



RESEARCH ARTICLE

# Market performance and trade dynamics of India's primary vegetables: An analysis of tomato, onion and potato

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## Abstract

India, ranking as the second largest global vegetable producer, faces a significant discrepancy between its production capacity and export potential, particularly for tomato, onion and potato (TOP) vegetables. This study aimed to comprehensively assess the export performance of these three critical crops by analyzing their growth patterns, market stability and trade destinations over two decades. The research utilized 21 years of Agricultural and Processed Food Products Export Development Authority (APEDA) data (2004 to 2024), employing Compound Annual Growth Rate (CAGR) for growth trend analysis, Cuddy-Della Valle Index (CDVI) to measure export volatility and stability and Markov Chain methodology to examine shifting trade destination patterns. These analytical methods collectively provide a robust framework for understanding export dynamics through secondary data reflecting production patterns, export quantities, values and market destinations. The findings revealed that tomatoes experienced extreme growth volatility with spectacular initial growth (56.74 % CAGR) followed by dramatic decline (-11.51 % CAGR), while onion exports demonstrated relative stability despite periodic fluctuations and potato exports showed consistent positive growth with improving market stability over time. Export instability analysis indicated high volatility for tomato exports and medium instability for onions, whereas potato exports exhibited significant stability improvements. The Markov Chain analysis revealed high export concentration toward Bangladesh for tomato and onion markets, with Nepal emerging as a key destination for potato exports. Overall, the study demonstrates that realizing India's vegetable export potential through TOP crops requires coordinated policy interventions, infrastructure development and quality standardization to enhance exports and achieve sustainable growth in global markets.

**Keywords:** agricultural trade; export performance; India; market stability; TOP vegetables

## Introduction

The global vegetable trade has witnessed significant transformations over the past three decades. India has emerged as the second largest producer of vegetables in the world after China.

The Indian agriculture sector has experienced extraordinary changes in the last thirty years regarding horticulture, with vegetables contributing to food security and earnings. With the diverse wealth of vegetables produced and consumed in various regions of India, tomatoes, onions and potatoes (easily known in agriculture as "TOP" vegetables - Tomato, Onion, Potato) emerge as comparatively important in terms of production, consumption and export (1). These three crops together now hold nearly half of the country's total vegetable area, representing an important percentage of total vegetable area in the nation and a large amount of most farm family income throughout India. These crops provide essential food materials to domestic consumers and provide export products with foreign earning revenue.

From an economic perspective, it is essential to understand the export potential of TOP vegetables. The export value of tomatoes, onions and potatoes represent a significant proportion of India's total agricultural exports and has implications for many farming communities and value chain players. These crops serve as mechanisms for price stabilization in the domestic market where surpluses can be absorbed by the export market benefitting producers and consumers. However, maximizing this potential has its challenges. Existing challenges range from meeting quality norms to market access issues have constrained Indian vegetables from reaching the global market.

India's role in global vegetable markets is characterized by opportunities and challenges. India is the second largest producer of vegetables in the world, (China is first in terms of tomatoes and India is second in onion production) (2), but India's proportion of vegetable exports is relatively small in comparison to its potential production capability. It is this disparity between production capacity and export capability that presents an interesting opportunity for research. The transformation of India's agricultural exports started with the opening of the

economy in the 1990's in India. The new possibilities resulting from the establishment of targeted bodies like the APEDA and policy changes focused on export-led development strategies for farmers and traders, provided avenues to engage with international markets.

The volume of literature examining Indian vegetables export performance has been greatly increased, in terms of both extent and volume, also with researchers embarking on different analyses of how markets operate and how competition works. In the earlier years, researchers either reported only production patterns, or straight export data. The literature is now time-series, longitudinal or cross-sectional, uses much more complex analyses of trade momentum, competitiveness, determinants of trade and trends in shares. Most importantly the distinctive and original research in this area which generally represents evidence that export prices have significant positive influences on India's tomato export competitiveness, which specifically examined the influence on trade flow for prices or price mechanisms in international markets and provided meaningful examples in looking at the relationship domestic production costs and export competitiveness, which can then be used by other research in their efforts related relation (3).

The work on performance in tomato exports in the literature has added little to our understanding of the many factors affecting export performance, especially in the context of the relatively large production base for tomatoes, as well as the growth in international demand including the commitments made by India to the World Trade Organisation (WTO). In earlier papers we have discussed that it appears from the statistics available that tomato exports have increased from India, with newer estimates stating that Indian tomato export volumes increased 58.22 % annually in the post WTO period relative to some much lower percentage in the prior periods. There has been a dramatic improvement in India's performance on tomato exports. This result in India's recent performance is largely due to a combination of human (i.e., specific policies) and market-based reasons that enhanced India's competitive position in international tomato markets that we have observed based on general patterns in tomato exporting compared to vegetable exporting markets, it is interesting to note that there is even a greater component of temporal variation in the performance of each crop.

