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Growth and Stability of Citrus Sector in West Bengal : A Decadal Analysis (2014-15 to 2023-24)

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ABSTRACT

Citrus fruits are among the most important fruit crops in India, contributing significantly to nutrition, livelihoods, and the horticultural economy. West Bengal, with its unique agro-ecological conditions, plays a notable role in citrus production, though its contribution is often overshadowed by central and north-western states. Understanding trends in area, production, and productivity is essential to inform policy and research for strengthening the citrus sector. This study examines a decade of data (2014-15 to 2023-24) on mandarin orange and other citrus (limes, lemons, pomelos, grapefruits, etc.), sourced from the Ministry of Agriculture and Farmers' Welfare, Government of India. Using growth models, trend regressions, and instability indices, we assessed performance and variability of citrus in the state. Results revealed significant inter-annual fluctuations in production, modest positive growth in mandarin, and high instability in other citrus. Productivity trends were largely stagnant, indicating challenges in technology adoption, varietal choice, and orchard management. Correlation analyses highlighted strong linkages between area expansion and production growth, but weaker associations with productivity. The findings underscore the need for targeted interventions in varietal improvement, pest and disease management, and post-harvest handling. This paper provides empirical evidence to guide state-level strategies for sustainable citrus development.

Keywords : Citrus, Growth, Stability analysis, West Bengal

Introduction

Citrus fruits represent one of the largest and most diverse groups of fruit crops globally, with immense economic and nutritional importance. Globally, citrus occupies over 10 million hectares and contributes nearly 170 million tonnes of production annually, dominated by sweet oranges, mandarins, lemons, limes, pummelos and grapefruits (FAO, 2023). Citrus fruits are valued not only for their refreshing taste but also for their rich content of vitamin C, flavonoids, dietary fiber, and essential oils that contribute to human health and wellness (Kumar *et al.*, 2021). They also underpin livelihoods of millions of small and marginal farmers across Asia, Latin America, and the Mediterranean basin.

India is the third largest citrus producer in the world after China and Brazil, with an area of over 1 million

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hectares and production exceeding 14 million tonnes (MoAFW, 2024). The country is particularly rich in genetic diversity of citrus, encompassing mandarins, sweet oranges, acid limes, lemons, and pummelos (Roy *et al.*, 2023). Among these, mandarins account for 41.75% of the citrus production, followed by sweet orange (26.47%), limes and lemons (26.36%) and other citrus (5.42%), cultivated across diverse agro-ecological zones. The citrus industry in India has been growing steadily; however, challenges such as citrus decline, pest and disease incidence (particularly citrus greening and tristeza), and post-harvest losses continue to affect productivity and profitability (Ladaniya, 2022).

West Bengal, although not traditionally viewed as a major citrus-producing state, contributes significantly to the eastern Indian citrus belt. During 2023–24, the area and production of citrus in the state was 24.01 thousand ha and 147.93 thousand MT, respectively; representing 3.61% of the total fruit production in West Bengal (MoAFW, 2024). In terms of output, citrus ranked eighth among major fruit crops, positioned after banana (1440.01 thousand MT), mango (882.27 thousand MT), pineapple (347.08 thousand MT), papaya (334.16 thousand MT), jackfruit (227.81 thousand MT), guava (223.76 thousand MT), and watermelon (222.53 thousand MT). This indicates that while citrus contributes a modest share to the overall fruit basket, it remains a crop of regional significance with scope for further expansion.

The state's humid subtropical climate supports cultivation of mandarins, limes, lemons, and other citrus fruits, primarily in districts such as Darjeeling, Kalimpong, Jalpaiguri, and Cooch Behar. Limes and lemons are grown in small scales in almost all the districts; whereas, pummelos are found mainly in homestead gardens or wild habitats. Sweet orange cv. Mosambi cultivation is getting popular in lateritic zone in West Bengal. Sweet Orange cv. Malta (*Siki Mosambi*) is also gaining popularity in the districts of Nadia, North 24Parganas, Purulia, Bankura, Purba Bardhaman, Birbhum, Murshidabad, and in northern districts like Alipurduar, Jalpaiguri, Siliguri areas of Darjeeling. Darjeeling Mandarin is one of the finest Mandarin and grown in the Darjeeling and Kalimpong hills. It was earlier predominantly grown in Buxa areas of present Alipuduar district. Santathalabari, the gateway of Buxa was famous for the market of oranges. The names were derived from two Nepali word *Santala* and *bari* means Oranges and garden respectively. The orange cultivation of the Buxa region was affected due to floods, landslide and decline problems were also started from the decades back. The Govt of West Bengal has started initiatives to rejuvenate Mandarin orange cultivation in the hills of Buxa region of Alipurduar district by distributing healthy planting materials, HRD training programmee etc. Citron is also important group of citrus particularly for its pleasant aroma and flavour. In West Bengal it is commonly known as *Gandharaj* and grown in backyard of home garden almost for all the districts of West Bengal. Lime and lemons is are cultivated throughout the state, mostly in Nadia,

North 24-Parganas, Purulia, Bankura, Midnapore-West. Citrus cultivation in West Bengal has potential both for local consumption and for supplying fresh fruits to metropolitan markets like Kolkata and neighboring states. Yet, systematic studies on the performance of citrus in West Bengal remain limited compared with states like Maharashtra, Madhya Pradesh, Punjab, or Andhra Pradesh.

