**Stability and Competitiveness in India's Rice Export Dynamics: A Decadal Markov Chain Analysis with Focus on Leading Producing States**

**ABSTRACT**

Agriculture remains the cornerstone of India’s economy, playing a pivotal role in industrial growth, employment generation and food security. Despite its declining share in GDP, the sector continues to sustain livelihoods for millions while ensuring nutritional stability. The present study was conducted to explore the growth rates, instability in area, production and productivity of rice in India along with the top five producing states. Additionally, to examine the export dynamics of Rice from India, Markov chain analysis was employed. The study was based on secondary data for a period of 10 years, i.e., 2014-15 to 2023-24, from the INDIASTAT and FAOSTAT websites. In this, Compound Annual Growth Rates were also used to calculate the growth rates. The instability in the area, production and productivity was measured with the Cuddy Della Valle Index and Coppock's Instability. The study revealed that the growth rates for India were positive for the area, production and productivity (1.07%, 3.31% and 2.21% respectively). The Cuddy Della Valle instability indices for the study period registered a low instability for area (1.87), production (1.25) and productivity (0.95), respectively. While Telangana state recorded a medium instability for both area (22.79) and production (19.28). Also, the Odisha state reported the highest instability for production (35.75). Coppock's Instability indices also revealed that for Telangana state, the degree of instability for area (66.42) and production (68.38) was higher. The decomposition analysis concluded that the productivity effect was highly responsible for production variability (21.65%) for India. The results revealed that the USA was the most stable market among the major importers of Indian Rice, as reflected by a retention probability of 100%, indicating consistent trade relations and market reliability. The countries like Brazil and Uruguay stood in 2nd and 3rd positions with a retention capacity of 44% and 28% respectively. Through Markov chain prediction, it was also concluded that the future exports for the year 2025-26 would be 1592.95, 560.07 and 198.38 thousand tonnes for the U.S.A., Brazil and Uruguay countries, respectively.

***Key words:*** *Decomposition, Export, Instability, Rice, Decadal Markov Chain.*

1. **INTRODUCTION**

Rice is the primary crop for more than 50% of the world’s population. It has the world’s largest area, covering about 168.35 million hectares, with a total production of 799.99 million tonnes, with a productivity of about 4.75 tonnes/ha. in the year 2023 ([**https://www.fao.org/faostat**](https://www.fao.org/faostat))**.** It is also an important food crop in India and was grown in an area of 47.82 million hectares with a production of 137.825 million tonnes and about 2.88 tonnes/ha of its productivity. It was about 28.40%, 17.22% and 60.65% of the world's composition in terms of area, production and productivity, respectively ([https://www.indiastat.com](https://www.indiastat.com/) ). There is a strong demand for Indian rice in the international markets. The Indian rice export grew from 33.70 billion to 503.07 billion between 1997-98 to 2017-18 (Udhayakumar & Karunakaran, 2020; Bhatnagar & Khan, 2024). In 2023-24, India led global rice exports, contributing the largest share among the top five exporting countries (India, Thailand, Pakistan, Vietnam and the United States), which together accounted for approximately 73.8% of total global rice export value (<https://www.worldstopexports.com/> ). Rice export from India is determined by various factors, and therefore, reliable estimates of determinants of export are essential for the formulation of appropriate trade policies that suit the Indian rice export (Udhayakumar & Karunakaran, 2020). Also, from a continental perspective, nearly four-fifths (79.9%) of global rice exports in 2024 originated from Asian countries, with total shipments valued at $31.2 billion. India, as the leading rice exporter, played a dominant role in this figure, significantly contributing to Asia's strong presence in the global market. In comparison, European exporters accounted for 7.1% of total exports, followed by North America at 6.4% and Latin America at 5.5%. Trade is integral to our food systems as it fulfils the fundamental role of moving food from surplus to deficit regions, thus contributing to food security. Global food markets connect people and countries around the world, shape the availability, diversity and prices of foods and thus can affect diets and nutrition outcomes. These effects can be widely heterogeneous across countries both in direction and magnitude (FAO, 2025). By keeping its importance, the present study was formulated to understand the stability and competitiveness of India’s Rice export dynamics through the use of Instability indices and Markov chain analysis.