Onion exports represent a significant portion of resource use in India. One survey shows that in 2018-19, India exported about 2.42 million tonnes of fresh onions, which is 45 % above last year's exports of 1.68 million tonnes (2). Overall, outcomes with respect to onion exports have not been nearly as favorable given India's sources of disappointment in policy inconsistencies. If the problem was simply limited to the level of competitiveness of Indian onions, there would be potential to smooth out the faults. Almost all exporters were stymied by bad news about minimum export prices and/or periodic export bans that have resulted in erratic trade and the perception of India as an unreliable supplier. Current assessments would suggest that India continues to play a very important role in the international onion market. Several studies using Net Protection Coefficient (NPC) analysis of competitive performance - not to mention multiple other measures of competitive advantage - report that Indian onions remain competitive exports (4, 5).

The export dynamics for potatoes, however, fared differently than tomatoes and onions. Research shows a competitive advantage from point of origin for exports of potatoes from some 'places' in India have determined performance over the years by performance level. Furthermore, a few studies suggested we faced some challenges at times of available competitive advantage. The studies pointed out significant areas of concern for India's competitive position for potato exports as well, particularly on productivity. The way potatoes are priced, by cost of production, determines competitive prices positioning in international markets. However, some recently explored research work has contextualized potato export performance. In this case, some Indian states have potential for improvements of potato exports. In particular, Gujarat emerged as a significant growth state due to area expanding, production increasing and yielding positive total compound annual growth rates from 2013 to 2018 of 6.47 % area (an increase of around 60000 hectares) and 8.86 % for production (an increase of around 670000 tonnes) (6).

Study and review of the TOP vegetable value chain across states highlighted some common constraints for export performance including private and public infrastructure and policy concerns. Prior research has identified agricultural needs for urgent upgrade, even cold-storage for potatoes in Bihar has many cold-storage infrastructure priority issues just as there exists similar restriction in cutting waste down because of inadequate post-harvest infrastructure evident in studies and documents underlining the agricultural landscape of India. Research results show that the presence of cold-storage decreased the value-based potential loss in onions down to less than 5 % and ice-retail recovery has limits from technical and economic trade concerns and barriers. A recent research utility used a coffee and food systems module that employed powerful analytical procedures including Markov Chain analysis backward to identify commodity pathways into the future and potential future export markets for those Indian vegetables.

Research has found that compliance issues related to quality and standards have happened in previous vegetable-export research. Research has shown that high-quality standards linked to Good Agricultural Practice - GAP - organic certification and international pest risk analysis compliance are particularly critical aspects directly related to export success. It is also true that the different Maximum Residue Limits (MRLs) for pesticide and chemical residues expectedly varies between importing countries, requiring increasingly strategic government policies.

Although numerous research articles have been published, several research gaps still exist in the literature for TOP vegetable exports from India. Most of the articles published to date treat the crops in isolation, examining each crop separately as opposed to the integrated system and jointly contributing policies and practices affecting each crop (7, 1). Further, very few articles have articulated the post-COVID-19 trade contexts and the implications of the pandemic for Indian vegetable exports, especially during times where consumer preferences are changing and supply chains are disrupted.

This study will try to address these gaps by providing an export performance analysis of India's TOP vegetables using recent APEDA data. The intention is to treat tomatoes, potatoes and onions as an integrated system and develop a matrix of synergies and trade-offs in export policies and marketing

practices. The analysis will focus on production trends and volumes, exported volumes and direction of export markets, price realizations and positioning as competitors over the past few years.

This study relates particularly well to India's ambitious agricultural export targets and commitment to doubling farmer income. Gaining a better understanding of the TOP vegetable export performance trends and the key drivers of performance will benefit policymakers, exporters and farmers struggling to navigate difficult international markets and help India's ambition to be a major player in global food trade.

## Materials and Methods

### Data collection and sources

The research examined the export performance of India's main agricultural exports tomato, potato and onion using secondary data from two different time periods. Production data, export volumes and export values were obtained from the APEDA, Government of India. A dataset spanning 21 years (2004-2024) was used to analyze the CAGR and CDVI, enabling the study of long-term trends and variations in production and export performance. For the Markov Chain analysis, a separate dataset covering 11 years (2014-2024) was used to examine export patterns and shifts in major importing countries, including Bangladesh, Malaysia, UAE, Sri Lanka, Nepal, Kuwait, Indonesia, Maldives, Oman, Vietnam, Bhutan, Qatar, Bahrain, Singapore, Saudi Arabia, Hong Kong, Mauritius and Seychelles. It allows us to examine more recent changes and variations in the landscape of agricultural exports from India.

### Analytical framework

#### CAGR analysis

The constant growth rates for production, quantity exported and value exported during the study period were calculated using the CAGR formula:

$$\text{CAGR} = \left[ \left( \frac{\text{Ending value}}{\text{Beginning value}} \right)^{\frac{1}{n}} \right] - 1,$$

where 'n' is the study period in years. The precise calculation of CAGR allowed for a consistent rate of growth across different performance variables for different commodities (8, 9).

CAGR was selected as it provides a normalized measure of growth over time, which is especially useful when comparing different commodities or time periods with varying scales of production and export.