Assessing area, production, and productivity trends over time is critical for several reasons. First, it provides insights into the dynamics of expansion and contraction of citrus cultivation. Second, it highlights the contribution of different citrus groups such as mandarin versus other citrus such as limes and lemons to the state's horticultural output. Third, instability analysis helps to identify risks and vulnerabilities in crop production systems, often linked with climate variability, biotic stresses, and market fluctuations (Chand and Raju, 2009). Finally, such analyses support evidence-based policymaking, resource allocation, and design of intervention strategies for productivity enhancement.

Against this backdrop, the present paper undertakes a comprehensive trend analysis of citrus in West Bengal over the past decade. The specific objectives are to assess temporal trends in area, production, and productivity of mandarin and other citrus; to estimate growth rates; to examine temporal variability; to explore correlations between area, production, and productivity; and to identify implications for policy and practice to enhance the citrus sector in the state.

Materials and Methods

Data Sources

The dataset for this study was compiled from the official publications of the Ministry of Agriculture and Farmers' Welfare, Government of India. Annual statistics on area and production of horticultural crops were extracted for the period 2014-15 to 2023-24. Data for mandarin orange were available consistently for all ten years. In contrast, area and production data for limes and lemons were available only for three years (2018-19 to 2020-21), while data for other citrus were missing in these years. To maintain consistency, limes and lemons and other citrus were grouped under 'Other Citrus'. Productivity (tonnes per hectare, MT/ha) was calculated as production divided by area. Data were cleaned and validated using Microsoft Excel prior to analysis.

Statistical Analysis

A series of statistical techniques were applied to assess growth and variability.

Descriptive statistics : Mean, standard deviation, coefficient of variation (CV), minimum, and maximum were computed for each series to understand the distribution and variability.

Compound annual growth rate (CAGR) : Growth was estimated using a log-linear model equivalent to Excel's LOGEST function :

$$yt = b.m^t \Rightarrow \ln yt = \ln b + \beta t$$

where $m = e^{\hat{a}}$

The CAGR was derived as $(m^{-1}) \times 100\%$ (Akther *et al.*, 2025).

Trend analysis : Ordinary least squares (OLS) regression was performed for each series (area, production, productivity) against time. The slope, intercept, coefficient of determination (R^2), standard error, and *p*-value were reported (Montgomery *et al.*, 2021).

Instability analysis: The Cuddy–Della Valle Instability Index (CDVI) was applied to measure variability corrected for trend :

$$CDVI = CV(\%) \times \sqrt{1 - R^2}$$

where CV is the coefficient of variation and R^2 is from the trend regression (Cuddy and Della Valle, 1978; Hazell, 1982).

Correlation analysis : Pearson correlation coefficients were calculated among area, production, and productivity to explore inter-relationships (Zar, 2014).

Share analysis : Proportional contributions of mandarin and other citrus to total citrus area and production were estimated annually and averaged for the period.

Software and visualization : Analyses were carried out in Python 3.10 using packages pandas, numpy, scipy, and matplotlib. Microsoft Excel was used for construction of tables and figures.

Results and Discussion

Overview of Citrus Statistics in West Bengal

Over the period from 2014-15 to 2023-24, citrus cultivation in the state shows distinct trends across area, production, and productivity (Figure 1). The area under citrus cultivation has expanded considerably, with Mandarin Orange increasing moderately from 4.01 to 4.47 thousand hectares (11.6%), while Other Citrus almost doubled from 8.24 to 19.53 thousand hectares (137.2%). Consequently, the total citrus area nearly doubled, rising from 12.25 to 24.01 thousand hectares (96.1%). In contrast, production trends are mixed. Mandarin Orange declined slightly from 39.1 to 38.29 thousand tonnes (–2.1%), whereas Other Citrus rose significantly from 74.5 to 109.64 thousand tonnes (47.2%), resulting in an overall increase in total citrus production from 113.6 to 147.93 thousand tonnes (30.2%).