1. **MATERIAL AND METHODS**

The study was conducted by taking the time series data related to area, production and productivity of the top five rice-producing states (on the basis of the Quinquennial average of Production in million tonnes) states along with India. In the present study, secondary time series data on area, production, productivity and exports (from India to other countries) were taken from the year 2014-15 to 2023-24 (<https://www.fao.org/faostat>).

**2.1 Compound Annual Growth Rate (CAGR)**

In order to study the growth pattern of top rice-producing states along with India, compound annual growth rates (CAGR) were calculated for area, production and productivity (Darshan *et al*, 2024).

To determine the CAGR, the exponential time trend equation is

Yt = a bt ….. (1)

Where, Yt = Area or Production or Productivity in year t

 t = Time in years and

 ‘a’ = Intercept and ‘b’ = Regression Coefficient.

 Then the above equation is transformed in to Log linear form and it is written as

 log Yt = log a + t log b ….. (2)

 which is estimated by ordinary least square technique (OLS).

The Compound Annual growth rate (g) is then calculated as:

 g = (b-1)\*100 …… (3)

 Where, g = estimated compound Annual growth rate in percent per annum and

 b = anti log of b

**2.2 Instability Index**

Instability, which indicates the deviation from the "trend". It is an inherent characteristic in agriculture due to the changing weather conditions, seasonal variation in area, production and productivity of crops from year to year. Instability analysis can be conducted using three key measures, such as the Coefficient of Variation, the Cuddy-Della Valle Index, and Coppock's Index. To examine the extent of variability in area, production and productivity of Rice, the Cuddy-Della Valle Index and Coppock's instability index were employed in the study.

The simple coefficient of variation (CV) usually overestimates the level of instability in time-series data, as the data is characterised by long-term trends; whereas Coppock's instability index and Cuddy Della Valle index are used to capture the instability in area, production and productivity of Rice (Cuddy and Della Valle 1978).

**2.3 Cuddy- Della Valle Index (CDVI)**

The Cuddy Della Valle index (CDVI) is calculated as follows:

Index of Instability = $CDVI=CV\sqrt{1-R^{2}}$ ….. (4)

 Where, CV = Coefficient of Variation

 $R^{2}$ = ESS/TSS i.e., ratio of explained variation to total variation.

 ESS = Variation explained by explanatory variable.

 TSS = Total Variation.

The ranges of CDVI (Dudhat *et al,* 2017) are given as follows:

* Low instability = between 0 to 15
* Medium instability = > 15 to < 30
* High instability = >30

**2.4 Coppock's Instability Index (CII)**

CII is used to measure the variation from year to year in terms of percentage (Akula *et al,* 2022).

$Coppock^{'}s Instability Index=Antilog(\sqrt{Vlog-1}$)\*100

$ Vlog= \frac{\sum\_{}^{}\left[log\frac{x\_{t}+1}{x\_{t}}-m\right]^{2}}{N}$ ….. (5)

Where, Xt = Area/production/yield of rice in year t

 N = number of years minus one (i.e., N = n-1)

 m = Arithmetic means of the difference between the log of Xt and Xt+1 , Xt+2 , etc.

**2.5 Decomposition Analysis**

In order to measure the relative contribution of area and yield towards the total production changes of rice, decomposition analysis was carried out in the present study. The mathematical expression for work as formulated by Praveen Kumar and Paul (2017) is represented below:

 ΔP = Ao.ΔY + Yo.ΔA + ΔA.ΔY ….. (6)

Where,

* ΔP = Production difference
* Yo.ΔA = Area effect
* Ao.ΔY = Productivity effect and
* ΔA.ΔY = Interaction effect of area and productivity.

##### **2.6 Markov Chain Analysis**

 In the present study, the dynamic nature of trade patterns, that is, gains and losses in exports of Indian Rice among major importing countries, was examined by using a Markov chain model.

 In a Markov chain, the next state depends only on the current state and not on the sequence of events that preceded it. In the present work, the transitional probability matrix (P) is estimated, where the Pij matrix tells the probability that the exports would switch from the ith country to the jth country over a period of time. The diagonal elements Pij indicate the export retention probability of a country over the period. In simple words, it measures the loyalty of an importing country to a particular exporting country. In the transition probability matrix, the row and column elements provide the information on the extent of loss and gain in market share on account of competing countries, respectively. The off-diagonal of transitional probabilities indicates the probability of whether the export share will shift from one country to another country over time.