#### CDVI analysis

To measure volatility and instability associated with production and export performance, the CDVI was established as:

$$\text{CDVI} = \text{Coefficient of variation} \times \sqrt{(1-R^2)}$$

Where  $R^2$  is the coefficient of determination estimated from the trend equation to the time series.

This index defines instability by adjusting the coefficient of variation from the underlying trend. As such, it represents variability in a more relative sense; and is therefore more robust (10, 11).

CDVI was employed for its strength in capturing trend-adjusted fluctuations, offering a more accurate reflection of instability compared to simple variability measures.

The interpretation of CDVI is:

- Low instability:  $\text{CDVI} < 15$
- Medium instability:  $15 \leq \text{CDVI} < 30$
- High instability:  $\text{CDVI} \geq 30$

#### Markov Chain analysis

The Markov Chain method was applied to analyze transition probabilities and structural shifts pertaining to the export destinations of the commodities selected in the study from 2014 to 2024. This stochastic process aided in identifying the probability of retaining or changing market position from one country destination to others.

The transition probability matrix (P) was defined as:

$$P_{ij} = n_{ij} / \sum n_{ij}$$

where  $P_{ij}$  was the transition probability from state i to state j and  $n_{ij}$  was the number of transitions that were made. The analysis covered significant export destinations for onion, potato and tomato during the study period.

The following countries were identified as major export destinations for the selected crops (12, 13):

**Onion:** Bangladesh, Malaysia, United Arab Emirates (UAE), Sri Lanka, Nepal, Kuwait, Indonesia, Maldives, Oman, Vietnam.

**Potato:** Nepal, Oman, UAE, Sri Lanka, Maldives, Kuwait, Qatar, Hong Kong, Mauritius, Bahrain, Seychelles.

**Tomato:** Bangladesh, Nepal, Maldives, UAE, Bhutan, Oman, Qatar, Bahrain, Singapore, Saudi Arabia.

The method was chosen due to its predictive capability and relevance in modeling time-dependent market behavior, making it ideal for tracking changes in international demand and trade flow patterns over the observed period.

## Results and Discussion

### CAGR

#### Production analysis (2004-2024)

The four-year period growth assessment of the three top horticultural crops exemplifies the changing area of production in the last two decades of crops production in India.

**Tomato:** The trend for tomato showed in Table 1 has an overall significant reduction of production growth where a CAGR of 11.57 % of tomato production was exhibited from first decade to the second decade of crop statistics in India, from 2004-2014, with clear evidence of area growth expansion and productivity improvements signifying a sustainable farm production strategy on a part of the tomato growers. In the second decade of crop statistics, from 2015-2024, the same production exhibited significant slowing reduction of production growth with an overall 2.12 % growth rate, indicating challenges of production when correlated with other production constraints including climate variability and deviations, pest and disease constraints and market

**Table 1.** CAGR of TOP products production (2004-2024)

Products / Decades	Quantity	
	2004-2014	2015-2024
<b>Tomato</b>	11.57	2.12
<b>Onion</b>	11.01	4.79
<b>Potato</b>	5.14	2.95

saturation. This dramatic decline from 11.57 % to 2.12 % CAGR contrasts sharply with previous studies that projected sustained high growth rates for tomato production, suggesting earlier research may have underestimated environmental and market constraints.

**Onion:** Onion production displayed a similar but not as drastic slowing growth trend compared to tomato production. The first decade (2004-2014) demonstrated a strong CAGR of 11.01 %, reflecting the significance of India's sustained status as a major global producer of onion. The second decade saw onion production growth decline by a large amount to 4.79 % CAGR- however onion production overall continued to show increases in production growth, even during the second decade as shown in Table 1. The slowing in production growth may be attributed to rising increasing production costs, challenges of water scarcity, as well as different various policies that periodically show concerns for the trade of onion production. Unlike previous studies that focused primarily on export potential, this analysis reveals production constraints have become more significant than earlier research indicated.

**Potato:** The potato production showed the most static growth trend, in contrast to the changing and higher variable growth rates of tomato and onion. In the first decade, CAGR produced a growth rate of 5.14 %, that lowered in the second decade during 2015-2024, however potato production continued to maintain positive growth at a growth rate of 2.95 % as shown in Table 1. Although potato production showed a moderate growth trend, it remained relatively stable since it is a steady crop to grow and building production processes, it also reflected better storage than the other two crops and demand. This stability was not fully captured in previous comparative studies, which often treated all vegetables uniformly.

#### EXPORT ANALYSIS (2004-2024)

**Export quantity performance:** The performances of export quantities show different patterns and volatility in the 3 crops over the two decades.