However, productivity (yield) indicates a declining trend across categories. Mandarin Orange yield fell from 9.75 to 8.56 t/ha (–12.2%), Other Citrus experienced a sharper decline from 9.05 to 5.61 t/ha (–38.0%), and overall citrus productivity reduced from 9.28 to 6.16 t/ha (–33.6%). These observations suggest that while area expansion has driven growth in overall citrus output, declining productivity poses a challenge to the sector's sustainability and efficiency.

The descriptive statistics (Table 1) provide a baseline understanding of citrus performance in West Bengal over the ten-year period (2014-15 to 2023-24). Other citrus consistently occupied a larger share of citrus area, with mean values substantially higher than those of mandarin orange. Production followed a similar pattern, reflecting the dominance of other citrus in the state's citrus economy. However, productivity levels remained modest and largely stagnant,

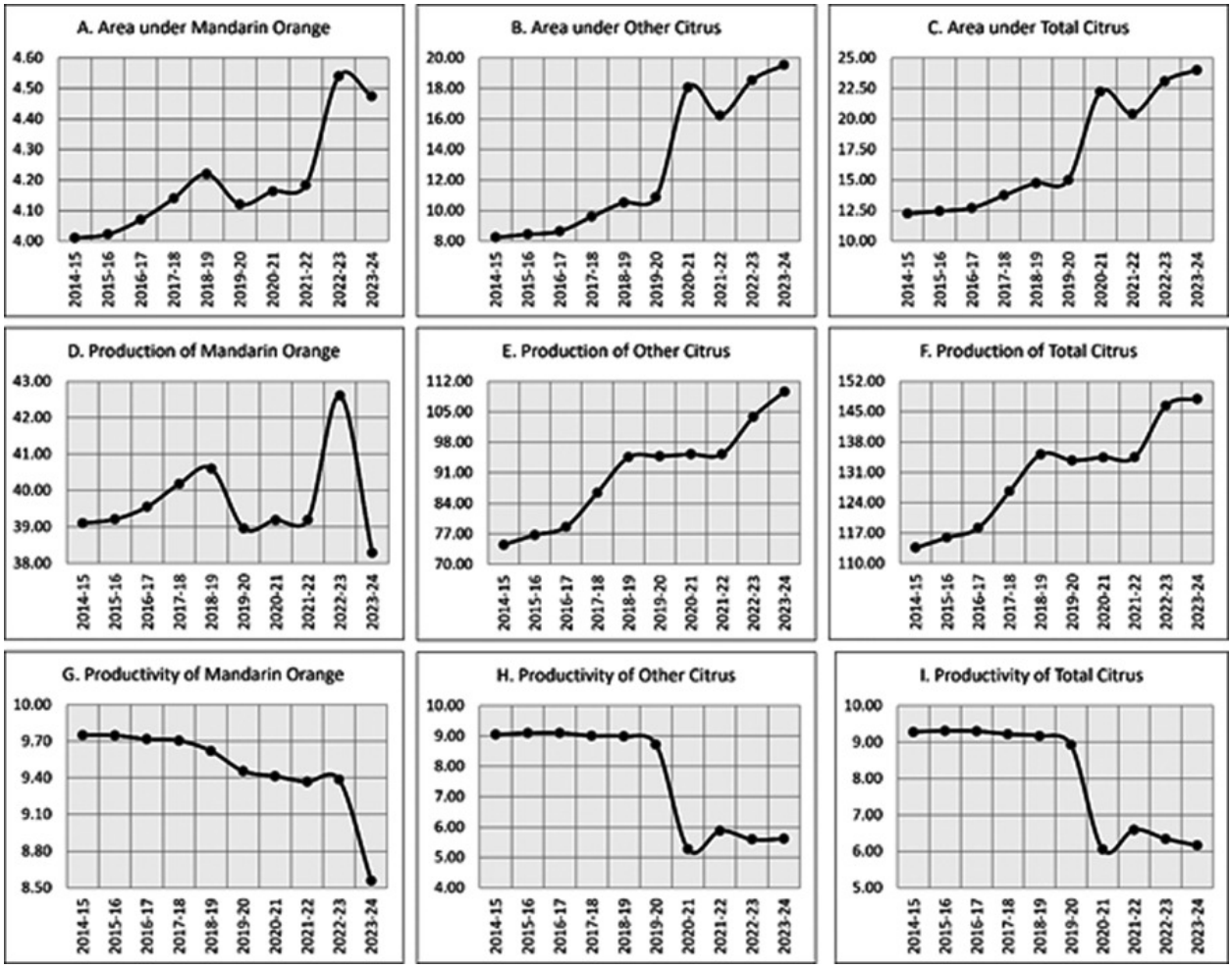

Figure 1. Area, Production and Productivity of Mandarin Orange, Other Citrus and Total Citrus in West Bengal from 2014-15 to 2023-24

