



## Spatio-Temporal Analysis of Hazelnut Production and Yield in Türkiye (1991–2022)

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### ARTICLE INFO

#### Research Article

Received : 18.08.2025  
Accepted : 18.11.2025

#### Keywords:

Hazelnut sector  
Black Sea region  
Production stability  
Structural factors  
Agricultural policy

### ABSTRACT

This study examines the dynamics of hazelnut production and yield in Türkiye between 1991 and 2022, based on long-term time series, spatial distribution, and regional comparisons. The findings reveal that fluctuations in production and yield have persisted, although a partial upward trend in production capacity has emerged in recent years. Spatial analyses confirm that the Black Sea belt remains the undisputed production core, while the Central Black Sea region, led by Samsun, has gained increasing importance. At the provincial level, Ordu, Giresun, and Sakarya stand out as key drivers of both total output and annual fluctuations. Overall, despite maintaining its global leadership, Türkiye's hazelnut sector continues to face multidimensional challenges, including low productivity, regional imbalances, production volatility, and quality issues which result in income fluctuations for growers, inconsistent supply for processors, and difficulties in meeting stable quality and export requirements. Over the long term, Türkiye's hazelnut production exhibits a clear upward trajectory. The average annual production increased from approximately 450 thousand tons in 1991–1999 to 559 thousand tons in 2000–2010, followed by a more moderate rise to 569 thousand tons in 2011–2019. A sharper growth pattern emerged in the recent period, with the average reaching 705 thousand tons in 2020–2022. Overall, these figures indicate a long-term increase of nearly 57% between the early 1990s and the early 2020s, reflecting structural improvements in production capacity despite year-to-year volatility. The relationship between yield and national production is weak ( $r = 0.11$ ), indicating that structural factors such as fruit-bearing tree counts and orchard area play a dominant role. Methodologically, the study integrates long-term time-series techniques (moving averages, percentage change, rolling volatility, simplified CUSUM) with spatial mapping and province-level contribution analysis, providing a novel multi-dimensional assessment of Türkiye's hazelnut sector over a 32-year period.

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## Introduction

Turkey is the undisputed leader in global hazelnut production, accounting for approximately 60–70% of world supply on its own (Kabaoğlu and Bozoğlu, 2023; Aydın Eryılmaz and Kılıç, 2019; Yavuz et al., 2022). Concentrated in the Black Sea region, hazelnut cultivation constitutes the primary livelihood for millions of smallholder family farms and forms the backbone of the region's socio-economic structure (Sertaç Gönenç, 2006; Kılıç et al., 2020; Ünver, 2024). However, the literature highlights several structural challenges facing Turkey's hazelnut sector. First, the country's hazelnut yield remains below the world average, undermining its competitiveness compared to rival producers (Ömür, 2023; Kabaoğlu and Bozoğlu, 2023). It has also been shown that high support prices, sustained over many years, expanded cultivation areas and created oversupply (Kılıç Topuz et al., 2019; Yavuz et al., 2022; Gönenç, 2006). While these policies

secured farmer incomes, they disrupted market balance and led to surplus and stock accumulation.

On the export side, Turkey continues to hold its leading position in global hazelnut trade. Turkey's share of the 290,570 tons of global hazelnut exports in 2024 is 183,093 tons, placing Türkiye in the leading position with a 63.01% share in global hazelnut exports (World Bank, 2024). Demir (2022), using the normalized revealed comparative advantage (NRCA) index, demonstrated that Turkey maintains a strong comparative advantage over other major producing countries. Similarly, Kılıç and Turhan (2020), Merdan (2024), and Kaplan and Çiçek (2025) show through time-series models that hazelnut exports are expected to maintain an upward trend in the medium term, though volumes will fluctuate with production cycles. Nonetheless, Turkey's heavy dependence on the EU market renders its competitive position vulnerable (Kabaoğlu and Bozoğlu, 2023).

Studies on sectoral sustainability also provide important insights. Meral et al. (2024) found significant interprovincial differences in economic sustainability scores, with enterprises in Samsun, Sakarya, and Düzce showing stronger performance. Hazneci et al. (2022) revealed that without subsidies, farmers would incur losses, underlining the critical role of agricultural support for sustaining production. At the same time, Erköse et al. (2020) argued that the root causes of sectoral problems lie less in small farm size and more in unequal power relations within the hazelnut market.

In recent years, research has increasingly addressed the environmental and quality dimensions of hazelnut production. Temizyürek-Arslan (2023), through a life cycle assessment (LCA) in Ordu province, identified chemical fertilizer use as the dominant source of environmental impacts, while labor-intensive harvesting accounted for the largest share of economic costs. Similarly, Valeriano et al. (2022) modeled the occurrence of the “rotten defect” in hazelnuts, linking it to climatic factors and fungal pathogens, and stressed the importance of developing predictive risk maps. These findings indicate that policy discussions in hazelnut production must extend beyond output levels to also include environmental sustainability and quality management.

Research on competitiveness and enterprise-level efficiency further emphasizes the need for transformation in the sector. Aydoğan (2023) found that corporate governance, e-commerce applications, and investments in skilled labor significantly enhanced competitiveness, while traditional low-cost strategies proved insufficient. Similarly, Kara (2024) showed that artificial neural networks can be used to forecast hazelnut prices, potentially helping to mitigate the adverse impacts of price volatility.

In summary, the existing literature demonstrates that while Turkey maintains global leadership in hazelnut production, it faces multi-dimensional challenges including low yields, market instability, environmental impacts, quality concerns, and regional disparities. In this context, data-driven analyses are essential not only to track production trends and spatial shifts but also to evaluate volatility, underlying determinants, sustainability indicators, and policy effects, thereby providing a holistic perspective on the sector’s future.

Comprehensive studies addressing long-term production and yield trends, spatial distribution, and regional disparities remain limited. This gap increases the need for evidence-based approaches in policymaking and producer organization strategies.

This study addresses this gap by analyzing Turkey’s hazelnut production and yield over the period 1991–2022 through time-series methods, spatial distribution analyses, regional comparisons, and determinant assessments. The aim is to uncover fluctuations, spatial clusters, and long-term dynamics in order to provide a comprehensive evaluation of the sustainability and strategic outlook of the hazelnut sector.

## **Materials and Methods**

The empirical foundation of this study is derived from the official Agricultural Production Statistics published by the Turkish Statistical Institute (TÜİK). The dataset covers

the period 1991–2022 and includes all provinces of Türkiye, thereby offering both a long-term temporal perspective and a comprehensive spatial coverage.

The selection of the 1991–2022 period is directly determined by data availability. According to official communication with the Turkish Statistical Institute (TÜİK), 1991 is the first year in which hazelnut-related production and yield statistics were systematically digitized and made available in structured form. Earlier records exist only as archived printed materials, which are not accessible in a consistent or machine-readable format. Therefore, the study relies on the earliest complete and standardized dataset obtainable through our official data request. The period 1991–2022 thus represents the longest continuous time span for which reliable, comparable, and fully structured national hazelnut data are available.

The core variables examined are total production measured in tons, average yield per tree expressed in kilograms per fruit-bearing tree, the number of fruit-bearing trees, the number of non-fruit-bearing trees, and the total area of hazelnut orchards measured in decares. This combination of variables provides an integrated framework to explore both structural determinants of production and productivity, as well as their geographic distribution.

The methodological approach employed in this study combines statistical time-series analysis, spatial analysis, structural correlation analysis, and robustness validation in order to capture the multidimensional dynamics of hazelnut production.

The methodological approach employed in this study combines statistical and spatial analyses in order to capture the multidimensional dynamics of hazelnut production. Time series analysis was used to examine long-term production and yield trends, annual rates of change, period averages, moving averages, and structural breaks. These techniques made it possible to identify persistent patterns as well as short-term fluctuations. Spatial analysis was conducted through the construction of choropleth maps and the application of clustering techniques, which allowed for the identification of production hotspots, spatial heterogeneity, and long-term shifts in the geographical center of production. Comparative and ranking analyses were applied to highlight provincial and regional differences, with slope graphs and grouped bar charts illustrating leadership changes and reconfigurations in the hierarchy of top-producing provinces.

To investigate underlying relationships, correlation and regression analyses were carried out between production outcomes and structural variables such as the number of fruit-bearing trees and total orchard area. These analyses helped determine whether production changes were more strongly associated with productivity improvements or with structural expansion. In addition, anomaly detection methods were applied to identify provinces or years that deviated markedly from long-term patterns, while resilience and stability indicators were used to assess the relative vulnerability of provinces to production shocks. Share and contribution analyses were performed to track how the proportional role of provinces in national output has evolved over time and to identify which regions have contributed most significantly to increases or decreases in total production.

The robustness of findings was tested through validation procedures. Out-of-time validation, in which the period 1991–2015 was used for training and 2016–2022 for testing, was combined with leave-one-province-out experiments to evaluate the generalization capacity of the models. All data processing, statistical analyses, and spatial visualizations were conducted using Python. Key libraries included Pandas for data handling and time series operations, Matplotlib and Seaborn for visualization of statistical results, and GeoPandas for spatial mapping and geographic analysis.

This integrated methodological design, combining temporal, spatial, and structural perspectives, provides a solid empirical basis for the systematic examination of Türkiye's hazelnut production dynamics and supports the formulation of evidence-based policy implications.