**Tomato:** The quantities of tomato exports represent the most volatile performance of any of the crops. In the first decade (2004-2014) tomato exports were recording setting with unprecedented scaling up, achieving an annualized growth rate of 56.74 %, indicating India's rapid rise of prominence in the international tomato export narrative. The extraordinary growing period was bolstered by increased harvest areas, better varieties and improved transport infrastructure. However, in the second decade (2015-2024) there was a dramatic reversal with a negative annualized growth rate of -11.51 % year on year as a comparison to the previous decade, representing possibly the most drastic decline in the space of horticulture exports overall as shown in Table 2. The reversal in tomato export quantities is indicative of a combination of challenges, including quality control challenges in producing highest caliber fruit, increased phytosanitary prohibitions and requirements,

more qualitative import producers in place globally and absorption of export supply demand domestically to create consistent exports for the processes. This extreme volatility pattern was not adequately predicted in previous export studies, which generally projected more stable growth trajectories.

**Onion:** The onion export quantity has also shown remarkable resilience and stability over the last two decades compared to other crops. During the first decade of our analysis there was a strong CAGR of 12.16 % and reflected India's strong position as one of the top suppliers of onion in the world. The second decade (2015-2024) on the other hand had only marginal growth with a CAGR of 0.50 %, or no growth at all as shown in Table 2. This marginal performance at a time of significant contraction and complications shows tremendous longevity and layering of support for onion exports, provided by consistent demand, established relationships and India's natural advantage in producing onions. The consistency of observed demand falls in line with the inherent nature of onion in most cuisines around the world and the ability of India maintain market share after they imposed sporadic conditions on the exports. Previous research often overlooked the impact of periodic export bans on long-term market relationships, which this analysis reveals as a critical factor.

**Potato:** Potato quantity record exports are positive in both decades examined, which is the most consistently of any crop studied. The first decade records a potential increase with an extremely robust CAGR of 23.78 %, which validates India as an emerging potato exporter. The second decade of the analysis demonstrated modest, but positive, growth at a CAGR of 5.47 %, though slower and more tempered as shown in Table 2. All in all, the steady positive trajectory confirms India's position within the global potato market, compounded with the growing processing capacity, storage and quality factors associated with Indian potato globally. This consistent performance differs from earlier studies that predicted greater volatility across all vegetable exports.

**Export value performance:** The gross export value for these products provides interesting additional insights into price trends and relative economic positions of the respective markets in conjunction with quantity performance insights.

**Tomato:** The tomato gross export value data has clearly illustrated price volatility that amplifies the quantity trends. In the first decade (2004-2014), the tomato export gross values had exceptional growth with an astonishing CAGR of 65.47 % as shown in Table 2, which was close to double the rate of growth in quantity and suggests unit gross values were increasing and moving into premium markets possibly. This remarkable gross value performance indicates deeper penetration into higher gross value and quality premium markets for Indian tomatoes. However, the second decade had a much worse -13.14 % CAGR for gross value decline, which was much worse than the quantity decline. This would suggest as much as volumes, Indian tomato exports were also under pressure for prices that would reflect quality and quality and market position pressures leading to price competition. The severity of this value decline was not anticipated in previous market analysis studies.

**Onion:** The export values for onion has significantly better performance as it relates to value growth before converging with quantity. In the 2004-2014 time period export values with tertiary categories had 18.38 % CAGR value growth compared to the

**Table 2.** CAGR of TOP products exports (2004-2024)

Products /Decades	Quantity		Value	
	2004-2014	2015-2024	2004-2014	2015-2024
<b>Tomato</b>	56.74406	-11.5132	65.47498	-13.1419
<b>Onion</b>	12.16296	0.500139	18.37995	0.421843
<b>Potato</b>	23.77707	5.47235	30.7142	4.546956



quantity 12.16 % CAGR as shown in Table 2. This suggests an obvious capacity to do value addition about price position. The premium price would also reflect that India likely had some reputation of quality onions and some leverage of price bargaining due to this reputation in global markets. For the second decade, the export gross value growth declined again to 0.42 %, essentially equal statistical performance as quantity growth, but suggested unit prices were stable rightfully although volume growth had paused. This is important to note as it indicated onion was consistently a stable valued product that India likely maintained its market reputation across global markets. This price stability advantage was underestimated in previous comparative export studies.

**Potato:** Export values for potato commodities have continued to outpace quantity growth indicating effective value adding techniques. The first decade achieved a value CAGR of 30.71 %, compared to a quantity CAGR of 23.78 % and that is impressive. The high value-producing growth is indicative of strength in premium positioning and on developing the potato market to higher-value segments. The second decade values considerably lost steam, although there was still positive value growth (4.55 % CAGR) which kept pace with quantity growth as shown in Table 2. All of this suggests there continues to be confidence in the quality of Indian potatoes and the ability to maintain price premiums with the growing number of competitors in the marketplace. Earlier research often failed to recognize this value-addition capability in the potato sector.

## CDVI

### Production instability (CDVI)

**Tomato:** The CDVI for tomato production decreased from 8.82 % (2004-2014) to 5.85 % (2015-2024) indicating production is becoming more stable over those two time periods as shown in Table 3. Given that both CDVI are in the low instability zone (0-15 %), while the growth rate may be slowing, tomato production is now at a stable level of production which has developed more trust and management capacities for producers. This improvement in production stability contrasts with previous studies that predicted increasing volatility due to climate change.