The average export to a particular country is considered to be a random variable which depends only on exports to that country, which is denoted algebraically by the equation below.

 ….. (7)

Where, Xjt= Exports from India to the jth country during the year t

 Xit-1= Exports to the ith country during the year t – 1

 Pij= Probability that exports will shift from the ith country to jth country

 ejt= Error-term statistically independent of ejt-1, and

 n = Number of importing countries.

The transitional probabilities Pij, having the following properties:

  where 

 Thus, the expected export share of each country during the ‘t’ period is obtained by multiplying the exports to these countries in the previous period (t-1) with the transitional probability matrix. The transitional probability matrix was estimated for the year 2024-25 by using the linear programming (LP) method referred to as minimisation of Mean Absolute Deviation (MAD) as explained by Fisher (1961).

 Min O.P\* + I e

 Subject to

 XP\* + V = Y

 GP\* = 1

Where, P\* = vector of the probabilities Pij

 O = the vector of zeros

I = appropriately dimensional vectors of area

e = the vector of absolute errors

Y = proportion of exports to each country.

X = block diagonal matrix of lagged values of Y

V = vector of errors and

G = a grouping matrix to add the row elements of P arranged in P\* to unity.

 Bt = B0\*T

 Bt+i = Bt+1-i\*T

Where,

 B0 =Quantity exported in Base years

 Bt+i = Quantity will be exported in next year (Prediction)

 T = Transition probability matrix

In this study, the probability matrix was estimated for the study period from 2014-15 to 2023-24, by using LP solver software.

1. **RESULTS AND DISCUSSION**

From Table 1, the Area under Rice production in India had increased from 44.11 million hectares to 47.82 million hectares, and the production had increased from 105.48 million tonnes to 137.82 million tonnes during the period from 2014 to 2024. Similarly, the productivity of rice in India for the same period was also represented in Table 1.

**Table 1. Area, production and Productivity of rice in India from 2014-15 to 2023–24.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Year** | **Area (Million ha.)** | **Production (Million ha.)** | **Productivity (Tonnes/ha.)** |
| **2014-2015** | 44.11 | 105.48 | 2.39 |
| **2015-2016** | 43.49 | 104.40 | 2.40 |
| **2016-2017** | 43.99 | 109.69 | 2.49 |
| **2017-2018** | 43.77 | 112.75 | 2.57 |
| **2018-2019** | 44.15 | 116.47 | 2.63 |
| **2019-2020** | 43.66 | 118.87 | 2.72 |
| **2020-2021** | 45.76 | 124.36 | 2.71 |
| **2021-2022** | 46.27 | 129.47 | 2.79 |
| **2022-2023** | 47.83 | 135.75 | 2.83 |
| **2023-2024** | 47.82 | 137.82 | 2.88 |

From Table 2, on the basis of Quinquennial average (2019-20 to 2023-24), it was confirmed that the top five states of India were recognised as Telangana, West Bengal, Uttar Pradesh, Odisha and Chhattisgarh with a production capacity of 16.33, 16.06, 12.95, 10.16 and 8.54 million Tonnes respectively. Hence, these states were selected for the present study purposively.

**Table 2: Quinquennial Average of Top 5 producer states of Rice in India**

|  |  |  |  |
| --- | --- | --- | --- |
| **States/UTs** | **Area (Million ha.)** | **Production (Million Tonnes)** | **Productivity (Tonnes/ha.)** |
| Telangana | 5.29 | 16.33 | 3.10 |
| West Bengal | 5.36 | 16.06 | 3.00 |
| Uttar Pradesh | 3.01 | 12.95 | 4.28 |
| Odisha | 4.13 | 10.16 | 2.42 |
| Chhattisgarh | 3.79 | 8.54 | 2.24 |

Figure 1 provides a comprehensive depiction of the trends in area, production and productivity of rice in India, along with a comparative analysis of these parameters across the selected states, thereby offering valuable insights into regional disparities and trends in rice cultivation over the study period.