## Results

This section examines hazelnut production and yield in Türkiye over the period 1991–2022, structured into ten thematic categories. A total of 35 research questions were defined, addressing time-series dynamics, spatial distribution, regional comparisons, production–yield relationships, stability, anomalies, contribution analyses, robustness tests, and policy-oriented implications. While the number and scope of questions could have been expanded, the categories chosen here aim to provide a comprehensive and multidimensional understanding of hazelnut production across both temporal and spatial scales. The analysis draws upon a set of descriptive statistical and spatial techniques, including year-to-year growth rate calculations, period averages, moving averages, CUSUM-based structural break assessment, choropleth mapping, provincial and regional rankings, slope-graph comparisons, correlation analysis, volatility profiling through coefficients of variation, anomaly detection, and provincial share and contribution analysis. In addition, a simple national-to-provincial linear prediction model was used for leave-one-province-out validation. The findings were supported by diverse visualization techniques such as line and bar charts, grouped bar charts, slope graphs, multiple line plots, boxplots, scatter plots, area graphs, spatial choropleth maps, spatial cluster maps, stacked bar charts, and table–graph integrations. This combination of methods and visualizations allowed both temporal trends and spatial patterns to be clearly identified. In sum, this section systematically explores the temporal dynamics, spatial distribution, regional variations, and production–yield relationships of hazelnut production in Türkiye, while also addressing stability, anomalies, and contribution analyses. Furthermore, the results provide a solid foundation for forward-looking policy implications and strategic priorities for the sector.

### 3.1. Time Series & Trend

This subsection addresses seven key questions concerning the temporal dynamics of hazelnut production and yield in Türkiye. Specifically, the analysis explores: (i) how the national production trend evolved between 1991 and 2022, (ii) how the average yield per tree developed over the same period, and (iii) whether production and yield exhibited synchronous patterns. In addition, the study

investigates (iv) the years in which the sharpest increases or declines occurred, as measured by annual percentage change, (v) how decadal averages (1990s, 2000s, and 2010s) compare with one another, (vi) how the use of a five-year moving average smooths short-term fluctuations, and (vii) whether structural breaks or turning points can be identified in the long-term trajectory.

In this section, long-term trends are analyzed using annual production and yield series for the period 1991–2022. A 5-year moving average (MA) was applied to the raw series, and long-term trends were evaluated using linear trend regression. A simplified CUSUM plot was created to visualize structural changes over time. This analysis does not constitute a formal hypothesis test; it aims to intuitively reveal potential breaks and deviations in the series.

As shown in Figure 1, Türkiye's total hazelnut production between 1991 and 2022 exhibits pronounced annual fluctuations. Several peaks and troughs can be observed during the period, with some years experiencing sharp declines. While the long-term trend does not display a consistent increase across all years, the average production levels in the last decade are higher compared to the early 1990s.

As shown in Figure 2, the average hazelnut yield per tree in Türkiye between 1991 and 2022 displays pronounced fluctuations. Several sharp declines are evident during the period. Unlike total production, the yield trend shows less evidence of a sustained long-term increase. Moreover, peaks in yield do not always coincide with peaks in total production (Figure 1), indicating that production changes are also influenced by variations in the number of fruit-bearing trees and the total orchard area.

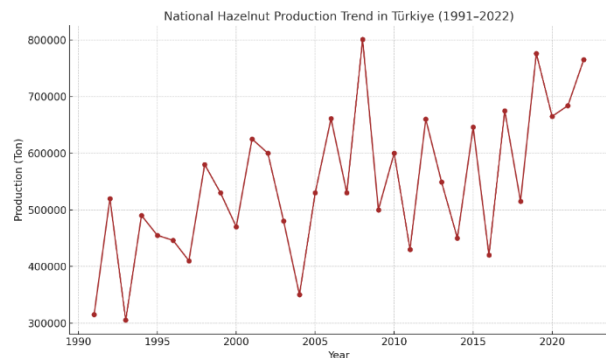


Figure 1. National Hazelnut Production Trend (1991–2022)

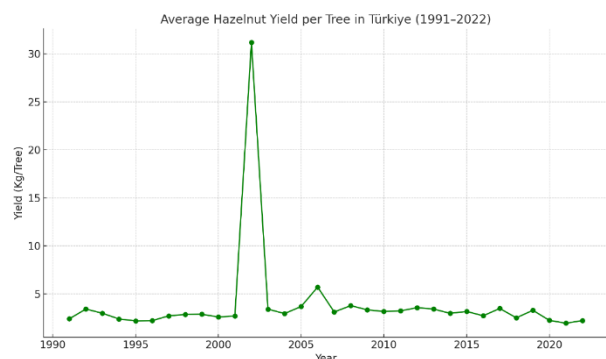


Figure 2. Average Hazelnut Yield per Tree in Türkiye (1991–2022)

As shown in Figure 3, the relationship between Türkiye’s annual average hazelnut yield per tree and total national production during 1991–2022 is weak, with a Pearson correlation coefficient of only 0.11. This indicates that changes in national production are not solely explained by yield fluctuations. The scatter plot also shows that years with relatively high yields do not always coincide with peak production years.

As shown in Figure 4, annual percentage changes in Türkiye’s total hazelnut production between 1991 and 2022 display considerable volatility. The largest increase was recorded in 1992, when production rose by about 65.08% compared to the previous year. The steepest decline occurred in 1993, with a decrease of approximately 41.35%. It is also evident that periods of strong growth are frequently followed by sharp declines.

As illustrated in Figure 5, Türkiye’s average annual hazelnut production has shown a consistent increase across decades. In the 1990s, the mean annual production was approximately 450,111 tons, rising to 554,679 tons in the 2000s and 572,105 tons in the 2010s. The current decade (2020–2022) has recorded the highest average so far, at around 704,667 tons. This upward shift in decadal averages suggests gradual long-term improvements in production capacity.

As shown in Figure 6, applying a five-year moving average smooths the pronounced annual fluctuations in Türkiye’s hazelnut production and provides a clearer view of the long-term trend. The smoothed curve indicates a

moderate upward trajectory from the early 1990s to the early 2020s, with distinct dips corresponding to low-yield periods such as the early 2000s and mid-2010s. A gradual increase in the moving average is also visible after 2017.

Using a simplified CUSUM (Cumulative Sum) method, potential structural changes in Türkiye’s hazelnut production between 1991 and 2022 were examined (Figure 7). The method flags years where cumulative deviations from the mean exceed a set statistical threshold. In this case, deviations are substantial in several multi-year stretches, particularly in the early 1990s and mid-2010s, which align with known low-yield and high-yield phases. While CUSUM here marks many consecutive years as being part of shifts, the most meaningful “turning points” appear around 1994–1995 (post-peak adjustment) and 2016–2017 (onset of higher sustained production levels).

The time series analyses for the period 1991–2022 reveal that Türkiye’s hazelnut production and yield are characterized not by steady growth but by substantial volatility and cyclical fluctuations. Synchronization between production and yield appears weak, with annual changes often marked by sharp increases or declines. Decadal averages and moving averages suggest a modest yet discernible upward trend over the long term, while the CUSUM analysis highlights structural breaks occurring in specific years. Overall, these findings indicate that hazelnut production exhibits a dynamic structure shaped by both short-term fluctuations and long-term shifts.

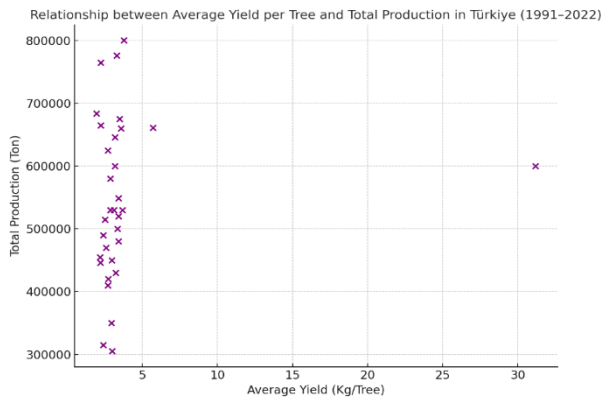


Figure 3. Relationship between Average Yield per Tree and Total Production (1991–2022)

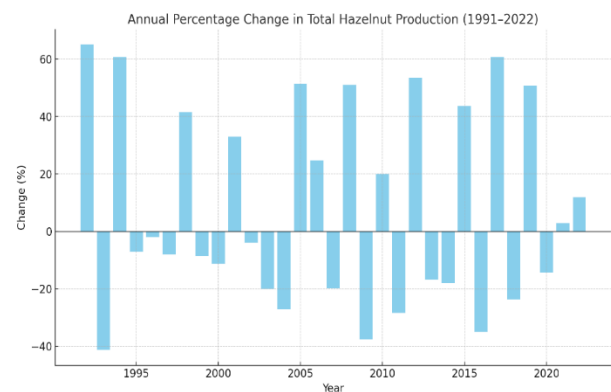


Figure 4. Years with the Sharpest Increases and Decreases in Production

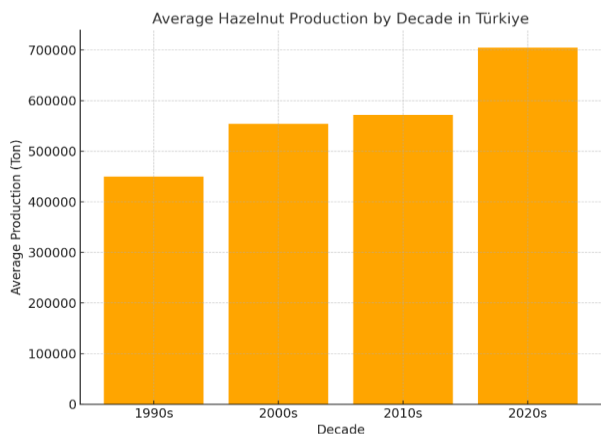


Figure 5. Decadal Average Production Levels

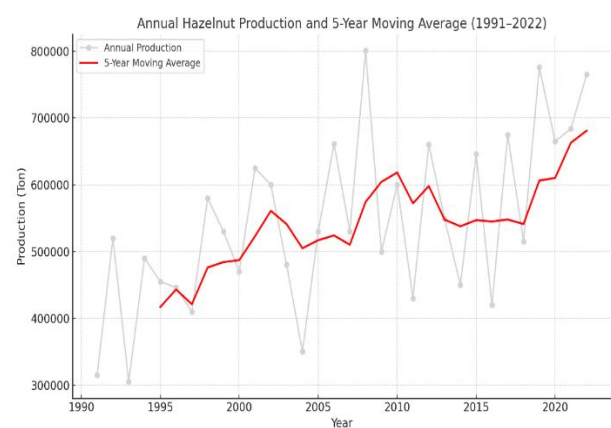


Figure 6. Annual Hazelnut Production and 5-Year Moving Average (1991–2022)

