Land of Karnataka, is the primary location for Arabica coffee production and cultivation of various other spice crops such as areca nut, pepper, cardamom, vanilla, lime, clove, and cinnamon. Despite the importance of coffee production, coffee growers encounter multiple challenges in cultivating and yielding high-quality coffee. Therefore, researchers have explored issues associated with coffee production and yield and suggested feasible solutions. To make informed decisions, it is essential to analyze the productivity and production of the coffee-growing region. This study used 25 years of coffee time series data obtained from the Coffee Board of India, Bengaluru, from 1995-1996 to 2019-2020, to investigate the coffee-growing region's problems. The data was analyzed using linear (linear, cubic) and nonlinear (exponential, logistic, and Gompertz) growth models. The results showed that the cubic model provided the best fit for the Chikkamagaluru district's coffee-growing region. Meanwhile, the linear and Gompertz models were the best fit for coffee output and productivity, respectively. The study revealed a decrease in Chikkamagaluru coffee productivity over the study period, despite an increase in the coffee-growing area.

Keywords: Growth, Trend, Run Test, Shapiro-Wilk’s test, Linear and Non-linear models

INTRODUCTION

Coffee is a highly prized global commodity crop that significantly impacts the economies of over 50 countries, especially in Asia, Latin America, and Africa. It is an internationally traded commodity alongside petroleum. In addition to being a major contributor to foreign exchange earnings, coffee cultivation significantly affects the socio-economic status of millions of individuals in numerous developing countries. India cultivates coffee on a total area of 459,730 hectares, with Arabica and Robusta accounting for 50.7% and 49.3% of the cultivated land, respectively.

Coffee, a member of the Rubiaceae plant family according to botany, is cultivated in India under a silvi-horti cropping system, where it is grown in the shade of a two-tiered mixed canopy of evergreen leguminous trees to maximize productivity. The Coffea genus, which includes around 70 commercially cultivated species, is primarily native to Africa. In India, two species of Coffea, Coffea arabica and Coffea canephora, are commonly grown, with Coffea liberica being a less frequent crop. Coffee is often intercropped with cardamom, orange, and pepper to generate additional revenue. Annual crops such as ginger, turmeric, brinjal, pineapple, chilies, cowpea, beans, and horse gram may also be planted as intercrops during the early stages of coffee plant growth to supplement income. Although intercropping has advantages such as weed suppression, it may also compete with coffee for moisture and nutrients. India is renowned for producing some of the world's finest shade-grown coffees, which have a rich, exotic flavor and a pleasant aroma due to the mixed shade canopy. Karnataka, Tamil Nadu, Kerala, and Andhra Pradesh are the primary producers of coffee in India, with other states such as West Bengal, Sikkim, Orissa, Manipur, Mizoram, Meghalaya, Nagaland, Madhya Pradesh, Tripura, Assam, and Arunachal Pradesh also cultivating the crop to a lesser extent. Summer rains in March and April are critical for coffee flowering, while coffee is also grown during the predominant North-East monsoons in states such as Tamil Nadu, Andhra Pradesh, and Orissa.

Coffee is predominantly cultivated in three Indian states, namely Karnataka, Tamil Nadu, and Kerala. Karnataka is the largest producer of coffee, contributing 71.03% to the nation's total output, while Kerala and Tamil Nadu contribute 20.46% and 6.68%, respectively. Coffee cultivation is limited to three districts in Karnataka, namely Chikkamagaluru, Kodagu, and Hassan. These districts produce 33.71%, 52.68%, and 13.60% of the state's coffee, respectively, and account for 38.54%, 44.96%, and 16.49% of the region. As of 2019-20, the coffee plantations in Karnataka employed an average of 516,776 individuals, with 51.11% in Kodagu, 28.55% in Chikkamagaluru, and 20.28% in Hassan.