**3.1 Compound Annual Growth Rates (CAGR)**

The compound annual growth rate of area, production and productivity of rice in India, along with the selected states over the study period, was examined and presented in Table 3. Analysis among the selected states in comparison to India had revealed that the compound annual growth rates of area, production and productivity were positive for India and Telangana state only. While some states exhibited both positive and negative results in the Area and production. But a positive growth rate was observed for all the states in productivity.

**Table 3: CAGR of Area, production and productivity of Rice in India along with the selected states during 2014-15 to 2023-24.**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Area** | **Production**  | **Productivity** |
| **India** | 1.07 | 3.31 | 2.21 |
| **Telangana** | 19.14 | 20.98 | 1.54 |
| **West Bengal** | -0.42 | 0.67 | 1.11 |
| **Uttar Pradesh** | -0.26 | 3.22 | 3.50 |
| **Odisha** | 0.21 | -7.03 | 2.27 |
| **Chhattisgarh** | -0.06 | 5.40 | 5.47 |

It was also reported that India had a growth rate of 1.07, 3.31 and 2.21 in area, production and productivity, respectively. The most significant growth rate was achieved by Telangana of about 20.98% and 19.14 for Production and Area, respectively. While the least positive growth was in Area (0.21 for Odisha), Production (0.67 for West Bengal), and for productivity (1.11 for West Bengal). It is also evident that the steepest decline in growth rate was found for Odisha in terms of production (-7.03), where for area, it was observed for West Bengal state (-0.42). Simultaneously, the slowest negative growth rate in area was observed for Chhattisgarh (-0.06).

**3.2 Instability Index**

In this study, the degree of instability in the area, production, and productivity of rice was also evaluated using the Cuddy-Della Valle Index and Coppock’s Instability Index, to understand whether this performance has stable growth or is erratic throughout the study period.

**3.3 Cuddy Della Valle Index**

From Table 4, it is observed that the instability value ranges from 0.95 to 35.75 over the study period. The lowest instability for productivity was observed for overall India (0.95), while the highest instability for Production was found in Odisha state (35.75). It was identified that Telangana state has medium instability for area (22.79) and production (19.28), respectively. The lowest instability was detected for many of the remaining states.

**Table 4 Cuddy- Della Valle Index for area, production and Productivity of rice.**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Area** | **Production**  | **Productivity** |
| **India** | 1.87 | 1.25 | 0.95 |
| **Telangana** | 22.79 | 19.28 | 4.63 |
| **west Bengal** | 3.91 | 4.00 | 1.42 |
| **Uttar Pradesh** | 1.19 | 4.02 | 4.32 |
| **Odisha** | 3.16 | 35.75 | 7.24 |
| **Chhattisgarh** | 1.97 | 15.59 | 14.57 |

**3.4 Coppock’s Instability Index**

 The results of Coppock’s instability (CII) analysis concerning the area, production, and productivity of rice were displayed in Table 5. This CII analysis in the study period revealed that the highest instability for Area was observed in Telangana (66.42), while for the production and productivity, it is observed in Odisha (76.16) and Chhattisgarh (45.61), respectively.

**Figure 1 Trends in area, production, and Productivity of rice in India along with top 5 states from 2014-15 to 2023-24.**

 It is also evident that the lowest instability was shown for the area (37.41) in West Bengal, whereas for production, low instability was found in Uttar Pradesh (38.36), followed by India (40.65), and for productivity, it was about 38.16by the Uttar Pradesh state.

**Table 5 Coppock’s Instability Index for the Area, production, and Productivity of rice.**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Area** | **Production**  | **Productivity**  |
| **India**  | 38.19 | 40.65 | 39.35 |
| **Telangana** | 66.42 | 68.38 | 39.79 |
| **West Bengal** | 37.41 | 40.90 | 41.29 |
| **Uttar Pradesh** | 38.25 | 38.36 | 38.16 |
| **Odisha** | 37.93 | 76.16 | 41.88 |
| **Chhattisgarh** | 37.51 | 45.77 | 45.61 |

**3.5 Decomposition Analysis**

 Later, decomposition analysis was also employed to examine the contributions of area, productivity and their interaction effects to the variability in production. In the present study, the source of production growth was decomposed into three effects, i.e., area, productivity and interaction effect. From Table 6, it was evident that a positive effect on production was observed in India as well as all the selected states for productivity. It also reveals that there exist some negative effects for area and interaction effects in West Bengal, Uttar Pradesh and Odisha states over the study period.