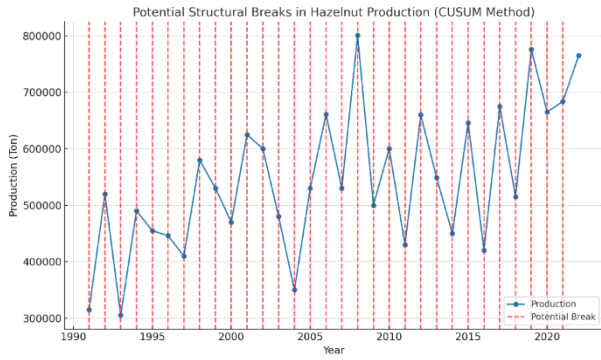


Figure 7. Potential Structural Breaks in Hazelnut Production (CUSUM Method)

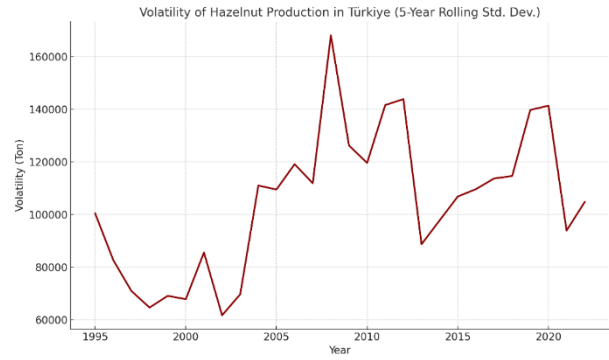


Figure 8. Volatility of Hazelnut Production in Türkiye (5-Year Rolling Std. Dev.)

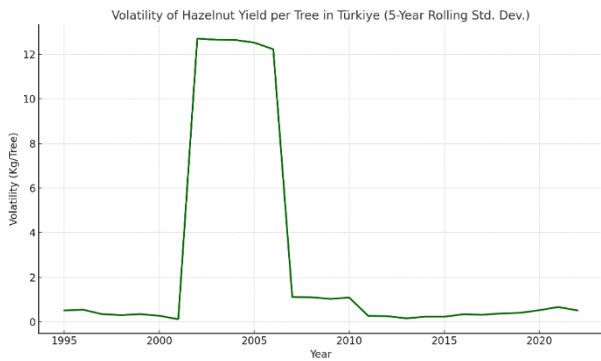


Figure 9. Volatility of Hazelnut Yield per Tree in Türkiye (5-Year Rolling Std. Dev.)

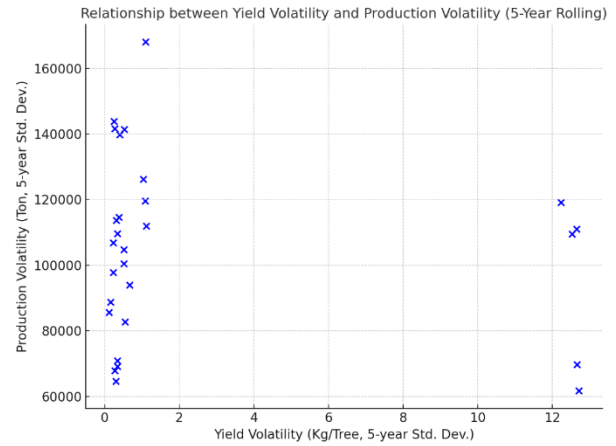


Figure 10. Relationship between Yield Volatility and Production Volatility (5-Year Rolling)

### Time Series & Volatility

This subsection addresses three key questions concerning the volatility of Türkiye's hazelnut production and yield. Specifically, the analysis examines: (i) how production volatility evolved across the years, (ii) in which sub-periods yield volatility increased or decreased, and (iii) whether there is a relationship between production and yield volatility.

For volatility analysis, variance, standard deviation, and Coefficient of Variation (CV) values for production series were calculated for each province and each year. Additionally, annual growth rates were used to measure interannual production changes. This approach allowed for comparing volatility levels at the provincial level and assessing long-term stability.

As illustrated in Figure 8, the five-year rolling standard deviation of Türkiye's hazelnut production reveals pronounced volatility across the 1991–2022 period. Production variability was particularly high in the early 1990s, reflecting large swings between peak and low-yield years. Volatility declined somewhat during the early 2000s but rose again in the mid-2010s, coinciding with sharp production fluctuations observed in those years. Toward the early 2020s, volatility appears to stabilize at relatively elevated levels, suggesting that while overall production capacity has grown, interannual variability remains a persistent challenge in Türkiye's hazelnut sector.

As shown in Figure 9, the five-year rolling standard deviation of average hazelnut yield per tree indicates strong fluctuations throughout 1991–2022. Yield volatility was most pronounced in the early 1990s and mid-2010s. The

trend shows cycles of increase and decrease, but without a clear long-term decline. Compared to production volatility (Figure 8), yield volatility displays a more variable pattern across shorter periods.

As depicted in Figure 10, the relationship between production volatility and yield volatility in Türkiye, measured by five-year rolling standard deviations, is weak and slightly negative, with a correlation coefficient of  $-0.16$ . This shows that fluctuations in yield do not consistently align with fluctuations in total national production.

The volatility analysis demonstrates that Türkiye's hazelnut production and yield between 1991 and 2022 were characterized by strong fluctuations rather than stability. Production volatility peaked in the early 1990s, declined in the early 2000s, and rose again in the mid-2010s, before stabilizing at relatively high levels in the early 2020s. Yield volatility followed a similar but more irregular pattern, with pronounced fluctuations in the early 1990s and mid-2010s and no clear evidence of long-term decline. The weak and slightly negative correlation ( $-0.16$ ) between production and yield volatility indicates that the two measures are only loosely connected, reflecting their largely independent dynamics.

### Spatial Distribution & Mapping

This subsection investigates the spatial dimensions of Türkiye's hazelnut production and yield across the period 1991–2022. Four questions are addressed: (i) how provincial-level production is distributed in the benchmark years 1991, 2000, 2010, and 2022; (ii) what yield maps for

the same years reveal about regional productivity patterns; (iii) how the highest production clusters are geographically positioned; and (iv) how the diffusion of production and yield outside the core Black Sea provinces has evolved.

Spatial analysis in this study was carried out using descriptive mapping techniques. Hazelnut production and yield values from the TÜİK dataset were mapped at the provincial level using GeoPandas-based choropleth maps. Provinces were categorized using quantile-based intervals and rank-based groupings, which allowed for a clear visual distinction of high-production and high-yield regions.

As visualized in Figure 11, hazelnut production is persistently concentrated along the Black Sea belt. A clear east–west corridor emerges with Ordu–Giresun–Trabzon on the eastern side and Samsun bridging toward the western belt that includes Sakarya–Düzce. Over time, the overall intensity increases (notably in 2010 and 2022), while the core geography remains stable. This confirms that national output is structurally anchored in a small set of coastal provinces, consistent with historical specialization.

Figure 12 shows that high-yield (kg/tree) hotspots do not always coincide with the top production provinces. In some years, several non-core provinces display relatively higher yields, while Black Sea provinces combine moderate yields with larger orchard scale to generate high output.

Table 1 presents the top five hazelnut-producing provinces in selected benchmark years (1991, 2000, 2010, 2022). The results consistently highlight Ordu, Giresun, and Trabzon as dominant centers in the eastern Black Sea region. By 2010, Samsun and Sakarya increasingly joined the top tier, reinforcing the dual east–west clustering pattern of Türkiye’s hazelnut sector.

Table 1. Highest Hazelnut Producing Provinces

Year	Province	Production (Ton)
1991	Ordu	94441
1991	Giresun	54214
1991	Bolu	46345
1991	Sakarya	45494
1991	Trabzon	31965
2000	Ordu	134975
2000	Sakarya	106014
2000	Giresun	56291
2000	Düzce	54670
2000	Samsun	44185
2010	Ordu	141714
2010	Sakarya	108150
2010	Samsun	83830
2010	Düzce	78902
2010	Giresun	74944
2022	Ordu	239935
2022	Samsun	111701
2022	Sakarya	98469
2022	Giresun	92305
2022	DÜZCE	83052

The spatial distribution of these leading provinces is further visualized in Figure 13, where the top five producers are marked in red tones while other provinces are displayed in lighter shades. The map confirms that production leadership is geographically concentrated along the Black Sea coast. Over time, a stronger bifurcation emerges: an eastern cluster (Ordu–Giresun–Trabzon) and a western cluster (Sakarya–Düzce), both of which remain the backbone of Türkiye’s global hazelnut dominance.