Based on the distribution of coffee plantations in different districts, Kodagu has the highest cultivation of Robusta, while Chikkamagaluru, which also grows areca nut, pepper, cardamom, vanilla, lime, clove, cinnamon, and other spice crops, has the majority of Arabica cultivation (Garde et al., 2021; Singh et al., 2021; Ray and Bhattacharyya, 2016). Silver oak trees are abundant in all of these plantations. Coffee production and yield face various challenges, prompting researchers to investigate and suggest appropriate solutions (Panchali and Prabakaran, 2017; Parmar et al., 2018; Parmar et al., 2016). Given the importance of coffee to the state's economy, this study aims to provide a detailed analysis of the expansion, trend, area, output, and productivity of coffee.

MATERIALS AND METHODS

This study utilizes secondary data on the area, production, and productivity of coffee in the Chikkamagaluru district. The data covers a 25-year time series, spanning from 1995-96 to 2019-20, and was obtained from the Coffee Board of India in Bengaluru.

Analytical tools and techniques applied

The rate of growth analysis is a method that evaluates the long-term trends in a time series by measuring the changes that have occurred as a result of its tendency to increase or decrease over time while ignoring short-term fluctuations. To estimate the long-term trend of coffee acreage, production, and productivity, the least squares estimation approach is typically used, which involves developing a mathematical relationship between the response variable and the trend in time. Many previous studies have used this method and expressed it using a mathematical expression, including Ajay and Sisodia (2018), Arun and Gupta (2020), Dhekale et al. (2014), Dinesh et al. (2018), Gomathi et al. (2019), and Ishfaq (2019). The following can be used to represent the mathematical expression:

1. Linear (Straight line) model

$$Y_t = \alpha + \beta t + \varepsilon \qquad \text{... [1]}$$

2. Cubic model

$$Y_t = \alpha + \beta t + \gamma t^2 + kt^3 + \varepsilon \qquad \text{... [2]}$$

where, α: Intercept or Average effect, β, γ and k: Slope or Regression Coefficients, Y_t: Area, production or productivity of coffee in time period t and ε: Error term.

Coefficients α, β, γ and k are parameters which are to be estimated. The relationship between the response variable and the time period is thought to be linear or curved in the models mentioned above. However, the actual data seen in nature may not conform to the assumptions of linearity, curvilinearity, or exponential functional shape (Mohankumar, 2012a, 2012b and 2012c). In order to describe the long-term trend in variables over time in different agricultural crops, growth rate analysis is also frequently used. Most growth models are "mechanistic," and the parameters have biologically relevant interpretations (Prajneshu and Das, 2000).

The following are some of the important nonlinear growth models, which are generally used to describe the growth in time-series data.

1. Exponential model

$$Y_t = \alpha\beta^t + \varepsilon \qquad \text{... [3]}$$

2. Logistic model

$$Y_t = \frac{\alpha}{1 + \beta\ exp(-kt)} + \varepsilon;\ \beta = \frac{\alpha}{Y_0} - 1 \qquad \text{... [4]}$$

3. Gompertz model

$$Y_t = \alpha\, exp(-\beta\, exp(-kt)) + \varepsilon;\ \beta = ln\left(\frac{\alpha}{Y_0}\right) \qquad \text{... [5]}$$

where, Y_t represents area, production or productivity of Coffee in time period *t*. α, β and k are parameters and ε denotes the error term.The parameter 'k' is the 'intrinsic growth rate', while the parameter 'α' represents the 'carrying capacity or yield ceiling'. For the third parameter, although the same symbol 'β' was used, yet this represented different functions of the initial value $Y_0$for different models (Khan *et al.*, 2013; Mehazabeen and Srinivasan, 2019; Selvi *et al.*, 2015).

Following the estimation of the model's parameters, a diagnostic analysis of the residuals from the fitted models is required to look for any violations of the fundamental assumptions of "residual independence" and "residual normality". The Run-test and Shapiro-Wilk tests, respectively, were used to evaluate the central hypotheses of "independence of residuals" and "normality of residuals" (Prajneshu and Das, 2000).

