Current Journal of Applied Science and Technology

Volume 42, Issue 15, Page 12-17, 2023; Article no.CJAST.100163
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Forecasting of Productivity of Pulse Crops in India: A Nonlinear Approach

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Authors' contributions

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

Article Information

DOI: 10.9734/CJAST/2023/v42i154122

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/100163

Original Research Article

Received: 01/04/2023
Accepted: 02/06/2023
Published: 15/06/2023

ABSTRACT

India is the world's top producer and consumer of pulse crops. Pulse crops are an essential source of protein, providing amino acids, vitamins, and minerals to supplement diets. These contain 22-24 percent protein, about twice as much as wheat. This research uses a non-linear growth approach to conduct an analytical evaluation of total pulse productivity in India from 1949-2020. For total pulse productivity in India, four different non-linear growth models were fitted: Logistic, Gompertz, Monomolecular, and Von Bertalanffy. Goodness of fit statistics such as Coefficient of determination, Root Mean Square Error, Mean Absolute Error, and Mean Absolute Percentage Error were used to choose the best model. The Logistic model was determined to be the best fit for productivity of total pulse crops grown in India, followed by the Gompertz model. Finally, the Logistic and Gompertz models were used to forecast India's total pulse productivity from 2020-21 to 2025-26.

Keywords: Gompertz; logistic; monomolecular; non-linear growth model; von bertalanffy.

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1. INTRODUCTION

In India, pulse crops are the main source of nutrition. Pulses provide high-quality protein and roughage to a country with a large vegetarian population. Pulses are annual leguminous crops that produce 1-12 grains or seeds of various sizes, shapes, and color within a pod for use as food and forage. The term "pulses" refers to crops farmed solely for dry grain, which excludes vegetable crops as well as crops used primarily for oil extraction. India is the world's leading producer, consumer, and trader of pulses. Pulses are grown in both the Kharif and Rabi seasons, however Rabi pulses account for more than 60% of overall production. Between 1950 and 2018, India's pulse production climbed from roughly 8.4 million tonnes to 25.2 million tonnes. Pulses are the primary source of proteins that have been shown to lessen the risk of diseases including colon cancer and heart disease [1]. Pulses are the primary source of protein in the Indian diet, and their demand is steadily increasing due to the rising population and affluence [2]. Pulses' net availability has decreased from 60 to 30 g/day/person between 1951 and 2014. Therefore, to meet the demand of pulses, India will require a continuous high growth in productivity.

Nonlinear growth models have been widely utilized to assess agricultural patterns in terms of rate of increase (Joshi and Saxena, 2002; Sarma, 2005; Rajarathinam *et al*., 2010). Pal and Mazumdar [3] investigated various nonlinear growth models, including Monomolecular, Logistic, and Gompertz models, to predict India's total groundnut production from 1950 to 2012. Based on multiple goodness of fit measures, Monomolecular and Logistic models outperformed Gompertz for their dataset. The best fitted model was used to forecast India's total groundnut production for 2014-20. Mata-Estrada et al., [4] compared the Gompertz-Laird, Logistic, Richards, and Von Bertalanffy growth models to examine the best fitted model on the data of Creole chickens. Analysis has been done using PROC NLIN to fit the non-linear growth curve. The Akaike information criteria, Bayesian information criteria and Coefficient of determination were used for the comparison of the goodness of fit of the models. The Von Bertalanffy was the best model for explaining growth of the birds. In contrast, both the Gompertz-Laird and Logistic models overestimated hatching BW and underestimated the final BW of CC. Rajan and Palanivel [5] compared the goodness of fit of 6 non-linear growth models for cotton area, production and productivity data in India collected during 1982-2013. They found that Gompertz, Quadratic and Reciprocal are best fitted model. Panwar et al., [6] used a non-linear technique to examine at wheat yield in Uttar Pradesh. From 1970 to 2010, time series data on yearly wheat yields in Uttar Pradesh were gathered from a variety of sources. Non -linear models such as Logistic, Gompertz, and Monomolecular models are used to calculate growth rates. To estimate non-linear growth rates, several non-linear processes were employed, including the Steepest Descent Method, Gauss Newton Method, Do Not Use Derivative Method, and Levenberg Merquadt Technique. They observed that the Logistic model outperformed the Gompertz and Monomolecular models. Using statistical tools and approaches ranging from graphs, charts, and diagrams to regression and time series analysis, a variety of research have been started to understand the growing trend of pulse crops in India.