Provincial Hazelnut Production in Türkiye (1991, 2000, 2010, 2022)

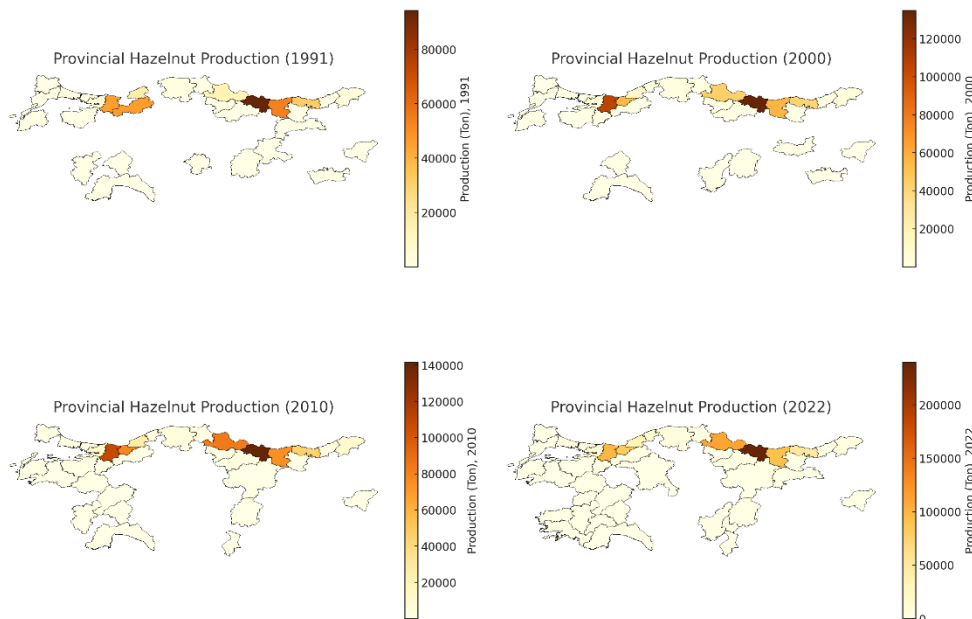


Figure 11. Provincial Hazelnut Production in Türkiye (Selected Years)

Provincial Hazelnut Yield per Tree in Türkiye (1991, 2000, 2010, 2022)

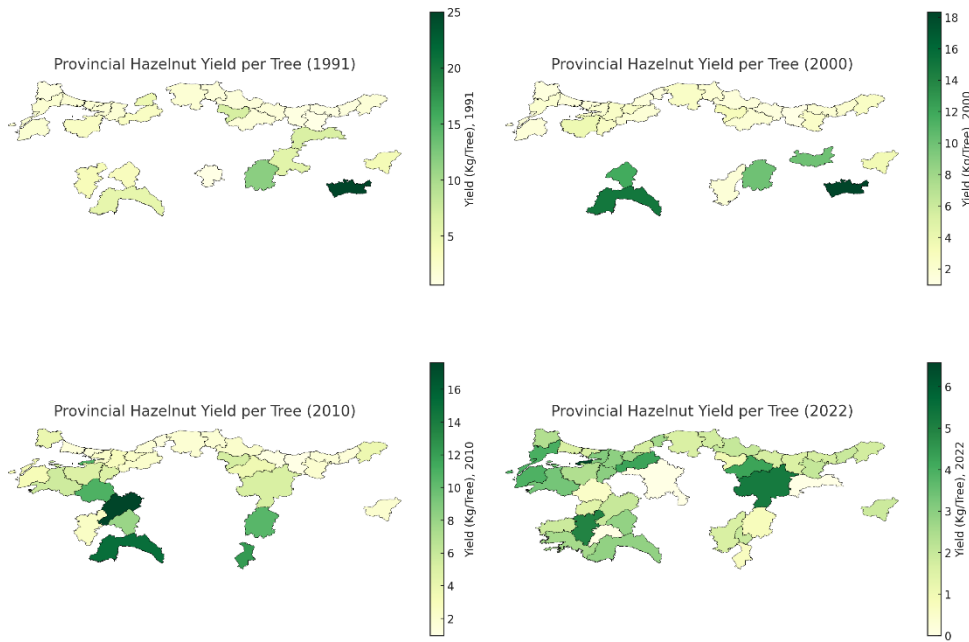


Figure 12. Provincial Hazelnut Yield per Tree in Türkiye (Selected Years)

Highest Hazelnut Production Clusters in Türkiye (1991, 2000, 2010, 2022)

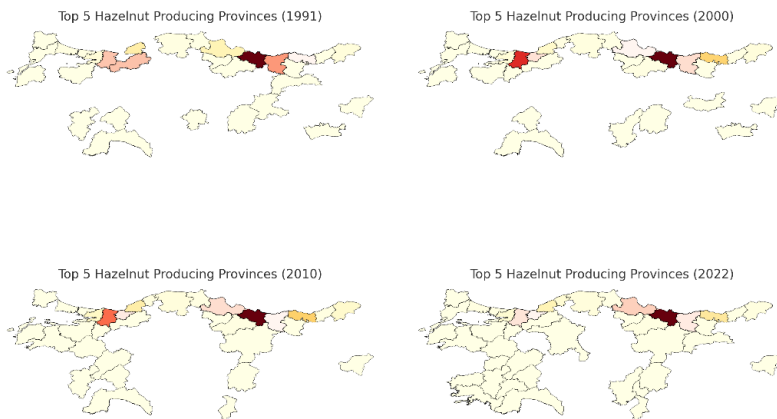


Figure 13. Highest Production Clusters

Table 2 summarizes the evolution of hazelnut production inside and outside the Black Sea region between 1991 and 2022. The results show that while non-Black Sea provinces contributed around %16 of national production in 1991, their share declined to 15.38% by 2022. The relative importance of the Black Sea region therefore increased over time, consolidating its position as the structural core of Türkiye’s hazelnut sector. The temporary rise in non-Black Sea contributions in 2000 and 2010 (around 24% and 21%, respectively) reflects episodic expansions into Marmara and other provinces. However, these gains proved unsustainable, as production remained overwhelmingly anchored in the Black Sea belt. The data confirm that Türkiye’s hazelnut industry continues to rely primarily on the eastern and western Black Sea clusters, with non-Black Sea areas playing only a supplementary role.

Table 2. Production Share Outside Black Sea

Year	Black Sea Total (Ton)	Non-Black Sea Total (Ton)	Non-Black Sea Share (%)
1991	263302	51698	16.41
2000	355439	114561	24.37
2010	475550	124450	20.75
2022	647365	117635	15.38

Table 3 compares the average yield per tree inside and outside the Black Sea region. Results show that, in all years, non-Black Sea provinces recorded substantially higher yields compared to the Black Sea provinces. For example, in 2010 the average yield outside the Black Sea was 4.261 kg/tree, compared to only 1.851 kg/tree within the core region. However, despite these localized yield advantages, the overall production share of non-Black Sea areas remained limited (Table 2).

Table 3. Yield Comparison: Black Sea vs Non-Black Sea

Year	Black Sea Avg Yield (Kg/Tree)	Non-Black Sea Avg Yield (Kg/Tree)
1991	1.944	3.192
2000	1.761	4.261
2010	1.851	5.299
2022	1.972	2.524

This discrepancy underscores that national leadership is determined more by orchard size and tree density rather than yield alone.

Overall, the spatial analysis demonstrates that Türkiye’s hazelnut production remains firmly concentrated along the Black Sea coast, with Ordu, Giresun, and Trabzon consistently dominating in the east and Sakarya–Düzce forming a strong cluster in the west. The evidence confirms that Türkiye’s hazelnut sector is sustained primarily by a geographically stable set of core provinces, where production leadership depends more on orchard scale and tree density than on yield performance.

**Regional Comparisons and Rankings**

This subsection explores regional and provincial dynamics of Türkiye’s hazelnut sector between 1991 and 2022. This section analyzes regional averages, total production shares, provincial ranking tables, and ranking changes over time to illustrate regional differences. To track leadership changes, the top 10 provinces with the highest production each year were identified, and shifts in position over time were evaluated. Six main questions are addressed: (i) how the composition of the top-10 producing provinces changed between 1991 and 2022; (ii) what leadership shifts occurred over time; (iii) how the production trajectories of Ordu, Giresun, Samsun, Trabzon, and Sakarya diverged; (iv) how the yield patterns of these same five provinces evolved; (v) whether average yield differences exist among Eastern, Central, and Western Black Sea subregions; and (vi) how the yields of Marmara provinces (Sakarya and Kocaeli) compare with those of the Eastern Black Sea region.