Test for independence (randomness) of residuals by Run Test

Non-parametric Run test is used to test the randomness of residuals.

H_0: The sequence of residuals is random

H_1: The sequence of residuals is not random

Test for normality of residuals by Shapiro-Wilk's (W) test

This is the standard test for normality. The values of W range from 0 to 1. When W=1 the given data are perfectly normal in distribution. When W is significantly smaller than 1, the assumption of normality is not met (Shapiro *et al*., 1968).

H_0: Samples follow normal distribution.

H_1: Samples do not follow normal distribution.

Test statistic is given by:

$$W = \frac{\left[\sum_{i-1}^{n} a_i x_{(i)}\right]^2}{\sum_{i-1}^{n}(x-\bar{x})^2}$$

where, $x_{(i)}$ is the i^{th} order statistic; $\bar{x}$ - sample mean and a_i is

$$(a_1, a_2, \cdots, a_n) = \frac{m^T V^{-1}}{\sqrt{(m^T V^{-1} V^{-1} m)}}$$

To test the goodness of fit of the models

Mean Absolute Percentage Error (MAPE)

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Y_t - \hat{Y}_t}{Y_t}\right| X\,100$$

where, Y_t= Actual values, $\hat{Y}_t$= Predicted values and n= number of observations

RESULTS AND DISCUSSION

The current study utilized annual data on the area, production, and productivity of Coffee crops in Karnataka for a period of 25 years, from 1995-96 to 2019-20. The data were used to construct both linear models, such as linear and cubic models, and nonlinear growth models, such as exponential, logistic, and Gompertz models, to estimate the trend in the aforementioned variables. The findings of the analysis are presented in the subsequent sections.

Area under Coffee

Table 1 presents the parameter estimates and their standard errors (in parentheses) for the models fitted to estimate the trend in the area under coffee. The results also include the probability values obtained from the Run-test and Shapiro-Wilk test, which were used to test the randomness and normality assumptions of the residuals. The findings indicated that the parameters of the linear, cubic, exponential, logistic, and Gompertz models were significant. Moreover, the number of runs and Shapiro-Wilk test statistic were non-significant for all the fitted models, suggesting that the assumptions of randomness and normal distribution of residuals were met. The models with significant parameters and met assumptions of independence and normality of residuals were considered well-fitted models. Based on the results, the linear and cubic models were found to be well-suited for estimating the trend in the area under coffee during the study period.

Coffee production

Table 2 presents the parameter estimates and their standard errors (in parenthesis) of all the fitted models for coffee production. The findings revealed that only the linear and exponential models had significant parameters, while some of the parameters of other models, including cubic, logistic, and Gompertz models, were non-significant. The results also indicated that the number of runs and Shapiro-Wilk test statistic were non-significant for the linear, cubic, exponential, logistic, and Gompertz models. Hence, the linear and exponential models were considered well-fitted to the coffee production data during the study period.

Table 1: Parameter estimates and goodness of fit criteria of different models for Area ('000 ha) under Coffee in Chikkamagaluru district for the period from 1995-96 to 2019-20

Parameter	Models				
	Linear	**Cubic**	**Exponential**	**Logistic**	**Gompertz**
α	72.77* (2.09)	59.92* (1.94)	73.76* (2.01)	91.99* (1.19)	92.35* (1.28)
β	1.09* (0.14)	6.64* (0.71)	0.01* (0.001)	-2.22* (0.76)	0.42* (0.04)
γ	-	-0.49* (0.07)	-	3.47* (0.65)	0.78* (0.037)

k	-	0.01* (0.001)	-	-	-
Test for randomness, normality of residuals and goodness of fit criteria					
Runs test (*Z*)	-3.33^{NS}	-2.08^{NS}	-3.33^{NS}	-3.33^{NS}	-3.33^{NS}
(*p* –value)	[0.08]	[0.06]	[0.08]	[0.08]	[0.08]
Shapiro-Wilk (*W*)	0.93^{NS}	0.92^{NS}	0.91^{NS}	0.87^{NS}	0.89^{NS}
(*p* –value)	[0.09]	[0.07]	[0.08]	[0.07]	[0.08]

Note: * Significant at 5 per cent, NS: Not Significant; Values in (.) indicate standard error; Values in [.] indicate Probability values.