**Onion:** Onion production may still be producing some instability, however the CDVI for onion production increased from 9.26 % to 10.76 % which are both in the low instability zone as shown in Table 3. The growing instability may be a reflection that onions are more susceptible to weather changes at planting and market price variability to determine sowing decisions. This increasing instability trend was not adequately captured in earlier stability analyses.

**Potato:** Potato production may be the most stable with the CDVI decreasing from 6.42 % to 5.14 % as shown in Table 3. The CDVI indicates good stability trends between decades which can be attributed to more established production system practices, stable management of irrigation and consistent demand in the end market. Previous research underestimated this stability advantage of potato production systems.

**Table 3.** CDVI of TOP products production (2004-2024)

Products / Decades	Quantity	
	2004-2014	2015-2024
Tomato	8.82	5.85
Onion	9.26	10.76
Potato	6.42	5.14

### Export instability (CDVI)

#### Export quantity instability:

**Tomato:** The quantity of tomato exports had high variability for both decades as shown in Table 4. The mean CDVI for quantity was 45.71 % during the first decade, which puts it in the high variability range (30 % and above). During the second decade, this variability increased to a mean CDVI of 55.79 %. This means we can infer that extremes of variability in volumes exported in tomato was experienced without proper long-term forecasting of market estimates. The extreme variability suggests there are difficult conditions to successfully forecast supplies in this product category exported outside of India. The contributing factors to the instability included variability from seasonal production, quality control issues, pest and disease invasiveness and domestic market price levels fluctuating consumer behaviours concerning exports. This level of export instability far exceeds what was reported in previous trade studies, suggesting earlier research may have used different methodological approaches or shorter time periods.

**Onion:** The exported onion quantity showed in Table 4 the evidence of medium instability and variability in the second decade. The mean CDVI increased from 20.76 % (2004-2014) to 29.60 % (2015-2024) barely missing the upper boundary of high instability at 30 %. The increase in instability can be accounted for by the frequency of periodic bans on exports due to domestic shortages, also crop production variability due to excessive weather factors and finally, storage causing loss of quality also contributing to quantity supply instability. The mean CDVI level during the last decade is nearing high instability of (30 %) suggests that there are difficult conditions to successfully forecast any amounts of export quantity despite the powerful amount of production in India. Previous studies often underestimated the impact of policy interventions on export stability.

**Potato:** Exported quantity of potatoes showed in Table 4 a significant improvement in stability. The coefficient of variation in exported quantity decreased from 33.78 % (2004-2014) to 14.20 % (2015-2024). This change classified the exported quantity's stability from the high instability level range to a low instability level range. The significant increase in stability was the only notable increase in stability improvement of the crops assessed in this study that was notable and clearly shows, improved and strong, export infrastructure, improved supply chain management, better quality producing supplying country, better storage facilities and better production planning for its export market. This dramatic stability improvement was not sufficiently highlighted in previous comparative studies.

#### Export value instability:

**Tomato:** Tomato export values Table 4 also demonstrate considerable instability, first decade CDVI being at 43.60 % and increasing by 3.43 % to 47.03 % during the second decade. Furthermore, export values are still in the high range of instability, but lower than quantity instability, suggesting tomato

**Table 4.** CDVI of TOP products exports (2004-2024)

Products / Decades	Quantity		Value	
	2004-2014	2015-2024	2004-2014	2015-2024
Tomato	45.71144	55.79448	43.60234	47.03283
Onion	20.76443	29.60801	23.12778	17.9417
Potato	33.7804	14.20408	35.0675	30.12477

prices were very unstable on international markets. The volatility in tomato export values could reflect a variety of issues related to quality inconsistencies, market acceptance and competition from other suppliers with differing pricing methods. Earlier market studies often failed to capture this level of price volatility.

**Onion:** Onion export values Table 4 show improved stability, with CDVI dropping from 23.13 % during the first decade to 17.94 % during the second decade, from medium instability to low-medium instability. While value instability did improve, quantity instability remained the same at medium instability indicating that exporters were able to do a better job of actualizing expected price realizations, thereby enhancing overall value. The value and CDVI reflect both good price premiums sustained and greater levels of market confidence, confidence pertaining to the quality of onions exported to those markets. This price management success was not adequately explored in previous research.

**Potato:** Potato export values Table 4 demonstrated higher stability as well, albeit not significantly higher than quantity at 35.07 % to 30.12 % for the last two decades, respectively. While it is still on the borderline of the medium and high instability range, meaning potato export values have more the potential to improve, the drop in volatility demonstrates that an improved price management strategy and market positioning has been implemented previously to lessen resulting value variability. Previous studies often overlooked this price stability achievement in potato exports.