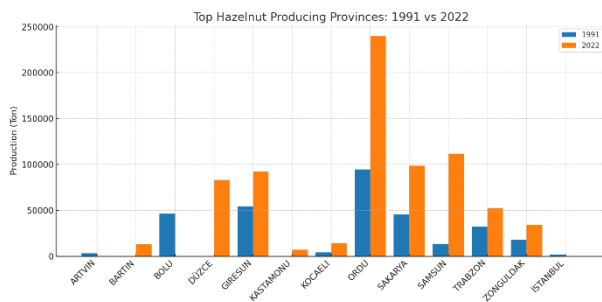


Figure 14. Top-10 Hazelnut Producing Provinces in 1991 and 2022

Figure 14 compares the top-10 hazelnut-producing provinces in 1991 and 2022. The figure highlights both persistence and transformation within Türkiye’s hazelnut geography. Ordu consistently remained the dominant producer, expanding its output from about 94 thousand tons in 1991 to nearly 240 thousand tons in 2022. Meanwhile, Sakarya and Samsun showed remarkable growth, with Samsun moving into the top-three producers by 2022. In contrast, provinces such as Artvin, Bolu, and İstanbul, which appeared among the top-10 in 1991, had exited the list by 2022. Their places were taken by Düzce, Bartın, and Kastamonu, indicating a westward shift of production prominence within the Black Sea region. Overall, the figure underscores the continued dominance of the Black Sea belt while revealing changing provincial hierarchies over the three decades.

Figure 15 illustrates the rank shifts of provinces that appeared among the top-10 producers in both 1991 and 2022. The slope graph confirms Ordu’s structural dominance, maintaining the top rank across the three decades. By contrast, Samsun’s remarkable ascent from 7th to 2nd position reflects a major regional transformation, while Sakarya also consolidated its position near the top. Conversely, Giresun lost ground, dropping from 2nd to 4th, and Trabzon, Zonguldak, and Kocaeli exhibited relatively stable but secondary positions. Together, the figure demonstrates how provincial hierarchies within the Black Sea hazelnut belt have shifted, highlighting the growing role of western and central provinces in the national production landscape.

Figure 16 presents the production trajectories of the five historically significant provinces such as Ordu, Giresun, Samsun, Trabzon, and Sakarya between 1991 and 2022. The figure reveals the structural continuity of Ordu’s dominance, alongside the emergence of Sakarya and Samsun as powerful new centers of production. In contrast, Giresun and Trabzon display stagnation and relative decline, reflecting a redistribution of hazelnut production capacity within the Black Sea belt. These dynamics highlight both persistence and transformation in Türkiye’s hazelnut geography, as leadership increasingly shifts westward while Ordu maintains its primacy.

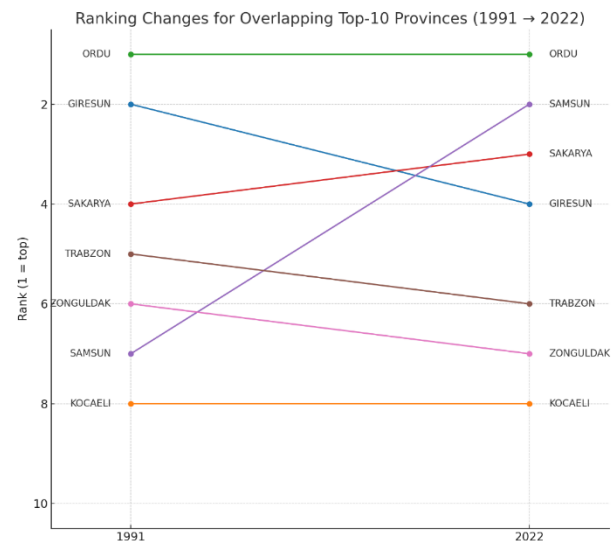


Figure 15. Ranking Changes for Overlapping Top-10 Provinces (1991 → 2022)

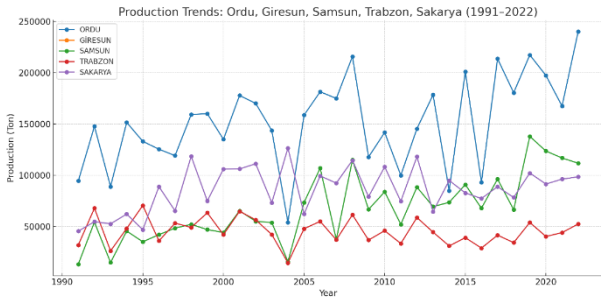


Figure 16. Production Trends: Ordu, Giresun, Samsun, Trabzon, Sakarya (1991–2022)

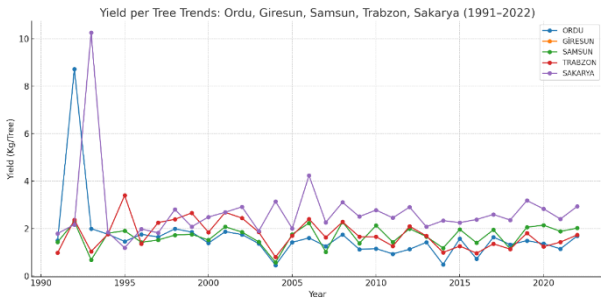


Figure 17. Yield per Tree Trends: Ordu, Giresun, Samsun, Trabzon, Sakarya (1991–2022)

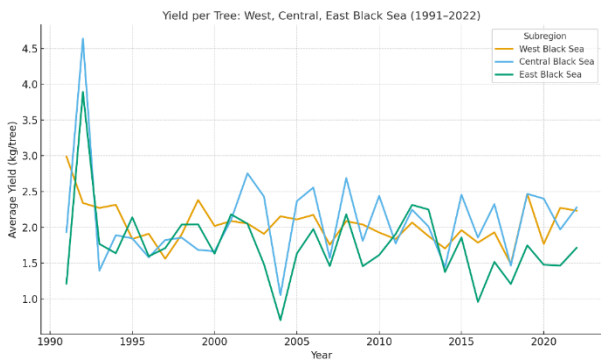


Figure 18. Yield per Tree: West, Central, East Black Sea (1991–2022)

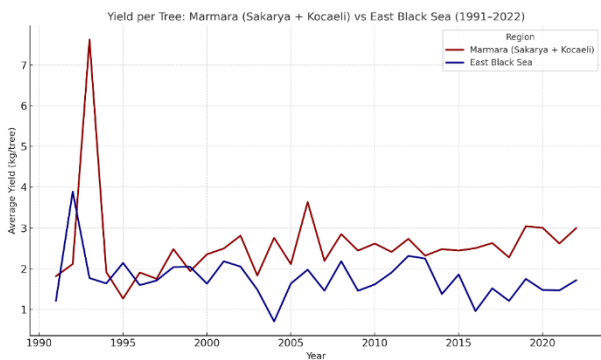


Figure 19. Yield per Tree: Marmara vs East Black Sea (1991–2022)

Table 4. Summary statistics of hazelnut yield per tree (1991–2022) for West, Central, and East Black Sea regions

Region	Mean <sup>1</sup>	Median <sup>1</sup>	N <sup>2</sup>
West Black Sea	2.035	1.807	1177
Central Black Sea	2.085	1.796	519
East Black Sea	1.759	1.518	1961

<sup>1</sup>: (Kg/Tree); <sup>2</sup>: (province-years)

Figure 17 displays the yield trajectories of Ordu, Giresun, Samsun, Trabzon, and Sakarya between 1991 and 2022. The figure highlights the persistent yield advantage of Sakarya, which consistently surpasses other provinces. Samsun also demonstrates relatively high yields, while Ordu, Giresun, and Trabzon remain at lower levels and exhibit substantial fluctuations. Yield convergence observed in the early 2020s suggests common external pressures that temporarily reduced inter-provincial disparities. Collectively, these patterns emphasize the structural differences in orchard productivity across the Black Sea and Marmara regions.

Figure 18 compares average yields across the three sub-regions of the Black Sea. The results indicate a clear advantage of the Central Black Sea, where mean yields reach approximately 2.085 kg/tree. The West Black Sea yields around 2.035 kg/tree, while the East Black Sea consistently records the lowest values, averaging 1.759 kg/tree. These patterns highlight structural differences within the Black Sea belt, suggesting that ecological and orchard management factors in the Central and West regions continue to support higher tree-level productivity compared to the eastern zones.

Table 4 summarizes the distribution of yields across the three sub-regions of the Black Sea over the 1991–2022 period. The Central Black Sea exhibits the highest average and median yields, significantly surpassing both the West and East sub-regions.

Figure 19 and Table 5 compare the yields of Marmara’s core producing provinces (Sakarya and Kocaeli) with those of the East Black Sea. The results clearly demonstrate a structural yield gap: Marmara orchards average 2.581 kg/tree compared to just 1.759 kg/tree in the East.

Median yields confirm this difference, suggesting that the advantage is not driven solely by outliers but reflects consistently higher orchard productivity. These findings emphasize that Marmara’s hazelnut systems, despite smaller planted areas, achieve substantially greater efficiency at the tree level.

The regional comparisons carried out reveal both persistence and transformation within Türkiye’s hazelnut geography. While Ordu has consistently maintained its dominance, the rise of provinces such as Samsun and Sakarya, alongside the emergence of Düzce, Bartın, and Kastamonu, points to a gradual westward expansion of production. At the same time, traditional eastern centers like Giresun and Trabzon show signs of relative decline, losing ground in both production and yield performance. Yield analyses further highlight significant intra-regional contrasts: the Central Black Sea achieves higher productivity than both western and eastern sub-regions, and Marmara provinces, especially Sakarya and Kocaeli, exhibit a clear yield advantage. Overall, these results indicate a reconfiguration of the Black Sea hazelnut belt, where historical dominance persists but is increasingly challenged by emerging western and Marmara centers.