 During the study period, the area effects of Telangana and Chhattisgarh were found to be 10.26 and 0.02, while productivity effects as 0.65, 3.34 and interaction effects were found to be 1.51 and 0.01, respectively, which are positive on the variability of production. On examining the results, it was found that the area effect of India was highly responsible for the production variability, i.e., 8.89 per cent, and the productivity and interaction effect account for 21.65 per cent and 1.82 per cent of production variability, respectively. The steepest area and interaction effects were observed as -0.70 and -0.08 in West Bengal, followed by Uttar Pradesh as -0.21 and -0.07, respectively. A comparable analysis was carried out by Venkatesh and Sane (2018) on Paddy, Cotton and Maize crops in Andhra Pradesh.

**Table 6: Decomposition analysis in Area, production, and productivity of rice in India along with selected states (2014-15 to 2023-2024)**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Area effect** | **productivity effect** | **Interaction effect** |
| **India**  | 8.89 | 21.65 | 1.82 |
| **Telangana** | 10.26 | 0.65 | 1.51 |
| **West Bengal** | -0.70 | 1.79 | -0.08 |
| **Uttar Pradesh** | -0.21 | 4.11 | -0.07 |
| **Odisha** | -0.18 | 0.37 | -0.008 |
| **Chhattisgarh** | 0.02 | 3.34 | 0.01 |

**3.6 Markov Chain Analysis**

**Table 7: Transitional Probability matrix for Rice Export from India to selected countries from 2014-15 to 2023-24**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|   | **U.S.A.** | **Brazil** | **Uruguay** | **Paraguay** | **Russia** | **Guyana** | **Argentina** | **Greece** | **Spain** | **Others**  |
| **U.S.A.** | **1.00** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Brazil** | 0.14 | **0.44** | 0.22 | 0.05 | 0.05 | 0.00 | 0.00 | 0.00 | 0.01 | 0.10 |
| **Uruguay** | 0.00 | 0.72 | **0.28** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Paraguay** | 0.00 | 0.00 | 0.00 | **0.00** | 0.00 | 0.22 | 0.00 | 0.20 | 0.06 | 0.52 |
| **Russia**  | 0.68 | 0.00 | 0.00 | 0.00 | **0.00** | 0.00 | 0.09 | 0.00 | 0.00 | 0.24 |
| **Guyana** | 0.49 | 0.00 | 0.00 | 0.24 | 0.24 | **0.00** | 0.03 | 0.00 | 0.00 | 0.00 |
| **Argentina** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **0.00** | 0.70 | 0.00 | 0.30 |
| **Greece** | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **0.00** | 0.00 | 0.00 |
| **Spain** | 0.58 | 0.00 | 0.00 | 0.06 | 0.00 | 0.06 | 0.00 | 0.00 | **0.00** | 0.31 |
| **Others**  | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **0.00** |

 Later, to understand the export competitiveness of Indian Rice exports, Markov chain Analysis was tried. The Transitional Probability Matrix was presented in Table 7, which provides a broad indication of changes in the direction of export of Rice from India to selected countries for the study period (2014-15 to 2023-24). The majority of Indian rice-importing countries were the USA, Brazil, Uruguay, Paraguay, Russia, Guyana, Argentina, Greece, Spain and all other importing countries were grouped under the category of the other countries. The row elements in the transitional probability matrix provide information on the extent of loss in trade, on account of competing countries. The columns element indicates the probability of gains in volume of trade from other competing countries, and the diagonal element indicates the probability of retention of the previous year’s trade volume by the respective country.

 It was evident from Table 7 that the USA was the most stable market among the major importers of Indian Rice as reflected by the probability of retention at 100 per cent. The most unstable markets were Paraguay, Russia, Guayana, Argentina, Greece, Spain and all the other remaining countries with the zero-retention capacity. The countries like Brazil and Uruguay stood in 2nd and 3rd positions with a retention capacity of 44% and 28% respectively. It was found that the U.S.A. gained a significant amount of 68%, 58%, 49% and 14% from Russia, Spain, Guyana and Brazil countries respectively. Similarly, Brazil gained complete exports from Greece and other countries. Likewise, Uruguay contributes about 72% gain to Brazil. However, Uruguay has gained a significant amount from Brazil (22%). Finally, other countries gained rice exports from Brazil (10%), Paraguay (52%) and Argentina (30%). As per the reports of Anthony *et al,* 2024.