#### Underlying factors influencing growth and instability

**Tomato:** Over the past two Decades, India's tomato production has seen an abrupt decline in growth rate from 11.6 % to 2.1 % CAGR from 2000-2021, compounded by climate stresses and pest pressures, with heatwaves and erratic rainfall reducing flowering and thus yield and fruit borer (*Helicoverpa armigera*) causing 40-50 % crop losses (14) and late blight disease (left as *Phytophthora infestans*) impacting yield by solely reducing yields under humid conditions (15). Export performance was catastrophic with export quantity declining 11.5 % and export value declining 13.1 %, with policy interventions such as export bans to maintain domestic supplies of tomatoes resulting in reduced exports, increased phytosanitary intervention has confused potential trade patterns, failing infrastructure including cold-chain and poor-quality control measures have contributed to post-harvest losses and less competitiveness (16). There was increased production stability via Integrated Pest Management (IPM) and crop insurance programs, that appeared to improve variance while then there remain export stability critically high above 45 % CDVI due to continued frequency of export bans either preventatively or due to erratic entry patterns faster than the disruption of export bans (17).

**Onion:** The onion sector in India is seeing a slowing trend in production growth with an expected CAGR decreasing from roughly 11.0 % to 4.8 % due to increased input costs (ie, water constraints driven by depletion of groundwater in conjunction with rising irrigation costs and policy uncertainty related to unrelenting export bans which dampened and outlawed incentives for farmers and lost area expansion) (18, 19). Export performances are revealing soles stagnant amounts (a CAGR of only 0.5 %), while Taka prices (which have not disadvantaged farmers at a 0.4 % value actuator) are lending further to Indian

identity due to more certainty around quality and an ongoing demand for excellent exports, supported by more tariff and a ban on Minimum Export Price (MEP) to improve farmers price realisation despite less stoic behaviour of exporters, or producers/channel (20). The sector is revealing disparate behaviours across different forms of tensions at various types of stability while quantity stability is losing ground as intra year movements have moved from 21 % to 30 % CDVI (this is trending higher due to and when largest volume dealers are unsure and unpredictable ie, empires and tsunamis arising from export bans, higher days of higher super norm market arrivals are not regular, weather anomalies, hoarding behaviours), while value stability has improved from 23 % to 18 % (as seen by startlingly effective policy and/or changes) primary input was good decisions from leaders through public policy concerning MEP and the implementation of differential export duties and related trade facilitation measures. Political climate is easier to manipulate by grossly improving futures and how private price can be tolerated primary behaviours focused on differences in more defined unit price fluctuation compared with other season prices (21).

**Potato:** The potato sector in India has exhibited moderate growth in production with the CAGR decreasing from 5.1 % to 3.0 %, driven by good irrigation systems, well-established potato production practices and the development of processing industries (22). Export performance is also continuing to grow but at declining rates, in terms of quantity decreasing as disappointing growth rates from 23.8 % to 5.5 % CAGR and value also disappointing from 30.7 % to 4.6 % CAGR, attributable to increased cold storage capacity and reduced supply linkages to local cold stores and local markets (23). We have also witnessed significant improvements in sector stability where quantity instability (CDVI) has decreased substantially from 33.8 % to 14.2 % and where value instability has also decreased to a lesser extent but as a result of increased investment in modern storage, cold-chain and improved supply linkages to improve overall market reliability and reduce volatility in production performance and in export performance (24, 25).

#### Markov Chain analysis - Trade direction stability

##### Tomato exports

In Table 5, the transitional probability matrix for tomato exports shows differences in retention probabilities of shares among major importing countries in the period of 2014 - 2024. Bangladesh is the most stable importer with the highest retention share probability of 70.6 % and represents a high level of marketing loyalty and stability. The 'others' category demonstrated high retention of 72.2 % showing that there was stable customer demand from a diversified pool of smaller markets. There was moderate retention in Nepal with 26.5 %. Markets such as Maldives, UAE, Oman, Qatar, Bahrain, Saudi Arabia had a retention probability of 0 % and represent that India has fully lost its market share and is likely to be highly variable in these destinations. This extreme market concentration and loss pattern was not adequately addressed in previous trade direction studies.

Finding consistent distribution of lost market shows Bangladesh took 29.8 % of incurred market share from losses incurred by Nepal and it has developed its competitive position and strong hold of the total overall market export of tomatoes. UAE took a huge share of the market from relocated losses from

**Table 5.** Transitional probability matrix of tomato export (2014-2024)

	Bangladesh	Nepal	Maldives	UAE	Bhutan	Oman	Qatar	Baharain	Singapore	Saudi Arab	others
Bangladesh	<b>0.706</b>	0.177	0.045	0.000	0.073	0.000	0.000	0.000	0.000	0.000	0.000
Nepal	0.298	<b>0.265</b>	0.030	0.163	0.000	0.190	0.037	0.000	0.000	0.016	0.000
Maldives	1.000	0.000	<b>0.000</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
UAE	0.221	0.548	0.000	<b>0.000</b>	0.000	0.000	0.231	0.000	0.000	0.000	0.000
Bhutan	0.000	0.000	0.000	0.890	<b>0.035</b>	0.056	0.000	0.007	0.012	0.000	0.000
Oman	0.000	0.000	0.000	1.000	0.000	<b>0.000</b>	0.000	0.000	0.000	0.000	0.000
Qatar	0.000	0.085	0.000	0.915	0.000	0.000	<b>0.000</b>	0.000	0.000	0.000	0.000
Baharain	0.000	0.000	0.000	1.000	0.000	0.000	0.000	<b>0.000</b>	0.000	0.000	0.000
Singapore	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.580	<b>0.044</b>	0.376	0.000
Saudi Arab	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>	0.000
others	0.046	0.000	0.004	0.227	0.000	0.000	0.000	0.000	0.000	0.002	<b>0.722</b>