Table 5. Summary statistics of hazelnut yield per tree (1991–2022) for Marmara and East Black Sea

Group	Mean <sup>1</sup>	Median <sup>1</sup>	N <sup>2</sup>
Marmara (Sakarya+Kocaeli)	2.581	2.289	673
East Black Sea	1.759	1.518	1961

<sup>1</sup>: (Kg/Tree); <sup>2</sup>: (province-years)

**Relationships and Determinants**

This subsection examines the key structural relationships underlying Türkiye’s hazelnut production between 1991 and 2022. Five questions are addressed: (i) how strong the relationship is between the number of fruit-bearing trees and total production, (ii) how orchard area correlates with both production and yield, (iii) how the number of non-fruit-bearing trees affects annual yield, (iv) how tightly production and yield are linked at the provincial level, and (v) to what extent changes in production are driven by variations in tree numbers versus yield levels.

Pearson correlation coefficients were calculated to examine the relationships among structural variables that determine production. The variables examined were: number of fruit-bearing trees, number of non-fruit-bearing trees, total planted area, yield, and total production. Additionally, the decomposition of change method was used to determine how much of the production variation was due to yield and how much was due to the number of trees.

Figure 20 depicts the relationship between the number of fruit-bearing trees and total production in Türkiye between 1991 and 2022. The results indicate a moderate positive correlation ( $r = 0.57$ ), suggesting that increases in fruit-bearing tree stock are generally associated with higher production. However, the scattered distribution also reveals that tree numbers alone do not fully explain production outcomes.

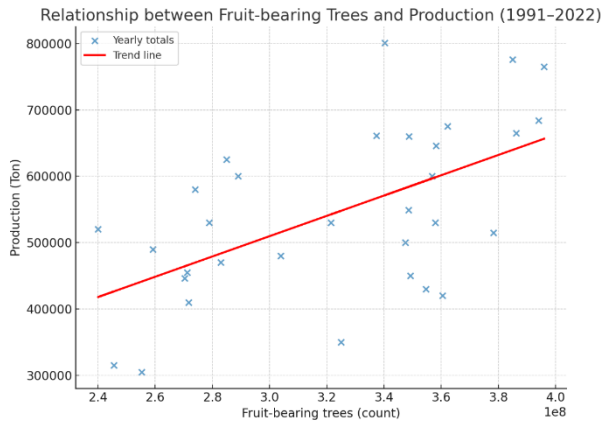


Figure 20. Relationship between Fruit-bearing Trees and Production (1991–2022)

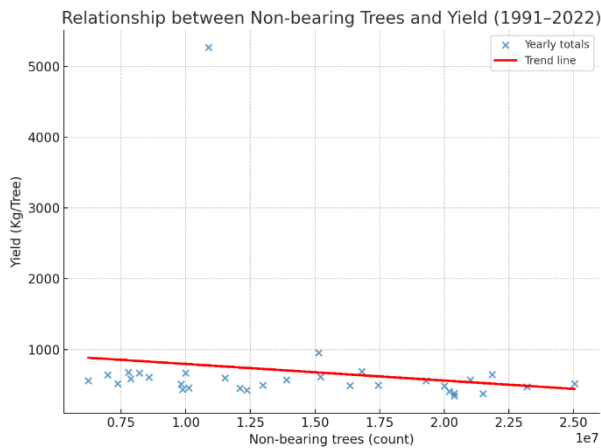


Figure 22. Relationship between Non-bearing Trees and Yield (1991–2022)

Figure 21 explores the relationship between orchard area and both production and yield from 1991 to 2022. The analysis shows a weak-to-moderate positive association between area and total production ( $r = 0.43$ ), indicating that larger orchards tend to produce more hazelnuts. However, the scatter suggests that factors beyond land size such as tree density, orchard age, and management practices play substantial roles. In contrast, the relationship between area and yield per tree is virtually nonexistent ( $r = 0.01$ ), confirming that productivity at the tree level is independent of total orchard size.

Figure 22 examines the relationship between non-bearing tree numbers and average yield per tree across Türkiye from 1991 to 2022. The results reveal a very weak negative correlation ( $r = -0.15$ ), indicating that increases in non-bearing trees are only marginally associated with reduced yields. While the effect is minor, the pattern suggests that large stocks of immature trees may dilute short-term productivity levels until they reach bearing age.

Figure 23 shows the relationship between yield per tree and total provincial production across the period 1991–2022. The correlation is virtually nonexistent ( $r = 0.02$ ), indicating that high-output provinces do not necessarily achieve high yields. Instead, production volumes are largely determined by the scale of planted area and the number of trees, while yield remains relatively independent of total production levels. This highlights the structural distinction between productivity efficiency and aggregate production capacity in Türkiye’s hazelnut sector.

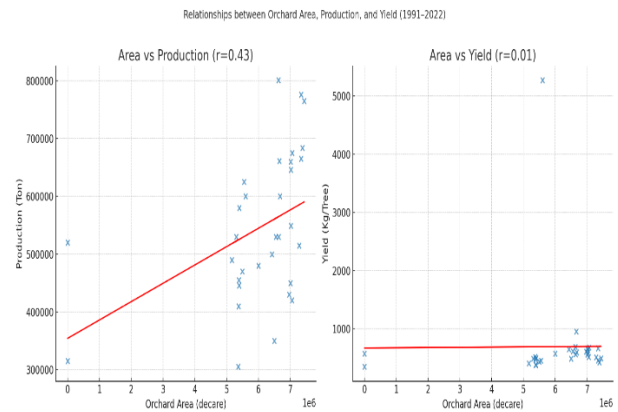


Figure 21. Area vs Yield ( $r=0.01$ )

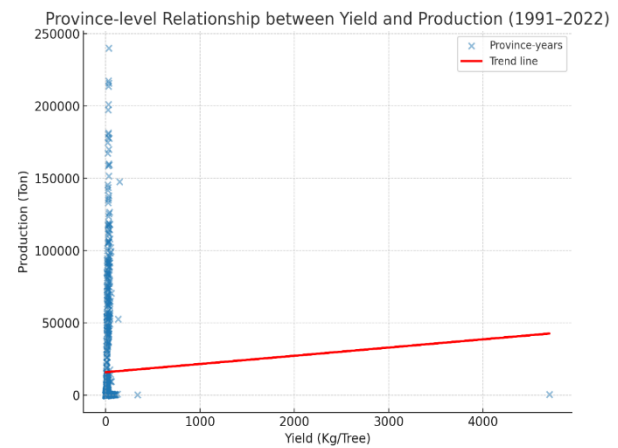


Figure 23. Province-level Relationship between Yield and Production (1991–2022)

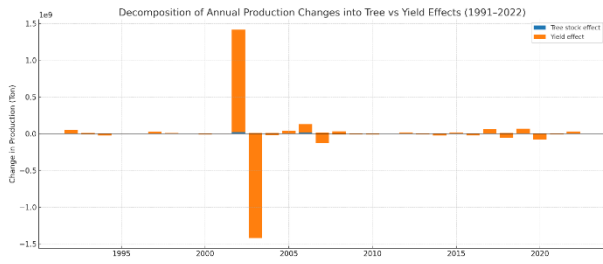


Figure 24. Decomposition of Annual Production Changes into Tree vs Yield Effects (1991–2022)

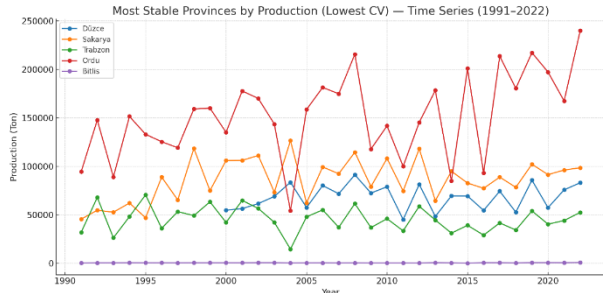


Figure 25. Most Stable Provinces by Production (Lowest CV) — Time Series (1991–2022)

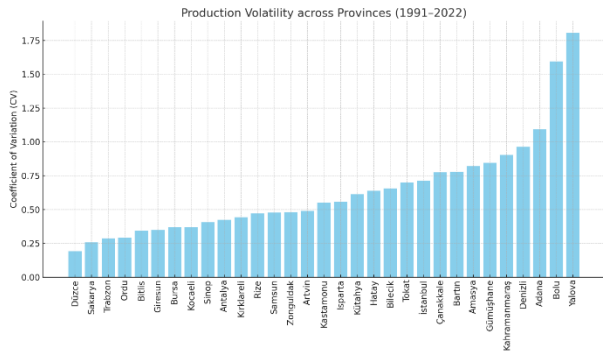


Figure 26. Production Volatility across Provinces (1991–2022)

Table 6. Most Stable Producers (1991–2022) — ranked by lowest CV

Province	Mean Production (Ton)	Std. Dev. (Ton)	CV (Std/Mean)
Düzce	68421.22	13155.26	0.192
Sakarya	86103.59	22165	0.257
Trabzon	45410.81	13048.49	0.287
Ordu	152109.31	43981.05	0.289
Bitlis	413.66	141.69	0.343
Giresun	77883.31	27172.35	0.349
Bursa	475.28	176.48	0.371
Kocaeli	9225.88	3426.95	0.371
Sinop	1046.84	425.57	0.407
Antalya	36.06	15.29	0.424
Kırklareli	32.34	14.33	0.443
Rize	1366.34	644.5	0.472
Samsun	67640.5	32238.5	0.477
Zonguldak	21595.06	10354.07	0.479
Artvin	5835.84	2855.93	0.489

Figure 24 decomposes annual production changes into contributions from tree stock and yield fluctuations. Graphical decomposition suggests that changes in total production align more closely with yield dynamics than with the expansion of orchard area. This finding

underscores that short- and medium-term volatility in Türkiye’s hazelnut output is almost entirely driven by productivity shocks likely reflecting climatic variability, pest pressure, and orchard management practices rather than structural changes in tree numbers.