2. MATERIALS AND METHODS

The proposed research examined at the growth pattern of total pulse productivity in India from 1949 to 2020. Indiastat.com has been used to obtain secondary data on total pulse crops. For estimating the growth in productivity of pulses, the study compared distinct non-linear growth models, such as Logistic, Gompertz, Monomolecular, and Von Bertalanffy. Selection criteria such as R^2, Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE) were used to determine the best fitted model.

2.1 Linear and Non-Linear Models

The response of a linear model is proportional to the explanatory variables. All of the parameters in such models have a linear relationship. A non-linear model, on the other hand, is one in which the linear relationship for at least one of the parameters does not hold. Consider the following equations:

$$y = a + b \quad (1)$$

$$y = a + b * t + c * t^2 \quad (2)$$

Characterizes a linear model, whereas equation:

$$y = y_0 * \exp(-a * t) \quad (3)$$

Represents a non-linear model. Two types of non-linear models are found in practice. The following are the equations:

$$y = \exp\,(\mathrm{a} + \mathrm{b} * \mathrm{t}^2) \quad (4)$$

and

$$y = \exp(-b * t) - \exp\,(-a * t) \quad (5)$$

Even if, both these models are nonlinear in parameters a and b but they are basically of different characters. Equation (4) can be transformed into linear form by taking natural algorithm:

$$lny = a + b * t^2 \quad (6)$$

Which is linear in parameters. Because the model in equation (4) can be transformed into linear form, it is referred to as intrinsically linear. However, because Equation (5) cannot be converted to a linear form, it is referred to as an intrinsically non-linear model.

If it is not possible to solve the non-linear equations exactly in a non-linear model, iterative approaches are used to estimate the parameters. Steepest descent method, Linearization (Taylor series) method, and Levenberg-approach Marquardt's are all important iterative procedures for approximating analytical solutions. The Levenberg Marquardt technique is the most commonly used method for computing non-linear least square estimators since it always converges and does not slow down even at the end of the iterative process.

2.2 Important Non-Linear Growth Models

2.2.1 Logistic model

"Pierre Verhulst" devised a Logistic model that suggested that the rate of population growth may be limited, and that it may be dependent on population size. The parameters of the logistic model can be easily understood. This model generates an S-shaped curve and is most commonly employed in fields where growth is symmetric around the point of inflection. Hence the Logistic equation is as follows:

$$y = \frac{a}{(1 + b * \exp(-k * t))} \quad (7)$$

Where y represents growth at time t and a, b, and k represent the parameters. The parameters 'a' and 'k' denote carrying capacity, intrinsic growth rate, and different functions of the initial value, respectively.

2.2.2 Monomolecular model

The Monomolecular model describes the progression of a growth situation in which the rate of growth is considered to be proportionate to the remaining resources. The Monomolecular model is most commonly utilised in fields where the rate of growth declines linearly as size grows with no inflection point. Monomolecular model may be written as:

$$y = a * [1 - b * \exp(-k * t)] \quad (8)$$

2.2.3 Gompertz model

In 1825, Gompertz proposed the Gompertz model for hazard in life tables. The Gompertz model is widely utilised, especially in fields where growth is asymmetrical at the point of inflection. The Gompertz model features sigmoid behaviour and has been proven to be very beneficial in biological processes. The Gompertz model is written as:

$$y = a * \exp\,(\,-\mathrm{b} * \exp\,(-\mathrm{k} * \mathrm{t})) \quad (9)$$

2.2.4 Von Bertalanffy model

Ludwig Von Bertalanffy proposed the Von Bertanlaffy's model in 1957, which is a non-linear model with a sigmoidal shape that is not symmetrical in relation to the inflection point. The model was originally developed in the ecological field to simulate the growth of fish and crustaceans over time. The Von Bertalanffy model is written as follows:

$$y = a * [1 - b * \exp(-k * t)]^3 \quad (10)$$

2.3 Initial Value Specification and Goodness of Fit

One of the most difficult problems in estimating parameters of non-linear models is initial value specification. The challenge of selecting initial values for parameters, on the other hand, can be overcome with a good understanding of the parameters' definitions in the context of the phenomenon being simulated. Wrong starting values lead to longer iterations, longer execution times, iteration non-convergence, and possibly convergence to an undesirable local minimum. There have been developed expressions that provide good starting values for some of the parameters [7]. The order of a, b, and k is the most efficient for determining initial values. For estimation of the initial values, we have used solver program in excel.

2.3.1 Goodness of Fit (GoF)

There is no single way for determining a model's quality of fit. The various elements of the data and model can be highlighted using a variety of approaches. The graphical comparison provides a quick visual examination of the GoF. The R^2, RMSE, MAPE, and MAE are utilised as the GoF criterion to analyse the model's fit using the formula:

$$R^2 = 1 - \left(\frac{RSS}{TSS}\right) \quad (11)$$

Where RSS is the residual sum of squares and TSS is the total sum of squares

$$RMSE = \sqrt{\frac{\sum(y-\hat{y})^2}{n}} \quad (12)$$

$$MAE = \sum\frac{|y-\hat{y}|}{n} \quad (13)$$

$$MAPE = \frac{100}{n}\sum\left|\frac{y-\hat{y}}{y}\right| \quad (14)$$

Where y is the observed value and $\hat{y}$ is the predicted value of total pulses productivity.

3. RESULTS AND DISCUSSION

Initially, the goal was to find a non-linear growth model that best reflected the total pulse productivity in India. For the period 1949 to 2020 in India, various growth models such as Logistic, Gompertz, Monomolecular, and Von Bertalanffy were considered for the modelling of productivity under total pulse crops. Table 1 shows the initial values for which the iterative technique converged, as well as estimated values following convergence of the total pulses.

All four models have been well fitted to the specified dataset, as shown in Fig. 1. However, when the models were compared using GoF criteria, it was discovered that the Logistic and Gompertz models outperformed the others. On the basis of MAE, RMSE, and MAPE, logistic has a minimum value of 41.64, 52.15, 7.70, and Gompertz has a minimum value of 42.99, 54.02, 7.94. The maximum values for R^2 Logistic and Gompertz are 0.75 and 0.73, respectively. Figs. 2 and 3 depict the best-fit logistic and Gompertz models, as well as the observed data value. The x-axis of the following graph represents time, while the y-axis represents productivity in million tonnes. The graphic shows that the observed and expected values for are very similar [8-10].

It is clear from the GoF criteria that Logistic and Gompertz model outperform than other fitted models, therefore, forecasting of total pulse productivity in India has been done by using these two models as shown in Table 2.

For the period 2020-26, the productivity of total pulses is expected to increase from 728.07 to 756.65 in the Logistic model and from 717.73 to 741.83 in the Gompertz model, according to forecasted values [11,12].