exporting learned several ends of tomato phases from experienced losses of an 89 % from Bhutan and, 91.5 % of the reduced market from losses of Qatar. It is notable that Nepal relative to incurred losses (73.5 %) also took market share from UAE (54.8 %) and, other importing markets, indicating some elements of compensation in market dynamics. Overall market quantitative analysis, including in limited tomatoes report, found there was evidence of market 0 % retention in six of the eleven major markets, indicative of high volatility in tomato export markets, because of the high volatility raised likely involves some significant structural shifts outcomes of tomato export destinations from India.

#### Onion exports

The transitional probability matrix for onion exports (Table 6) from 2014 to 2024 demonstrated a solid relative stability of the market share with general movement of importing countries in and out of the import market from India. However, the stability of the exporting markets is much different. Bangladesh strongly indicates market loyalty with 65.2 % market retention, the most loyal and stable onions importer of India. The other category indicated 100 % retention which suggests that the demand for Indian onions is provided by the many smaller markets. In contrast Malaysia has the total market exit with 0 % retention indicating a total loss of this market over the study period. Previous studies often failed to analyze destination-specific stability patterns with this level of detail.

The evaluation of the share redistribution finds that Bangladesh lost 26.4 % as share to Sri Lanka and lost 5.8 % share to Vietnam, but Bangladesh maintained its leading dominant share of the onion import market. The various importing markets made meaningful loss of their existing share to Bangladesh. The UAE lost its entire share to Bangladesh demonstrating a full 100 % redistribution of share (with the UAE being below the line). Sri Lanka received a great deal of share redistributed to it due to all of Nepal's share loss and large amounts from losing markets. Malaysia resulted in an apparent 100 % loss share with share up draft primarily coming from Malaysia's loss going to the UAE (84.7 %) and Kuwait (15.3 %). As indicated, the analysis shows that 8 of the 11 major markets (Malaysia, UAE, Sri Lanka, Nepal, Kuwait, Maldives, Oman and Vietnam) show a 0 % retention, representative of the extent of volatility in the onion export markets.

#### Potato exports

The transitional probability matrix of potato exports Table 7 presents a markedly different pattern of stability in market share for potato exports compared to tomato and onion when comparing mid-2014 to mid-2024. Regarding absolute market stability, Nepal stood alone at 100 % retention and virtually stood alone for most stability overall, making them by far the best and most stable importer of Indian potatoes. Oman displayed 84.7 % retained market share and had a stable and

**Table 6.** Transitional probability matrix of onion export (2014-2024)

	Bangladesh	Malaysia	UAE	Sri Lanka	Nepal	Kuwait	Indonesia	Maldives	Oman	Vietnam	others
Bangladesh	<b>0.652</b>	0.026	0.000	0.264	0.000	0.000	0.000	0.000	0.000	0.058	0.000
Malaysia	0.000	<b>0.000</b>	0.847	0.000	0.000	0.153	0.000	0.000	0.000	0.000	0.000
UAE	1.000	0.000	<b>0.000</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sri Lanka	0.000	0.000	0.000	<b>0.000</b>	1.000	0.000	0.000	0.000	0.000	0.000	0.000
Nepal	0.000	0.000	0.000	0.000	<b>0.000</b>	0.000	0.424	0.000	0.576	0.000	0.000
Kuwait	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>	0.000	0.000	0.000	0.000	1.000
Indonesia	0.000	0.156	0.000	0.673	0.000	0.000	<b>0.000</b>	0.171	0.000	0.000	0.000
Maldives	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>	0.000	0.000	1.000
Oman	0.893	0.000	0.107	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>	0.000	0.000
Vietnam	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>	0.000
others	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>1.000</b>

**Table 7.** Transitional probability matrix of potato export (2014-2024)

	Nepal	Oman	UAE	Sri Lanka	Maldives	Kuwait	Qatar	Hong Kong	Mauritius	Baharain	Seychelles	others
Nepal	<b>1.000</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Oman	0.000	<b>0.847</b>	0.134	0.000	0.000	0.000	0.000	0.019	0.000	0.000	0.000	0.000
UAE	1.000	0.000	<b>0.000</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sri Lanka	0.051	0.160	0.000	<b>0.297</b>	0.000	0.000	0.013	0.009	0.000	0.000	0.041	0.429
Maldives	1.000	0.000	0.000	0.000	<b>0.000</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kuwait	1.000	0.000	0.000	0.000	0.000	<b>0.000</b>	0.000	0.000	0.000	0.000	0.000	0.000
Qatar	1.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>	0.000	0.000	0.000	0.000	0.000
Hong Kong	1.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>	0.000	0.000	0.000	0.000
Mauritius	0.000	0.000	0.000	0.959	0.000	0.000	0.000	0.000	<b>0.000</b>	0.041	0.000	0.000
Baharain	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>	0.000	0.000
Seychelles	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>	0.000
others	0.559	0.008	0.054	0.140	0.050	0.065	0.003	0.008	0.100	0.006	0.005	<b>0.000</b>

consistent demand for Indian potatoes and were good stability case. Sri Lanka exhibited moderate stability with 29.7 % retained market share and only grew relative to other cases of imports from India. This extreme concentration on Nepal was not captured in previous market diversification studies.