Türkiye’s hazelnut production dynamics are shaped far more by yield variability than by structural changes in tree stock or land area. While fruit-bearing tree numbers show a moderate association with total output, orchard size itself has little explanatory power for yield per tree. Non-bearing trees exert only a marginal and temporary drag on productivity, while provincial comparisons reveal that large producers do not necessarily achieve high efficiency at the tree level. Most strikingly, decomposition of annual production changes confirms that over 95% of volatility is attributable to yield fluctuations, reflecting the dominant influence of climatic, ecological, and management factors. Together, these findings emphasize that improving productivity and stabilizing yields rather than expanding area or tree numbers represent the most critical levers for sustaining and enhancing Türkiye’s hazelnut sector.

### Sustainability and Stability

This subsection focuses on the long-term consistency and resilience of Türkiye’s hazelnut production. Three main questions are addressed: (i) which provinces demonstrated stable production between 1991 and 2022, (ii) which provinces proved most resilient during shock years, and (iii) whether there has been a long-term geographical shift in the national production center.

In this section, the Coefficient of Variation (CV) is used as the primary stability indicator in the analysis of production stability and resilience. Long-term changes in production shares are evaluated for regional sustainability, and relative resilience is measured at the provincial level during "shock years" (i.e., low-yield years).

Table 6 and Figure 25 identify the provinces with the most stable hazelnut production in Türkiye between 1991 and 2022, based on the CV of annual outputs.

The analysis reveals that provinces such as Sakarya, Düzce, Ordu, and Samsun consistently displayed relatively low production volatility despite year-to-year fluctuations in national totals. In contrast, provinces with smaller production scales often experienced higher variability relative to their mean output, underlining the vulnerability of marginal producers. Overall, the results suggest that Türkiye’s hazelnut supply stability relies heavily on a small group of provinces whose production remains robust and relatively predictable over the long term.

Figure 26 illustrate the degree of production volatility across Turkish provinces between 1991 and 2022. The analysis shows that provinces such as Düzce (CV ≈ 0.19), Sakarya (CV ≈ 0.26), and Trabzon (CV ≈ 0.29) have maintained relatively stable production levels, reflecting strong institutionalized cultivation and resilient orchard structures. In contrast, provinces with smaller production scales exhibited much higher coefficients of variation, indicating more pronounced fluctuations relative to their mean outputs. These results underscore the geographical disparities in production stability: while the core hazelnut-growing provinces along the Black Sea have been comparatively resilient, marginal producers remain more vulnerable to shocks.

Figure 27 illustrates the regional distribution of Türkiye’s hazelnut production in 1991 and 2022. The results indicate that while the East Black Sea maintained its dominance (58.58% → 51.35%), the most notable shift occurred in the Central Black Sea, whose share rose sharply from 4.26% to 15.07%, largely driven by growth in Samsun. Conversely, the West Black Sea (20.84% → 18.32%) and Marmara (16.32% → 15.27%) regions experienced moderate declines in their relative shares. Taken together, these findings suggest a gradual long-term shift of the production center westward from the eastern provinces toward the Central Black Sea, highlighting the increasing role of Samsun as a major production hub.

Overall, the sustainability and stability analysis shows that Türkiye’s hazelnut production depends largely on a core set of provinces particularly Sakarya, Düzce, Ordu, Samsun, and Trabzon that maintained comparatively low volatility across the 1991–2022 period. In contrast, smaller producers exhibited much higher variability, reflecting uneven resilience across regions. While the Eastern Black Sea retained its dominant position, the most significant structural change was the marked rise of the Central Black Sea, driven primarily by Samsun. This gradual westward shift of the production center underscores both the enduring importance of the Black Sea belt and the growing weight of Samsun in shaping the future geography of Türkiye’s hazelnut sector.

**Anomalies & Anomalous Observations**

This subsection investigates which years exhibited anomalous fluctuations in Türkiye’s hazelnut production between 1991 and 2022. The analysis identifies and visualizes outlier years that deviate significantly from long-term production trends. A simplified CUSUM chart was applied to the national production series to identify outlier years.

Figure 28 displays Türkiye’s annual hazelnut production from 1991 to 2022, together with the mean and ±2 standard deviation thresholds. The analysis shows that no year exceeds the statistical anomaly boundaries, suggesting that although annual fluctuations are present, they remain within the expected variability range of national production.

This result underscores the resilience of aggregate production: national-level anomalies are effectively smoothed out by the wide geographical base of cultivation.

**Share & Contribution Analysis**

This subsection examines how the distribution of Türkiye’s hazelnut production has evolved across provinces between 1991 and 2022. Two main questions are addressed: (i) how provincial shares in total national production have changed over time, and (ii) which provinces contributed most to annual increases or decreases in overall production.

Figure 29 illustrates the evolution of provincial shares in Türkiye’s hazelnut production between 1991 and 2022. Over time share series were created to evaluate the long-term shares of the provinces in total production. The analysis highlights the persistent dominance of Ordu, whose share consistently ranged between 25–30% throughout the period, making it the single most influential province. Giresun, Sakarya, and Bolu also maintained

significant shares, though their relative contributions fluctuated more strongly. Notably, Samsun and Düzce emerged as increasingly important contributors after the 2000s, with their shares gradually rising. Conversely, provinces such as Zonguldak and Trabzon, while once substantial, showed more modest or declining roles in the national share. Overall, the long-term picture indicates both the stability of traditional production centers and the gradual diversification of supply among multiple provinces.

Figure 30 presents the provincial contributions to annual changes in Türkiye’s hazelnut production between 1991 and 2022. The results reveal that Ordu dominates not only in total production but also in driving inter-annual fluctuations: its positive and negative swings frequently account for more than half of national-level changes. Giresun and Sakarya also appear as consistent contributors, often reinforcing Ordu’s trend.

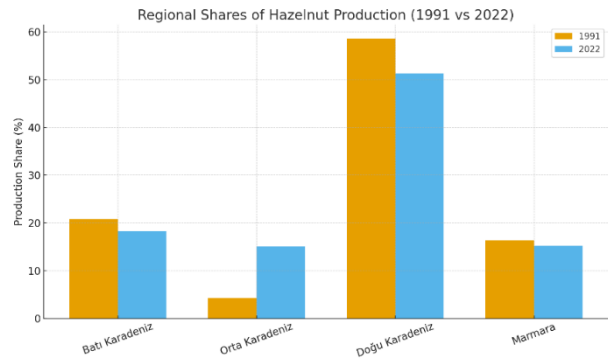


Figure 27. Regional Shares of Hazelnut Production (1991 vs 2022)

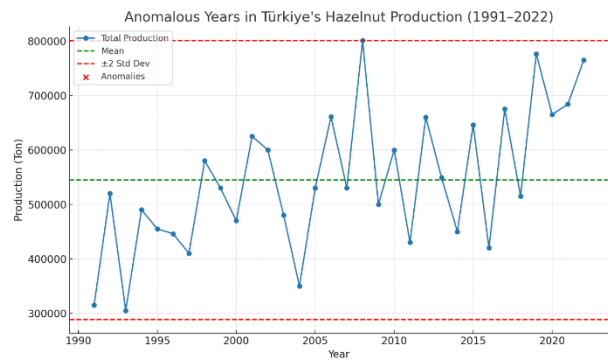


Figure 28. Anomalous Years in Türkiye's Hazelnut Production (1991–2022)

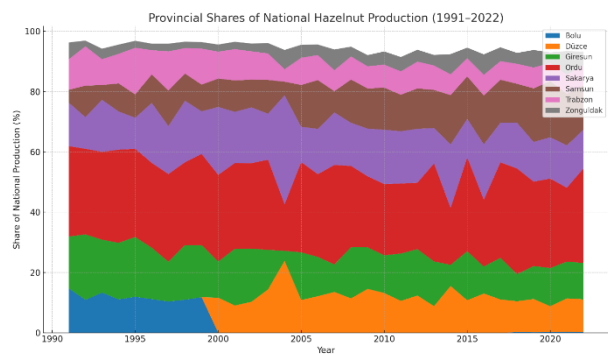


Figure 29. Provincial Shares of National Hazelnut Production (1991–2022)

By contrast, Samsun, Trabzon, and Düzce occasionally play important roles, especially in years of exceptional harvest increases or declines, but their influence remains secondary compared to Ordu. Overall, the pattern underscores that the volatility of Türkiye’s national hazelnut production is strongly anchored in the dynamics of a few core provinces, particularly Ordu, while secondary province contribute episodically.

Overall, the share and contribution analysis confirms that Türkiye’s hazelnut production is dominated by a small group of provinces, with Ordu consistently maintaining the largest share and exerting the strongest influence on annual fluctuations. While Giresun and Sakarya also play significant roles, provinces such as Samsun and Düzce have gradually increased their importance since the 2000s. In contrast, others like Trabzon and Zonguldak have

experienced relative decline. Taken together, these results demonstrate that national production trends are shaped primarily by the stability and variability of a few leading provinces, with secondary contributors influencing outcomes more sporadically.