covering around 8-9 MT/ha for mandarins and 7-9 MT/ha for other citrus. The coefficient of variation (CV) was relatively high for other citrus in both area and production, suggesting greater vulnerability to fluctuations. In India, such instability has likewise been attributed to multiple factors, including the introduction of new or experimental fruit varieties, shifts in consumer preferences, market volatility, and the variable success of cultivation influenced by climatic fluctuations and disease outbreaks (Priyanka and Kerur, 2023). The minimum and maximum values underscore inter-annual variability. Mandarin area expanded consistently, whereas other citrus oscillated with sharp increases and decreases. This uneven performance suggests that while other citrus cultivation benefitted from gradual area expansion, mandarin orange remained constrained by inadequate management practices.

Table 1 : Descriptive statistics of area, production, and productivity of citrus crops in West Bengal (2014-15 to 2023-24)

Statistics	Mandarin Orange			Other Citrus			Total Citrus		
	A	P	Y	A	P	Y	A	P	Y
Mean	4.19	39.69	9.47	12.87	90.96	7.63	17.06	130.65	8.03
Maximum	4.01	38.29	8.56	8.24	74.50	5.28	12.25	113.60	6.05
Minimum	4.54	42.61	9.75	19.53	109.64	9.10	24.01	147.93	9.31
S.D.	0.18	1.21	0.36	4.64	11.67	1.77	4.79	11.95	1.51
C.V.(%)	4.26	3.05	3.77	36.09	12.82	23.14	28.07	9.15	18.84

A = Area (Thousand ha); P = Production (Thousand MT); Y = Productivity (MT/ha)

Growth Dynamics of Area, Production, and Productivity

Growth rates estimated through the LOGEST model highlight critical differences between mandarin and other citrus categories (Table 2). Mandarin orange recorded marginal growth in certain years. The production Compound Annual Growth Rate (CAGR) was positive but lower than that of area, and productivity gains were almost absent. Priyanka and Kerur (2023) reported positive CAGR in orange cultivation in India due to increasing consumer awareness of the health benefits. These trends suggest that area expansion rather than yield improvements remains the principal driver of citrus growth in the state. Similar findings have been documented at the national level, where citrus growth has largely relied on increasing area rather than yield-enhancing technologies (Goyal *et al.*, 2020). Bairwa *et al.* (2012) also reported that the productivity of fruit crops in India was almost stagnant from 1991-92 to 2007-08.

Table 2. Compound annual growth rates (CAGR) for area, production, and productivity of citrus crops in West Bengal (2014-15 to 2023-24)

Statistics	Mandarin Orange			Other Citrus			Total Citrus		
	A	P	Y	A	P	Y	A	P	Y
CAGR (%)	1.20	0.14	-1.04	11.78	4.24	-6.74	8.99	2.97	-5.53
log_slope	0.01	0.00	-0.01	0.11	0.04	-0.07	0.09	0.03	-0.06
log_intercept	1.38	3.67	2.29	2.00	4.32	2.32	2.41	4.74	2.32

A = Area (Thousand ha); P = Production (Thousand MT); Y = Productivity (MT/ha)

By contrast, other citrus area expanded at a moderate but consistent pace, yielding positive CAGR values. Production also showed a steady increase, suggesting that farmers perceive other citrus as remunerative and resilient under West Bengal's agro-ecological conditions. However, productivity exhibited negative growth, pointing to decline in yield levels. This stagnation has been reported elsewhere in India where productivity gains are often offset by declining soil fertility, pest incidence, and inadequate orchard rejuvenation (Ladaniya, 2022).

Trend Analysis of Area, Production, and Productivity

The linear trend regressions provide further clarity on the trajectory of citrus cultivation (Table 3). For other citrus, the slope coefficients for area and production were positive and statistically significant, confirming sustained expansion across the decade. The intercepts suggest that production levels were initially modest but improved gradually. However, productivity slopes were statistically non-significant, underscoring yield stagnation. This indicates that despite more land being devoted to other citrus, the underlying technological and management practices have not improved yields. Mandarin orange exhibited weaker slopes, often non-significant, especially for productivity. This reflects inconsistent cultivation practices and perhaps lower economic incentives for farmers to invest in mandarin orchards.