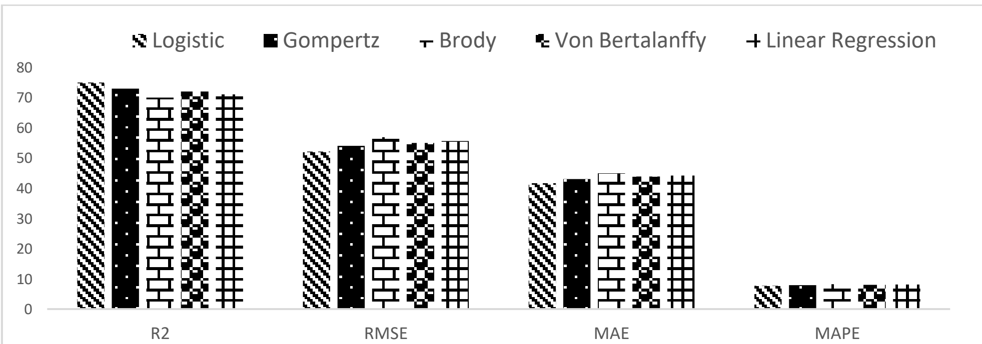

Fig. 1. Goodness of fit statistics

Table 1. Initial parameter values for different non-linear growth models

Parameters	Logistic	Gompertz	Monomolecular	Von Bertalanffy
A	7866.46	3243.15	2373.58	2644.97
B	17.93	2.07	0.83	0.46
K	0.008	0.004	0.002	0.003

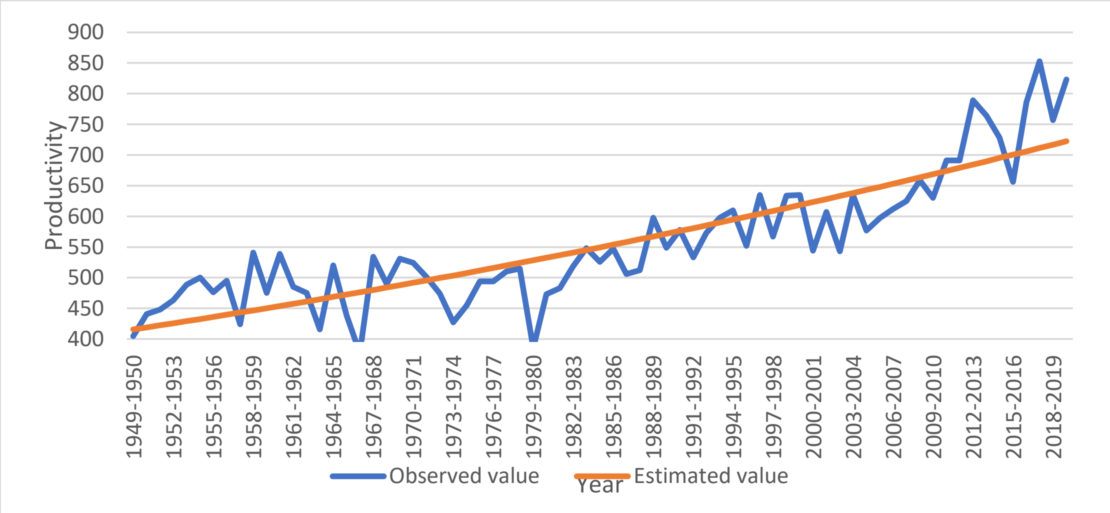

Fig. 2. Observed vs estimated values of total pulse productivity for logistic model