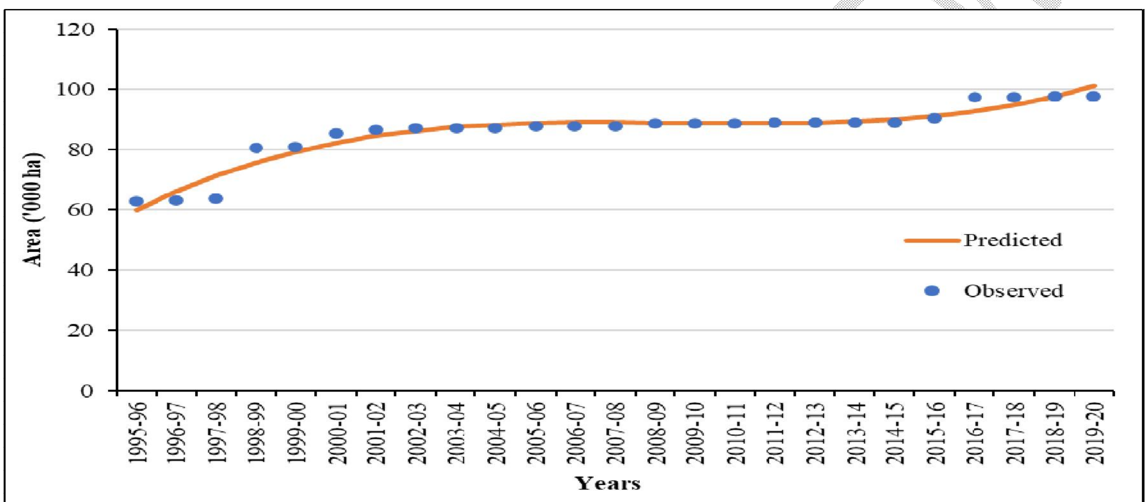

Fig. 1: Observed and predicted values of Area under Coffee in Chikkamagaluru district by Cubic model for the period from 1995-96 to 2019-20

Table 2: Parameter estimates and goodness of fit criteria of different models for Production ('000 MT) of Coffee in Chikkamagaluru district for the period from 1995-96 to 2019-20

Parameter	**Models**				
	Linear	**Cubic**	**Exponential**	**Logistic**	**Gompertz**
α	65.21* (2.44)	59.30* (4.28)	65.48* (2.36)	73.24* (1.52)	73.31* (1.58)
β	0.48* (0.17)	2.75^{NS} (1.57)	0.006* (0.002)	-2.82^{NS} (2.21)	0.26* (0.08)

γ	-	-0.18^{NS} (0.15)	-	2.41^{NS} (1.37)	0.69^{NS} (0.14)
k	-	0.004^{NS} (0.004)	-	-	-
Test for randomness, normality of residuals and goodness of fit criteria					
Runs test (Z)	-0.83^{NS}	-1.25^{NS}	-0.83^{NS}	-1.25^{NS}	-1.25^{NS}
(p –value)	[0.40]	[0.21]	[0.40]	[0.21]	[0.21]
Shapiro-Wilk (W)	0.97^{NS}	0.95^{NS}	0.97^{NS}	0.94^{NS}	0.94^{NS}
(p –value)	[0.84]	[0.37]	[0.84]	[0.17]	[0.17]

Note: * Significant at 5 per cent, NS: Not Significant; Values in (.) indicate standard error; Values in [.] indicate Probability values