Table 3. Linear OLS regression results and Cuddy–Della Valle Instability Index for citrus crops in West Bengal (2014-15 to 2023-24)

Statistics	Mandarin Orange			Other Citrus			Total Citrus		
	A	P	Y	A	P	Y	A	P	Y
Slope per year	0.05	0.06	-0.10	1.43	3.73	-0.50	1.48	3.79	-0.44
Intercept	3.97	39.41	9.91	6.43	74.17	9.89	10.39	113.58	10.00
R^2	0.73	0.02	0.68	0.87	0.94	0.74	0.88	0.92	0.76
p value	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S.E. of slope	0.01	0.14	0.02	0.20	0.34	0.10	0.20	0.39	0.09
CDVI (%)	2.20	3.01	2.13	12.98	3.19	11.72	9.83	2.52	9.16

A = Area (Thousand ha); P = Production (Thousand MT); Y = Productivity (MT/ha)

Stability in Citrus Production

The stability analysis using the Cuddy-Della Valle Index (CDVI) reveals important dimensions of citrus performance (Table 3). For mandarin orange, CDVI values for area and production were moderate, indicating relatively stable growth trajectories. This aligns with earlier observations that citrus productivity in India is constrained by citrus huanglongbing, canker, and other biotic stresses (Bove, 2006).

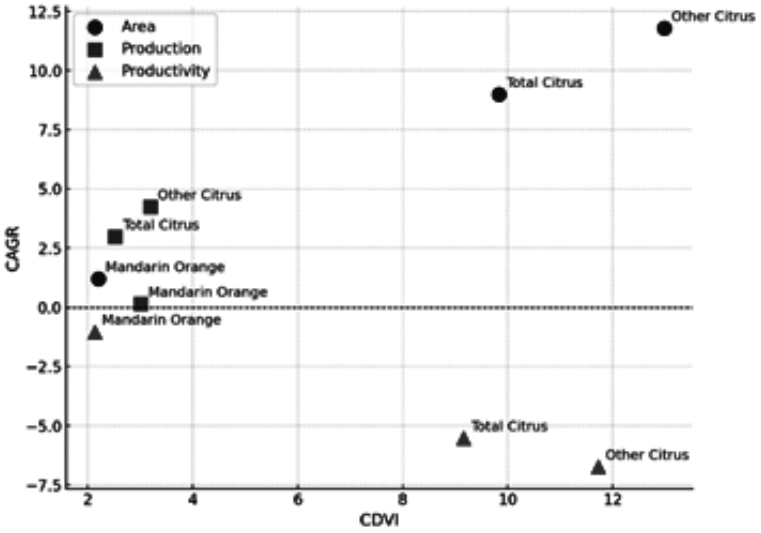

Figure 2. Growth vs. Instability in Area, Production and Productivity of citrus crops in West Bengal

Other citrus showed significantly higher instability, particularly in productivity. This reflects the fragile nature of lime and lemon cultivation in the region. High instability reduces farmers' confidence in maintaining orchards, leading to abandonment or conversion to other crops. This trend is consistent with the observations of Goyal *et al.* (2020), who reported that for lemon, fluctuations in area contributed more significantly than fluctuations in productivity to overall production instability, whereas for orange, the instability in area and productivity were nearly equal during the period 2010–11 to 2018–19. Scatter plots of CAGR versus CDVI (Figures 2) provide a useful synthesis. While mandarin clusters around medium instability, other citrus occupies the quadrant of high instability. This reinforces the notion that policy support for stabilizing other citrus cultivation is urgently required.

Correlation Analysis

The correlation matrix provides insights into the interdependence among area, production, and productivity (Figure 3). For mandarin orange, correlations were less consistent, with weaker linkages between area and production. This suggests that other factors such as citrus decline exerted greater influence on production variability.

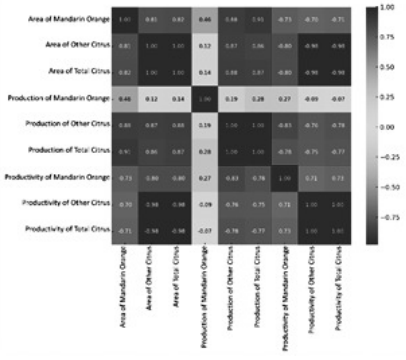

Figure 3. Pearson correlation coefficients among area, production, and productivity of citrus crops in West Bengal (2014-15 to 2023-24)

Weak correlations with productivity further emphasize the absence of systematic yield improvements. For other citrus, area and production were highly correlated, indicating that production growth was primarily driven by area expansion. However, productivity was weakly correlated with both area and production, showing that yields remained independent of area expansion. This reflects a common trend in Indian horticulture, where productivity improvements often lag behind area growth.

Share of Mandarin and Other Citrus

The share analysis underlines the dominance of other citrus crops in West Bengal's citrus landscape (Table 4). Across the decade, other citrus crops accounted for the majority of citrus area and production, with shares often exceeding 70%. Mandarin contributed less consistently, maintaining notable but smaller proportions and reflected a declining trend.