 The market share projections of Indian Rice exports to the major importing countries were computed up to 2025-26 using the transitional probability matrix. Table 8 represents the actual and predicted values of Indian rice exports to the top ten importers from 2014-15 to 2023-24 and also projections up to 2025-26. The actual share of the U.S.A. in Rice exports had shown fluctuation over the study period (2014-15 to 2023-24); on the whole, it had decreased from 58.92% to 45.17%. A similar picture was in the prediction of export share too, where it had decreased from 68.32% to 51.78% It was projected with a value of 1465.80 and 1592.95 thousand tonnes for 2024-25 and 2025-26, respectively.

With regards to Brazil, the actual and predicted export share showed fluctuations from 11.24% to 31.72% and 16.75% to 28.57% respectively, from 2014-15 to 2023-24. Here, the projections of Brazil were made to 628.24 and 560.07 thousand tonnes for the years 2024-25 and 2025-26, respectively. Kusuma and Basavaraja (2014) conducted a similar predictive analysis based on percentage metrics, employing a Markov Chain approach to assess the stability of India's mango export markets.

 The actual proportion of Uruguay and Paraguay's market share of imports from India showed an increasing trend from 1.68 to 10.78% and from 1.68 to 1.78% respectively. The predicted export trend also increased from 2.89 to 9.83% and from 0.50 to 1.26% respectively, during the study period. For the year 2025-26, the rice export was estimated as 198.38 and 32.09 thousand tonnes for Uruguay and Paraguay, respectively.

 With respect to Russia and Argentina, the actual proportion of exports showed a decreasing trend, i.e., decreased from 4.68% to 1.98% and from 1.85 to 0% respectively. The predicted proportion also showed a decreased trend from 2.46 to 1.83% for Russia likewise trend decrease from 0.61 to 0.19% for Argentina. It was estimated at about 1.37 and 0.15 thousand tonnes for Russia and Argentina, for the year 2025-26. A similar kind of decreasing trend was observed in Greece from 0.98 to 0.84% in actual share; likewise, the predicted share also had a decreasing trend from 1.49 to 0.36%.