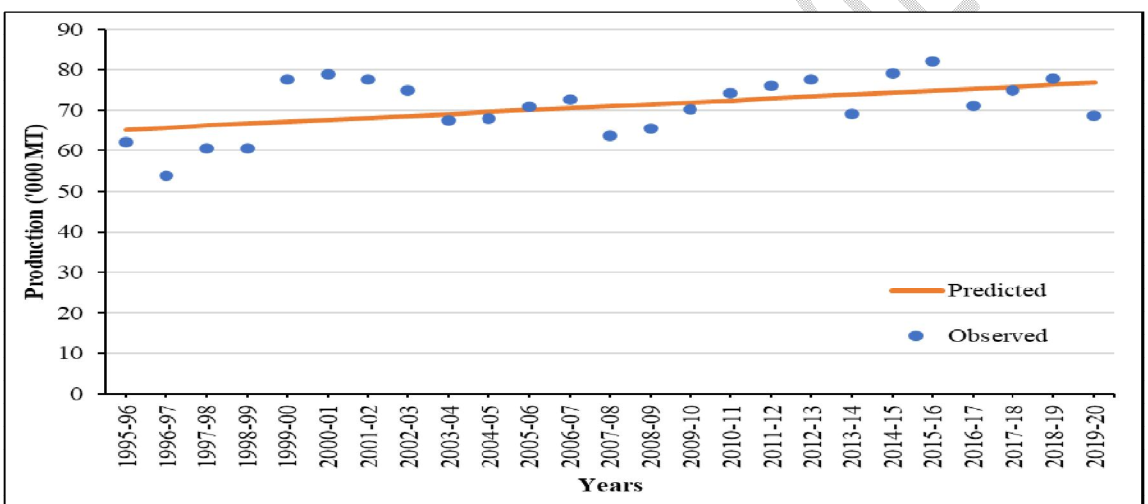

Fig. 2: Observed and predicted values of Production of Coffee in Chikkamagaluru district by linear model for the period from 1995-96 to 2019-20.

Coffee productivity

Table 3 presents the parameter estimates and their standard errors (given in parentheses) for the fitted models of Coffee productivity using the data from 1995-96 to 2019-20 in Karnataka. The results showed that the parameters of the linear, exponential, and Gompertz models were significant, while the parameters of the cubic and logistic models were non-significant. Moreover, the number of runs and Shapiro-Wilk test statistic for all fitted models were non-significant (p-value > 0.05), indicating that the assumptions of randomness and normal distribution of residuals were met. Only models that had significant parameters and satisfied the assumptions of independence and normality of residuals were considered well-fitted models. Therefore, the linear, exponential, and Gompertz models were well-suited for analysing the productivity of Coffee during the study period.

Table 3: Parameter estimates and goodness of fit criteria by different models for Productivity (Kg/ha) of Coffee in Chikkamagaluru district for the period from 1995-96 to 2019-20

Parameter	Models				
	Linear	**Cubic**	**Exponential**	**Logistic**	**Gompertz**
α	895.63* (27.17)	969.34* (46.71)	898.21* (28.10)	828.56* (24.80)	791.78* (32.29)
β	-5.39* (1.94)	-38.61* (17.20)	-0.006* (0.002)	-0.002^{NS} (0.002)	-0.18* (0.05)
γ	-	3.08^{NS} (0.001)	-	0.08^{NS} (0.01)	0.84* (0.11)
k	-	-0.07^{NS} (0.04)	-	-	-
Test for randomness, normality of residuals and goodness of fit criteria					
Runs test (*Z*)	-0.41^{NS}	-0.41^{NS}	-0.41^{NS}	-0.45^{NS}	-0.41^{NS}
(*p* –value)	[0.67]	[0.67]	[0.67]	[0.69]	[0.67]
Shapiro-Wilk (*W*)	0.97^{NS}	0.97^{NS}	0.97^{NS}	0.94^{NS}	0.97^{NS}
(*p* –value)	[0.74]	[0.67]	[0.78]	[0.75]	[0.65]