Table 4. Shares (%) of mandarin and other citrus in total citrus area and production in West Bengal (2014-15 to 2023-24)

Year	Share in Area (%)		Share in Production (%)	
	Mandarin Orange	Other Citrus	Mandarin Orange	Other Citrus
2014-15	32.75	67.25	34.42	65.58
2015-16	32.29	67.71	33.82	66.18
2016-17	32.02	67.98	33.47	66.53
2017-18	30.13	69.87	31.73	68.27
2018-19	28.62	71.38	30.04	69.96
2019-20	27.48	72.52	29.13	70.87
2020-21	18.73	81.27	29.15	70.85
2021-22	20.49	79.51	29.14	70.86
2022-23	19.67	80.33	29.10	70.90
2023-24	18.64	81.36	25.88	74.12

The combined analyses present a coherent picture of citrus cultivation in West Bengal. Modest but steady expansion in mandarin area and production, stagnant productivity, and high instability in other citrus. This pattern suggests that production growth is largely area-driven, with limited yield enhancement. This phenomenon is not unique to West Bengal; similar trends have been documented in other citrus-growing states, highlighting systemic challenges in productivity enhancement (Bairwa *et al.*, 2012; Goyal *et al.*, 2020). Gurung *et al.* (2020) explained

the infestation of insect-pests and diseases, poor cultural practices and lack of quality planting materials are the main reasons for decline in area and production. The high instability in other citrus crops has serious implications for farmer livelihoods and market stability. Variability in yields not only reduces income predictability but also affects supply chains and pricing. Addressing instability requires multi-pronged strategies such as developing disease-resistant varieties, producing disease-free planting material, promoting scientific orchard management, and investing in irrigation infrastructure to buffer against climatic shocks.

Strategic Interventions

The stagnation in productivity reflects an urgent need for technological interventions. Encouraging the adoption of scientific crop cultivation and promoting sustainable agricultural practices are essential for improving productivity (Priyanka and Kerur, 2023). Research has shown that yield gaps in citrus can be narrowed through practices such as canopy management, balanced nutrient application, and integrated pest and disease management. Extension services in West Bengal must prioritize dissemination of such practices to farmers, accompanied by training and demonstrations. Without rigorous nursery standards and pack-house protocols, fruit lots vary in size, juice content, and exterior quality, limiting access to premium retail and export channels. National reviews of citrus technology transfer underline the need to scale disease-free planting material and modern nursery systems.

Post-harvest losses also contribute to low realized productivity. Citrus fruits are perishable and prone to damage during handling and transportation. Deficits in grading, pre-cooling, and cold-chain capacity leads to price volatility and shrinkage, issues especially acute for perishable citrus fruits. Investment in cold storage, pack houses, and value-addition units could enhance the profitability of citrus cultivation (Ladaniya, 2022). The state could also leverage branding initiatives to differentiate its niche citrus produce like Darjeeling mandarin in domestic and export markets. The dominant export flows of Indian citrus to Bangladesh and Nepal, geographies adjacent to West Bengal, suggests realistic near-term cross-border opportunities for the state to boost the export through strategic planning.

At the policy level, the findings underscore the importance of focusing not only on expansion of area but also on stabilization of yields and reduction of variability. State documents also highlight push factors such as pack-house management contracts, cold-chain investments, FPO mobilization, etc., useful to citrus clusters in North Bengal and the plains. Establishing center of excellence on citrus, launching citrus-based mission mode projects, strengthening farmer collectives, facilitating access to credit, and providing crop insurance could further mitigate risks associated with citrus sector in West Bengal.

Most of the Mandarin orange orchards in Darjeeling Hills are seedling origin. In this locality, the crop is seldom provided recommended nutrient and Mandarin is intercropped with heavy feeder crop like ginger, turmeric, maize etc. The soils of these areas are acidic in nature and annual

rainfall is also high. Prevailing acidic soil favours micro nutrient deficiencies and development of aluminium toxicity along with deficiency of zinc and other micronutrients. This situation for a long period creates a stress condition to Mandarin orchard and plants suffer with for proper nutrition. Use of rootstock may have better role for proper biotic and abiotic stress resistance as well as combating the toxicity effect of elements which may lead to invigorate the condition of prevailing orchard scenario in association with proper nutrient management. The proper canopy management to get the solar light interception is seldom practiced by the local growers of this region.

Scope of canopy management through rejuvenation of old senile orchard as well as pruning of semi old orchard also be addressed. Mandarin oranges are also grown in the Buxa Dooars area of Alipurduar district and sub–Himalayan Terai region. The cultivation of Mandarin oranges to be promoted in the non-traditional areas of Jalpaiguri, Cooch Behar, Alipurduar and Siliguri areas. There is an ample scope of lime/lemon and sweet orange cultivation in this state. Location specific screening of different cultivars of lime/lemon and sweet orange are to be required. Pumellos are found profusely in the northern parts of the state. Wide survey and documentation is required for selecting better clones.