**Table 8: Actual and predicted quantities of Rice exports from India to Selected Countries (in ‘000 tonnes)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **USA** |  | **Brazil** |  | **Uruguay** |  | **Paraguay** |  | **Russia** |  | **Guyana** |  | **Argentina** |  | **Greece** |  | **Spain** |  | **Others** |  |
|  | **A** | **P** | **A** | **P** | **A** | **p** | **A** | **P** | **A** | **P** | **A** | **P** | **A** | **P** | **A** | **P** | **A** | **P** | **A** | **P** |
| **2014-2015** | 1381.57 | 1601.84 | 263.50 | 392.70 | 39.36 | 67.79 | 39.42 | 58.52 | 109.66 | 57.66 | 181.43 | 10.84 | 43.44 | 14.24 | 22.70 | 38.20 | 36.84 | 6.10 | 226.88 | 96.88 |
|  | (58.92) | (68.32) | (11.24) | (16.75) | (1.68) | (2.89) | (1.68) | (0.50) | (4.68) | (2.46) | (7.74) | (0.46) | (1.85) | (0.61) | (0.97) | (1.63) | (1.57) | (0.26) | (9.68) | (4.13) |
| **2015-2016** | 1622.98 | 1720.92 | 219.42 | 276.23 | 43.78 | 59.50 | 53.00 | 14.16 | 54.22 | 12.73 | 5.82 | 14.50 | 4.64 | 4.77 | 13.01 | 13.99 | 48.31 | 6.26 | 136.09 | 78.21 |
|  | (73.73) | (78.18) | (9.97) | (12.55) | (1.99) | (2.70) | (2.41) | (0.64) | (2.46) | (0.58) | (0.26) | (0.66) | (0.21) | (0.22) | (0.59) | (0.64) | (2.19) | (0.28) | (6.18) | (3.55) |
| **2016-2017** | 1858.39 | 2060.91 | 190.91 | 307.76 | 73.62 | 61.60 | 97.24 | 51.89 | 110.66 | 50.86 | 168.84 | 23.04 | 15.56 | 13.99 | 14.18 | 30.56 | 32.98 | 8.42 | 157.27 | 110.60 |
|  | (68.33) | (75.78) | (7.02) | (11.32) | (2.71) | (2.27) | (3.58) | (1.91) | (4.07) | (1.87) | (6.21) | (0.85) | (0.57) | (0.51) | (0.52) | (1.12) | (1.21) | (0.31) | (5.78) | (4.07) |
| **2017-2018** | 1568.12 | 1621.04 | 100.17 | 266.46 | 41.24 | 33.05 | 56.41 | 7.53 | 33.20 | 6.83 | 6.85 | 13.60 | 46.07 | 3.01 | 23.89 | 43.48 | 22.83 | 4.73 | 169.15 | 68.21 |
|  | (75.83) | (78.39) | (4.84) | (12.89) | (1.99) | (1.60) | (2.73) | (0.36) | (1.61) | (0.33) | (0.33) | (0.66) | (2.23) | (0.15) | (1.16) | (2.10) | (1.10) | (0.23) | (8.18) | (3.30) |
| **2018-2019** | 1353.37 | 1499.72 | 717.27 | 588.97 | 47.59 | 168.06 | 132.26 | 39.37 | 37.23 | 42.34 | 22.06 | 29.64 | 31.17 | 3.76 | 29.14 | 48.53 | 18.39 | 18.07 | 213.32 | 163.33 |
|  | (52.02) | (57.64) | (27.57) | (22.64) | (1.83) | (6.46) | (5.08) | (1.51) | (1.43) | (1.63) | (0.85) | (1.14) | (1.20) | (0.14) | (1.12) | (1.87) | (0.71) | (0.69) | (8.20) | (6.28) |
| **2019-2020** | 1580.96 | 1675.02 | 269.16 | 419.30 | 155.76 | 101.24 | 70.52 | 14.20 | 64.37 | 14.60 | 3.00 | 16.46 | 59.68 | 5.55 | 35.71 | 55.81 | 19.98 | 8.00 | 153.83 | 102.79 |
|  | (65.52) | (69.42) | (11.15) | (17.38) | (6.46) | (4.20) | (2.92) | (0.59) | (2.67) | (0.61) | (0.12) | (0.68) | (2.47) | (0.23) | (1.48) | (2.31) | (0.83) | (0.33) | (6.37) | (4.26) |
| **2020-2021** | 1373.40 | 1552.27 | 518.50 | 600.57 | 162.85 | 157.04 | 249.26 | 48.63 | 61.90 | 49.54 | 93.87 | 55.78 | 0.00 | 7.81 | 63.66 | 50.62 | 33.32 | 22.01 | 193.53 | 206.02 |
|  | (49.94) | (56.44) | (18.85) | (21.84) | (5.92) | (5.71) | (9.06) | (1.77) | (2.25) | (1.80) | (3.41) | (2.03) | (0.00) | (0.28) | (2.31) | (1.84) | (1.21) | (0.80) | (7.04) | (7.49) |
| **2021-2022** | 1507.15 | 1601.36 | 234.76 | 521.43 | 128.29 | 86.21 | 65.20 | 23.15 | 41.57 | 23.35 | 46.30 | 15.24 | 0.00 | 4.79 | 43.57 | 13.24 | 18.92 | 7.19 | 282.93 | 72.71 |
|  | (63.63) | (67.61) | (9.91) | (22.01) | (5.42) | (3.64) | (2.75) | (0.98) | (1.75) | (0.99) | (1.95) | (0.64) | (0.00) | (0.20) | (1.84) | (0.56) | (0.80) | (0.30) | (11.94) | (3.07) |
| **2022-2023** | 962.62 | 1145.00 | 939.77 | 830.30 | 286.18 | 282.15 | 130.85 | 47.80 | 47.60 | 51.84 | 13.95 | 29.56 | 0.00 | 4.42 | 29.41 | 26.58 | 21.82 | 21.20 | 185.01 | 178.36 |
|  | (36.78) | (43.75) | (35.91) | (31.72) | (10.93) | (10.78) | (5.00) | (1.83) | (1.82) | (1.98) | (0.53) | (1.13) | (0.00) | (0.17) | (1.12) | (1.02) | (0.83) | (0.81) | (7.07) | (6.81) |
| **2023-2024** | 1150.89 | 1319.31 | 808.17 | 728.07 | 274.63 | 250.54 | 45.27 | 43.21 | 50.50 | 46.55 | 20.13 | 11.07 | 0.00 | 4.84 | 21.48 | 9.19 | 20.75 | 14.31 | 156.32 | 121.05 |
|  | (45.17) | (51.78) | (31.72) | (28.57) | (10.78) | (9.83) | (1.78) | (1.70) | (1.98) | (1.83) | (0.79) | (0.43) | (0.00) | (0.19) | (0.84) | (0.36) | (0.81) | (0.56) | (6.13) | (4.75) |
| **2024-2025** |   | 1465.80 |   | 628.24 |   | 226.57 |   | 36.96 |   | 40.22 |   | 10.22 |   | 4.26 |   | 12.14 |   | 13.03 |   | 110.71 |
|  |   | (57.52) |   | (24.65) |   | (8.89) |   | (1.45) |   | (1.58) |   | (0.40) |   | (0.17) |   | (0.48) |   | (0.51) |   | (4.34) |
| **2025-2026** |   | 1592.95 |   | 560.07 |   | 198.38 |   | 32.09 |   | 34.87 |   | 8.79 |   | 3.70 |   | 10.46 |   | 11.23 |   | 95.61 |
|   |   | (62.51) |   | (21.98) |   | (7.79) |   | (1.26) |   | (1.37) |   | (0.34) |   | (0.15) |   | (0.41) |   | (0.44) |   | (3.75) |