Note: * Significant at 5 per cent, NS: Not Significant; Values in (.) indicate standard error; Values in [.] indicate Probability values

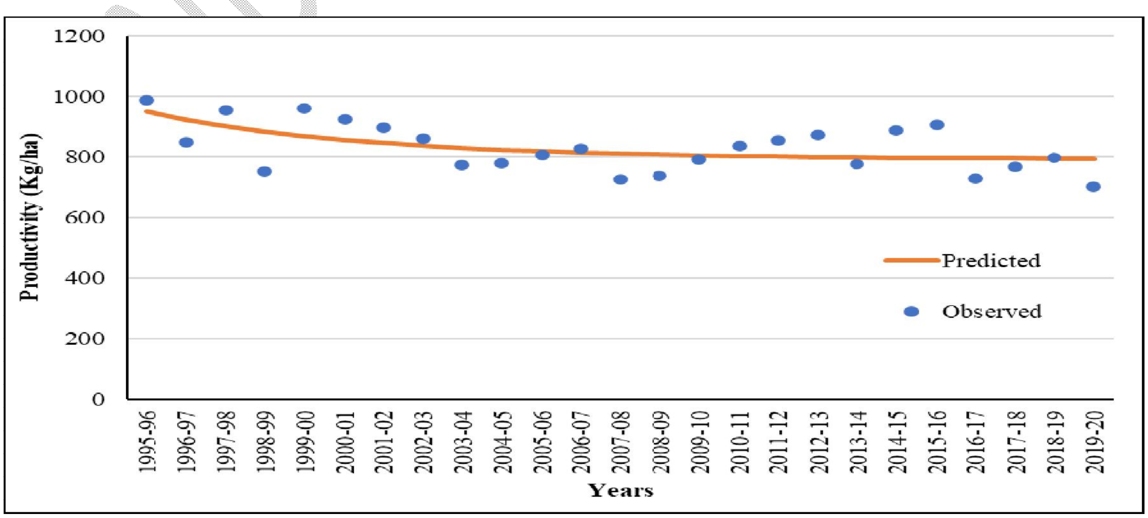

Fig. 3: Observed and predicted values of Productivity of Coffee in Chikkamagaluru district by Gompertz model for the period from 1995-96 to 2019-20.

CONCLUSION

The study utilized two linear and three non-linear models to examine the growth and trend of the coffee crop in Karnataka in terms of area, production, and productivity. Among the models fitted, the cubic model was found to be the best fit for the area under coffee in the Chikkamagaluru district. Meanwhile, the linear and Gompertz models provided the best fit for coffee production and productivity in the same district. The results of the study revealed a decreasing trend in Chikkamagaluru coffee production over the study period, while the area planted with coffee in the district increased.

REFERENCES

Ajay, K. G. and Sisodia, B. V. S., 2018, Analysis of trend and growth rate of wheat crop and forecast of its production in Uttar Pradesh. *J. Pharmacogn. Phytochemical.,* **7**(5): 3306-3310.

Arun, K. and Gupta, R. K., 2020, Forecasting the production and area of mango in Himachal Pradesh by using different statistical models. *International Journal of Bio-resource and Stress Management*, **11**(1): 14-19.

Dhekale, B. S., Mahdi, S. S., Garde, Y. A. and Sahu, P. K., 2014, Parametric and nonparametric regression models for area, production and productivity trends of rice (oriza sativa) crop. *Int. J. Agric. Stat.,* **10**(1): 211-216.

Dinesh, K. P., Bishvajit, B. and Manjunath, V., 2018, Nonlinear modeling of area and production of sugarcane in Tamil Nadu. *Int. J. Curr. Microbiol. App. Sci.*, **7**(10): 3136- 3146.