Therefore, to revitalize the citrus sector in West Bengal, following strategies may be adopted :

A. Variety and planting material

1. **Varietal diversification :** Beyond specialty citrus varieties of the state, it is essential to introduce disease-resistant and nutritionally enriched cultivars that align with the growing consumer demand for healthy fruits.
2. **Rootstock–scion optimization :** Selection of rootstocks proven under Eastern Himalayan conditions is critical to balance vigour, fruit quality, and disease tolerance. Dwarfing rootstocks such as Flying Dragon and Trifoliate orange should also be evaluated under the acidic soil conditions of the North Bengal hills.
3. **Clean nursery chains :** Large-scale production of disease-free planting material must be prioritized through techniques such as shoot-tip grafting, containerized nurseries, and molecular indexing for viral and virus-like pathogens. Licensing of nursery technologies developed by ICAR-Central Citrus Research Institute, Nagpur (ICAR-CCRI), coupled with capacity-building for public and private nurseries, will ensure the supply of certified plants.

B. Nutrition, water, and climate resilience

1. **Orchard management :** Adoption of scientific planting systems such as half-moon terraces on hill slopes and raised-bed or high-density planting in plains, along with canopy management and ground cover techniques will improve light interception, control weeds, and stabilize yields during dry spells.

2. **Soil health management :** Farmers should transition towards soil- and leaf-test-based integrated nutrient management programmes for more precise and sustainable orchard nutrition.
3. **Irrigation access in hill belts :** Wider promotion of drip irrigation, fertigation, and water-harvesting structures tailored to hilly ecosystems is required to address water scarcity.
4. **Soil and water conservation :** Innovative natural resource management practices should be popularized and adopted. ICAR Research Complex for NEH Region, Meghalaya developed many innovative natural resource management techniques which may be applicable to the North Bengal citrus-growing belts.
5. **Citrus based integrated farming systems :** Proper land use through citrus based farming systems approach by integrating citrus with other crops and livestock/poultry/ fishery enterprises will support natural resource conservation and provide supplementary income to smallholders, particularly during the non-bearing years of citrus orchards.
6. **Orchard rejuvenation :** Ageing and low-productivity orchards must undergo systematic rejuvenation through top-working or phased replacement programmes.

C. Plant health management

1. **HLB-Vector Management :** Management of Huanglongbing (HLB) demands routine surveillance, removal of infected trees, psyllid control, and synchronized block-level interventions.
2. **Control of Phytophthora and Borers :** Growers must be trained on drainage improvement, trunk protection, wound treatment, and orchard sanitation to combat gummosis and borer infestation, both of which are serious issues in the state.
3. **Trap-Based Insect Management :** Low-cost and eco-friendly trap-based technologies should be popularized for pests such as citrus leaf miner and fruit fly.

D. Postharvest, processing, and markets

1. **Mechanized Postharvest Handling and Cold Chain :** Standardization of mechanized postharvest systems and cold chains in line with buyer specifications is vital to reduce losses and access premium markets.
2. **Processing Clusters :** Establishing citrus-processing clusters and MSME units will enable the manufacture of processed products, functional foods, and value-added commodities from citrus waste. Institutes such as ICAR-CCRI have already developed innovative products that can be licensed to industry players.
3. **GI-Led Branding for Darjeeling Mandarin :** With the GI application for Darjeeling mandarin

(Application No. 943) by Uttar Banga Krishi Viswavidyalaya (UBKV) under review, it is imperative to prepare a code of practice covering maturity indices, size grades, eco-labels, and traceability. GI branding can unlock premium domestic and regional export markets. Additionally, collaboration with the Tourism Department could promote "Hills Citrus Trails" as a form of horti-tourism.

E. Institutional support and outreach

1. **Decision support systems :** To promote integrated orchard management and precision citriculture, a decision support system (DSS) leveraging the power of artificial intelligence (AI), internet of things (IoT), remote sensing and geographic information system (RS-GIS) should be introduced. Development of such DSS, though time as well as cost consuming, is the need of the hour.

2. **FPO/FPC-centred cluster development:** To aggregate production for input services, calendar of operations, supply chain management, processing and marketing, FPO/FPC-centred cluster development is advisable. The district and block headquarters should be developed as Agri-growth Centre and Rural Business Hub, respectively in the line of One District One Product - Districts as Export Hubs (ODOP-DEH).

3. **Capacity building :** Capacity building of the growers should be the major crux of the citriclture-led development. The State Government should collaborate with ICAR-CCRI and State Agricultural Universities (SAUs) for rapid dissemination of advanced citrus-technologies in order to narrow the adoption gap.