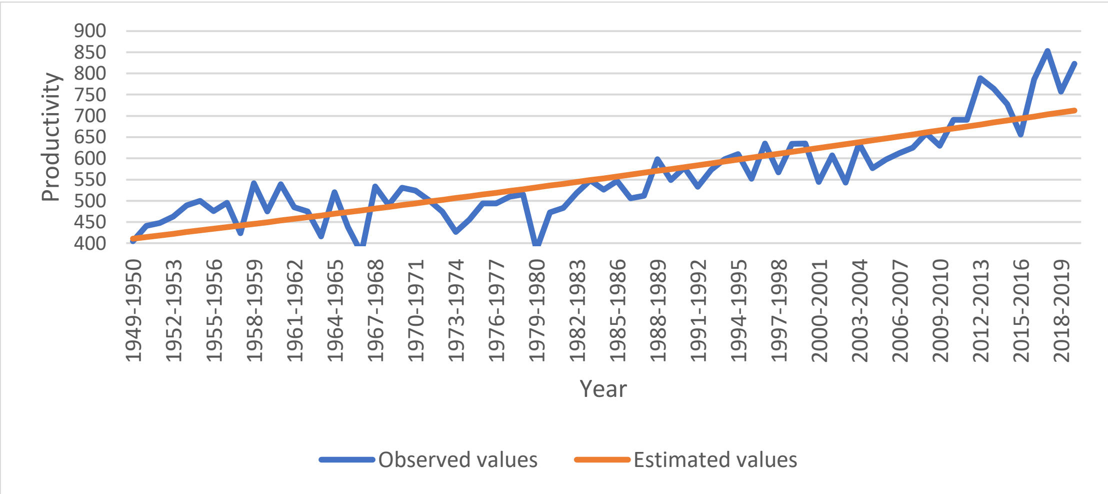

Fig. 3. Observed Vs estimated values of total pulse productivity for Gompertz model

Table 2. Forecasted values for the period 2020-21 to 2024-25 using Logistic and Gompertz models

Year	Logistic Model	Gompertz Model
2020-21	728.0676	717.7316
2021-22	733.7046	722.5307
2022-23	739.3806	727.3404
2023-24	745.096	732.1607
2024-25	750.8509	736.9914

4. CONCLUSION

This study employs a non-linear growth technique to analyze overall pulse productivity in India from 1949 to 2020. The study concluded that Logistic model was shown to be the best fit for overall pulse crop productivity in India, followed by the Gompertz model. Finally, the Logistic and Gompertz models were applied to anticipate total pulse productivity in India from 2020-21 to 2025-26.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Jukanti AK, Gaur PM, Gowda CLL, Chibbar RN. Nutritional quality and health benefits of chickpea (*Cicer arietinum* L.): A review. British Journal of Nutrition. 2012;108:S11–S26.

2. Chauhan JS, Singh BB, Gupta S. Enhancing pulses production in India through improving seed and variety replacement rates. Indian Journal of Genetics and Plant Breeding. 2016;76(4): 1-10.
3. Pal S, Mazumdar D. Forecasting groundnut production of India using nonlinear growth models. Journal Crop and Weed. 2015;11(Special Issue): 67-70.
4. Mata-Estrada A, Gonzalez-Ceron F, Pro-Martínez A, Torres-Hernandez G, Bautista-Ortega J, Becerril-Perez CM, Vargas-Galicia AJ, Sosa-Montes E. Comparison of four nonlinear growth models in creole chickens of Mexico. Poultry Science. 2020;99:1995-2000.
5. Rajan SM, Palanivel M. Comparison of non-linear models to describe growth of cotton. International Journal of Statistics and Applied Mathematics. 2017;2(4):86-93.
6. Panwar S, Singh KN, Kumar A, Sarkar SK, Paul R, Rathore A, Sivaramane N. Forecasting of growth rates of wheat yield of Uttar Pradesh through non-linear growth models. Indian Journal of Agricultural Sciences. 2014;84(7):856-859.
7. Borah M, Mahanta D. Rapid parameter estimation of three parameter non-linear growth models. International Journal of Mathematical Archive. 2013;4(2):274-282.
8. Bürger R, Chowell G, Lara-Díıaz LY. Comparative analysis of phenomenological growth models applied to epidemic outbreaks. Mathematical Biosciences and Engineering. 2019;16(5):4250-4273.
9. Kaplan S, Gürcan EK. Comparison of growth curves using non-linear regression function in Japanese quail. Journal of Applied Animal Research. 2018;46(1):112-117.
10. Balan C, Kathiravan G, Thirunavukkarasu M, Jeichitra V. Non-linear growth modelling in mecheri breed of sheep. Journal of Entomology and Zoology Studies. 2017; 5(5):2005-2008.
11. Hojjati F, Ghavi Hossein-Zadeh N. Comparison of non-linear growth models to describe the growth curve of Mehraban sheep. Journal of Applied Animal Research. 2018;46(1):499-504.
12. Panghal P, Kumar M, Rani S. Estimation of annual compound growth rates of guava (*Psidium guajava* L.) fruit in Haryana using Non-linear model. Journal of Applied and Natural Science. 2019;11(4):778-784.

Peer-review history:
The peer review history for this paper can be accessed here:
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