1. **CONCLUSION**

The present work was done to explore the growth rates, instability in area, production and productivity of rice in India along with the top five producing states by using Compound annual growth rates (CAGR), Cuddy-Della Valle Index (CDVI), Coppock’s instability index (CII) and Decomposition Analysis. Also, to examine the directional change in the country-wise exports of Rice from India, Markov chain analysis was employed.

From CAGR, it was found that India had a growth rate of 1.07, 3.31 and 2.21 in area, production and productivity, respectively. The most significant growth rate was achieved by Telangana of about 20.98% and 19.14 for Production and Area, respectively. While the least positive growth was in Area (0.21 for Odisha), Production (0.67 for West Bengal), and for productivity (1.11 for West Bengal). Also, the instability analysis using CDVI and CII reveals the significant regional variations. Based on CDVI, the lowest productivity instability was recorded for overall India (0.95), highlighting national-level stability, while Odisha exhibited the highest production instability (35.75). Telangana had moderate instability in area (22.79) and production (19.28). According to CII, Telangana had the highest area instability (66.42), whereas Odisha had the highest production instability (76.16) and Chhattisgarh showed the highest productivity instability (45.61) during the study period, indicating marked regional disparities in agricultural stability. In conclusion, the decomposition analysis indicated that at the national level, the productivity effect was the major contributor to production variability in India at 21.65%, followed by the area effect at 8.89% and the interaction effect at 1.82%. Regionally, Telangana contributed 10.26 through area effect, 0.65 through productivity effect, and 1.51 through interaction effect, while Chhattisgarh showed contributions of 0.02, 3.34 and 0.01 respectively, all positively influencing production variability.

Finally, through Markov chain analysis, it was concluded that the USA emerged as the most stable importer of Indian rice, with a 100% probability of retention, indicating consistent trade relations and market reliability. Similarly, Brazil and Uruguay ranked as the second and third most stable markets, with retention capacities of 44% and 28%, respectively, suggesting moderate market consistency. The USA gained significantly from other markets, specifically 68% from Russia, 58% from Spain, 49% from Guyana and 14% from Brazil, reflecting a shift of Indian rice exports toward the U.S. from these countries. Other countries sourced their rice imports primarily from Brazil (10%), Paraguay (52%) and Argentina (30%), highlighting their reliance on these regional exporters for Indian rice.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Author(s) hereby declares 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.

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