4. **Citripreneurship development :** The Government of West Bengal should promote citripreneurship particularly in the area of citrus nursery and citrus processing. The CitriHub agribusiness incubation centre of ICAR-CCRI is competent to provide citribusiness incubation support to the existing and aspiring startups and agripreneurs.

5. **Leveraging Public-Private Partnerships :** Public–Private Partnerships (PPPs) hold significant potential for fostering innovation and investment in the citrus sector. Strategic collaboration among government agencies, private enterprises, research institutions, and farmer organizations can accelerate technology development and dissemination, strengthen infrastructure, and promote value-added product creation. By bridging the gap between research and field practice, PPPs ensure that scientific advancements are effectively translated into practical solutions and measurable benefits for farmers.

6. **Area expansion in non-traditional citrus growing pockets :** Area expansion activities should be undertaken in non-traditional citrus growing pockets. For example, the red and lateritic zone of West Bengal holds a great

potential for sweet orange and acid lime cultivation.

7. **Citrus Advisory, State Citrus Dashboard and Market Intelligence :** A state e-advisory along with on-ground farmer field schools may be co-developed with ICAR-CCRI and/or SAUs covering end-to-end citrus value chain. Additionally, a real-time dashboard should be developed integrating information of State Department of Horticulture, mandi arrivals/ prices, weather forecast and advisories, export pack-house throughput and other support schemes/programmes. State should also ensure that citrus is notified under Pradhan Mantri Fasal Bima Yojana (PMFBY) in key districts and should bundle crop insurance with low-interest working capital for input adoption.

F. Policies and schemes

1. **Citrus Clean-Plant and Accredited Nursery Mission :** A state-level programme should focus on the production of index-tested, disease-free planting material through shoot-tip grafting, micro-budding, and containerized nurseries. A hub-and-spoke model involving public clean-plant hubs and private satellite nurseries should be promoted. The nursery technologies developed by ICAR-CCRI may be licensed by the state. State Government may tap or converge the funds of various schemes while building a state network. The nursery standards for specialty citrus crops should be standardized/refined and notified.

2. **Citrus Cluster Development Programme :** The state should operationalize citrus clusters under the Horticulture Cluster Development Programme with a dedicated Cluster Development Agency involving FPOs/FPCs to coordinate pre-production→ production → post-harvest → market/branding. Detailed project reports (DPRs) should cover planting material pipelines, rejuvenation, fertigation, pack-houses, cold-chain, and brand activation to make the clusters globally competitive. Integration with schemes such as Mission for Integrated Development of Horticulture (MIDH) will strengthen the programme.

3. **Citrus Rejuvenation Mission :** Drawing on North-East models, the mission should support top-working, canopy renewal, contingency irrigation, and nutrition advisory services etc. by providing financial assistance or performance-linked incentives. A "Decline Containment Plan" must be implemented for annual surveillance of HLB disease and other insect-pests, IPDM advisories including vector management through synchronized cluster-level interventions. ICAR-CCRI may be engaged as the technology partner under a consultancy project.

4. **Pack-House, Cold-Chain and Export Readiness Scheme :** Co-funding APEDA-compliant

packhouses, pre-coolers and reefer vans for citrus sector is essential. The state should incentivize mechanized postharvest handling, traceability and export training. State may extend subsidies for mechanized postharvest handling and quality assurance and also introduce "Export starter" grant. Special emphasis should be given to developing sea- and air-shipment export protocols for Darjeeling mandarin by ICAR-CCRI. *Operation Greens (TOP to TOTAL)* scheme of Ministry of Food Processing Industrie should be fully leveraged for price stabilization, logistics support, and working capital in citrus clusters. The State Government should first designate citrus as a priority crop under the *Operation Greens* window and establish a seasonal trigger protocol linked to data from state-regulated markets.

Conclusion

This study provides the first comprehensive statistical assessment of citrus in West Bengal over the past decade. The results show that the mandarin orange sector is highly unstable, while other citrus crops have expanded steadily, yet productivity gains remain elusive. Production growth has been largely area-driven rather than yield-led, underscoring systemic inefficiencies in orchard management and technology adoption. The high instability indicates vulnerability to climatic shocks and pest-disease pressures. Correlation analysis confirmed the central role of area expansion, while share analysis emphasized the dominance of other citrus in total citrus output. Moving forward, strategic interventions are required, including promotion of improved varieties, expansion of certified nurseries, training on scientific orchard management, systematic citrus rejuvenation and investments in post-harvest infrastructure. Such measures will not only stabilize productivity but also enhance farmer incomes and strengthen the citrus sector in West Bengal's horticultural economy. The findings offer critical evidence for policymakers, researchers, and extension agencies working toward sustainable citrus development. Further analysis incorporating district level data and contribution of specific crops to other citrus category would yield deeper insights in this context.

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