The assessment of the total market shares that were redistributed shows that overall, there were several countries that included the UAE, Maldives, Kuwait, Qatar, Hong Kong, Bahrain and Seychelles which was 0 % retained market share redistributing everything (100 %) to Nepal. This has led to total redirects significantly increasing Nepal's dominance as the destination for India's potato exports and has lessened Sri Lanka's position despite retaining (70.3 %) of original shares, they did gain a substantial amount from the remaining markets that included (95.9 %) of everything lost from Mauritius. For the category "others", this had 0 % retained share with almost everything being redirected mostly to Nepal (55.9 %) and some overlapping with Sri Lanka (14 %). Overall, the results indicate that perfect retention values combined with the ability to gain so much from the other losses indicates a rather concentrated destination of Indian potato exports.

#### **COVID-19 Pandemic impact on export trends (2020-2024)**

The COVID-19 pandemic significantly influenced export performance in the latter part of the second decade, compounding the already declining trends observed from 2015 onwards. The pandemic created unprecedented disruptions in global supply chains, affecting all three crops but with varying intensities. Tomato exports, already experiencing decline, faced additional challenges due to their perishable nature and the breakdown of cold chain logistics during lockdowns, with vegetable prices declining substantially at the pandemic's onset and over 80 % of farms reporting sales declines (26). Export restrictions implemented by the Indian government to ensure domestic food security further destabilized international market relationships, particularly affecting the onion sector where periodic bans became more frequent. The government repeatedly imposed export bans on onions, converting the export policy from 'free to prohibited' to control domestic prices. These export restrictions, while intended to provide relief to domestic consumers, significantly hurt farmers' interests and damaged India's image as a reliable exporter (27). The pandemic also highlighted infrastructure weaknesses in processing and storage facilities, which had been building throughout the second decade. International buyers shifted preferences toward processed and packaged vegetables during the pandemic, disadvantaging India's fresh produce export model. Enhanced phytosanitary requirements implemented by importing countries created additional barriers, while labor shortages in the informal vegetable handling sector disrupted export logistics. During the COVID-19 lockdown, vegetable prices soared across India with up to 40 % hikes in seasonal vegetables like tomato, spinach and capsicum, while more perishable gourds sold at three times higher prices. These pandemic induced factors accelerated the export performance decline, revealing the vulnerability of India's vegetable export strategy that relied heavily on fresh produce without adequate investment in processing infrastructure (28).

## **Conclusion**

The comprehensive analysis of India's top three vegetable exports (2004-2024) reveals dramatic shifts in production and export performance with critical implications for policy formulation. Production growth rates declined significantly across all crops: tomato CAGR fell from 11.57 % to 2.12 %, onion from 11.01 % to 4.79 % and potato from 5.14 % to 2.95 % between the two decades. Export performance showed even more striking divergence - tomato exports collapsed from 56.74 % to -11.51 % CAGR with export values declining from 65.47 % to -13.14 %, while potato exports demonstrated remarkable consistency with quantity growth moderating from 23.78 % to 5.47 % and achieving unprecedented stability improvement (CDVI decreasing from 33.78 % to 14.20 %). Onion exports stagnated with quantity growth dropping to 0.50 % CAGR yet maintained price stability with value growth at 0.42 %. The Markov Chain analysis exposed extreme market concentration risks, with tomato exports showing 0 % retention probability in six major markets and potato exports becoming heavily dependent on Nepal (100 % retention). The COVID-19 pandemic exacerbated existing vulnerabilities, particularly affecting tomato exports through supply chain disruptions and increased phytosanitary barriers. These findings underscore the urgent need for crop-specific export strategies, with potato sector's stability improvements through enhanced storage and supply chain management offering valuable lessons for revitalizing tomato and onion export performance.

## **Future research gaps**

Future studies should address climate resilience strategies for vegetable exports, conduct granular state level export performance analysis, evaluate the impact of bilateral trade agreements on market stability, examine processing infrastructure development potential and assess the effectiveness of integrated pest management programs on export quality consistency.

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## **Authors' contributions**

VA carried out the survey, analysed the data and formulated the manuscript. RB assisted in data collection and Analysis as part of the research study. ND contributed by developing ideas, reviewing the manuscript and assisting with procuring research grants. PG helped in summarizing and revising the manuscript. GS contributed to summarizing and provided additional support and contributions to the research study. BKP help to carry out the analysis part. All authors read and approved the manuscript.



## Compliance with ethical standards

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