Garde, Y., Chavda, R., Thorat, S., and Pisal, R., 2021. Forecasting of area, productivity and prices of mango in Navsari district, Gujarat. *J. Crop Weed*, **17**(3): 17-28.

Gomathi, T., Vasanthi, R., Padmarani, S., Patil, S. G. and Kalpana, M., 2019, Statistical analysis of area and production of banana in Trichy district. *Int. J. Chem. Stud.,* **7**(3): 2544-2547.

Ishfaq, A. S., 2019, Trend analysis of area, production and productivity of apple fruit in Jammu and Kashmir. *J. Gujarat Res. Society*, **15**(21): 601-611.

Khan, Shaista, Bhardwaj, R. K., Sexena, R. R., Bhagat, R. K. and Jatav, G. K., 2013, Non-linear statistical modeling for area, production and productivity of rice crop in Chhattisgarh. *Asian J. Soil Sci*., **8**(1): 98-102.

Mehazabeen, A. and Srinivasan, G., 2019, A study on area, production and productivity of banana in Y.S.R. district of Andhra Pradesh. *Int. J. Res. Anal. Rev*.,**6**(2): 1-6.

Mohan Kumar, T.L., Sathishgowda, C.S., Darshan, and M.B. Andsheelarani, S., 2012b, Coffee production modelling in India using nonlinear statistical growth models. *Agric. Update*, **7**(1&2): 63-67.

Mohankumar, T. L., Darshan, M. B., Sathishgowda, C. S. and Sheelarani, S., 2012a, Comparison of nonlinear statistical growth models for describing coffee export trend in India, *Asian J. Hort*., **7**(1): 31-35.

Mohankumar, T. L., Sathishgowda, C. S., Munirajappa, R. and Surendra, H. S., 2012c, Nonlinear statistical growth models for describing trends in area under coffee production in India. *Mysore J. Agric. Sci.,* **46** (4): 745-750.

Panchali, M. S. and Prabakaran, 2017, Linear and non-linear models on paddy crop in different agro climatic zones of Tamil Nadu. *Int. J. Stat. Appl. Math.*,**2**(6): 277-281.

Parmar, R. S., Bhojani, S. H. and Chaudhari, G. B., 2018, Application of regression models for area, production and productivity trend of maize crop for Panchmahal region of Gujarat state. *Int. J. Trend in Sci. Res. Dev*., **4**(1): 1-5.

Parmar, R.S., Rajarathinam, A., Patel, H.K. and Patel, K.V., 2016, Statistical modeling on area, production and productivity of cotton crop for Ahmedabad region of Gujarat state. *J. Pure. Appl. Microbiol*., **10**(1): 751-759.

Prajneshu and Das, P. K., 2000, Growth models for describing state-wise wheat productivity. *Indian J. Agric. Res.*, **34**(3):179-181.

Ray, S., and Bhattacharyya, B., 2016. A statistical investigation on analysis of food consumption pattern in India. *J. Crop Weed,* **12**: 47-54.

Selvi, R. P., Muraligopal, S., Vasanthi, R. and Swaminathan, B., 2015, Statistical analysis of trend in the maize area, production and productivity in India. *Ann. Plant and Soil Res.*, **17**: 233-237.

Shapiro, S. S., Wilk, M. B. and Chen, H. J., 1968. A comparative study of various tests for normality. *J. Amer. Stat. Assoc.,* **63**(324): 1343-1372.

Singh, B., Arya, K., and Sharma, K., 2021. Statistical analysis for trend and change point detection of sugarcane production in India. *J. Crop Weed,* **17**(2): 170-176.

Yasmeena, I., Mir, S. A., Nageena, N., Wani, M. H. and Pukhta, M. S., 2019, Trend analysis of area, production and productivity of cherry in Jammu and Kashmir. *Int. J. Curr. Microbiol. App. Sci.,***8**(2): 2135-2144.