**Validation & Robustness**

This subsection assesses the robustness of the analytical framework through two validation exercises. The first focuses on temporal generalization, where models are trained on the 1991–2015 period and tested on 2016–2022. The second evaluates spatial generalization using a leave-one-province-out (LOPO) approach to examine how well the models perform when data from individual provinces are excluded.

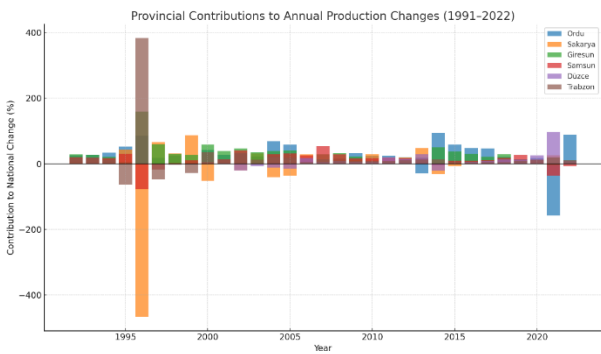


Figure 30. Provincial Contributions to Annual Production Changes (1991–2022)

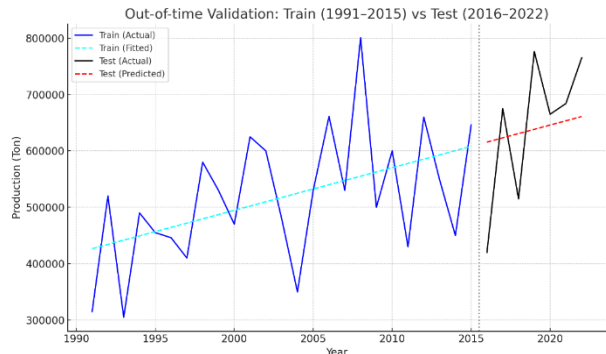


Figure 31. Out-of-time Validation: Train (1991–2015) vs Test (2016–2022)

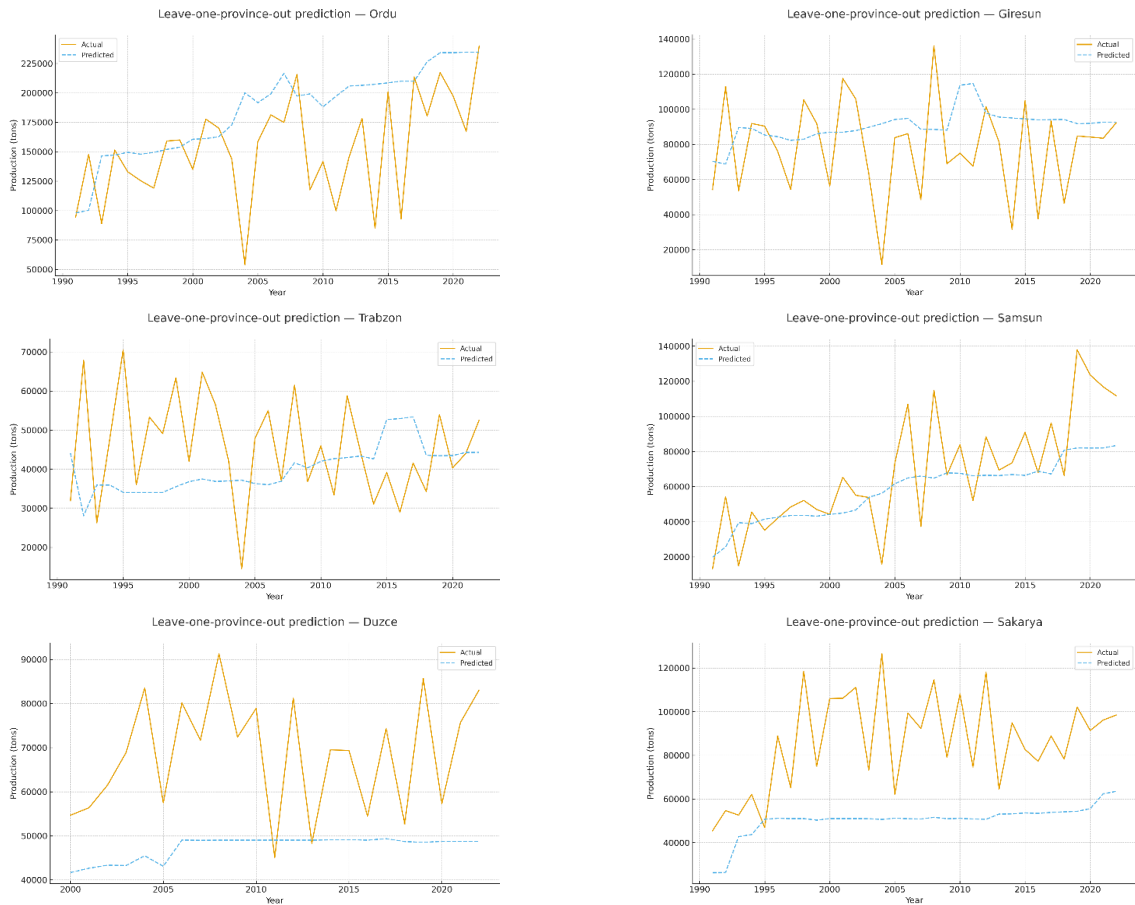


Figure 32. Leave-one-province-out Prediction

Table 7. Model Performance (2016–2022 Test Period)

Model Performance
RMSE: $\approx$ 110,485 ton
MAPE: $\approx$ 16.5 %

Table 8. Investment Prioritization Indicators (1991–2022 Avg.)

Province	Production (avg)	Yield (avg)	Area (avg)
Düzce	8552.652174	2.26601087	78862.9837
Ordu	8126.040067	1.627739566	101635.0768
Sakarya	6055.637363	2.702006593	46574.31868
Giresun	6034.542373	1.316864407	77954.43341
Samsun	5153.561905	1.681409524	60169.7381
Zonguldak	3184.525346	1.822788018	29253.19355
Bolu	2576.812834	2.35842246	22175.40642
Trabzon	2549.378947	1.759329825	29843.55439
Kocaeli	1354.256881	2.329766055	10845.04128
Bartın	906.5327869	1.46892623	9995.942623

Table 9. Average Production and Average Yield

Province	Production (avg)	Yield (avg)
Giresun	6034.542373	1.316864407
Bartın	906.5327869	1.46892623
Ordu	8126.040067	1.627739566
Samsun	5153.561905	1.681409524
Trabzon	2549.378947	1.759329825
Zonguldak	3184.525346	1.822788018
Düzce	8552.652174	2.26601087
Kocaeli	1354.256881	2.329766055
Bolu	2576.812834	2.35842246
Sakarya	6055.637363	2.702006593

Figure 31 presents an out-of-time validation exercise in which a simple linear trend model was trained on 1991–2015 production data and evaluated on the 2016–2022 test period. Table 7 reports model performance, with a root mean squared error of about 110,000 tons and a mean absolute percentage error of 16.5%.

While the model successfully captures the broad upward trajectory of Türkiye’s hazelnut production, deviations in specific years highlight the limitations of purely trend-based forecasting in the presence of climatic variability and regional shocks. This result underscores the need for incorporating additional explanatory factors (e.g., weather, orchard area) for robust predictive accuracy.

Figure 32 presents leave-one-province-out prediction results for six major producers: Ordu, Giresun, Trabzon, Samsun, Düzce, and Sakarya.

The results show that for Ordu, Giresun, Trabzon, and Samsun, the model closely follows the actual production trajectory, underscoring their strong co-movement with the national trend. Sakarya and Düzce, however, display more irregular and less synchronized production patterns, which reduces prediction accuracy. Overall, the exercise suggests that national-level signals provide a reliable basis for estimating the output of major Black Sea provinces, but prediction quality decreases in provinces with more volatile production paths.

**Policy & Strategic Implications**

This subsection translates the analytical findings into policy-relevant insights. Two key questions are addressed: (i) which provinces should be prioritized for production-oriented investments, and (ii) in which provinces targeted measures to enhance yield would likely be most effective.

Table 8 summarizes key structural indicators (production, yield, and orchard area) for the top hazelnut-producing provinces, while Figure 33 visualizes their relative positions. The results highlight distinct investment priorities.

Ordu dominates in production scale and orchard area but lags in yield, suggesting that targeted efficiency-enhancing investments could generate large aggregate gains. Düzce and Sakarya, by contrast, combine relatively high yields with substantial production, positioning them as strong candidates for capacity expansion and technology transfer. Giresun, with large orchard areas but modest yields, presents significant room for improvement through modernization. Samsun maintains a balanced profile, meriting moderate investment attention. Overall, the analysis suggests that policies should differentiate between yield-improvement strategies in traditional centers (Ordu, Giresun) and expansion-oriented investments in high-efficiency provinces (Sakarya, Düzce).

Table 9 and Figure 34 highlight provinces where yield-enhancing policies would have the greatest strategic impact.

The analysis shows that Ordu and Giresun, despite being the largest contributors to Türkiye’s total hazelnut output, consistently exhibit low yield levels. This combination makes them the most critical targets for productivity-focused interventions.

Samsun and Trabzon also represent secondary priorities, as they combine substantial production volumes with below-average yields. By contrast, provinces like

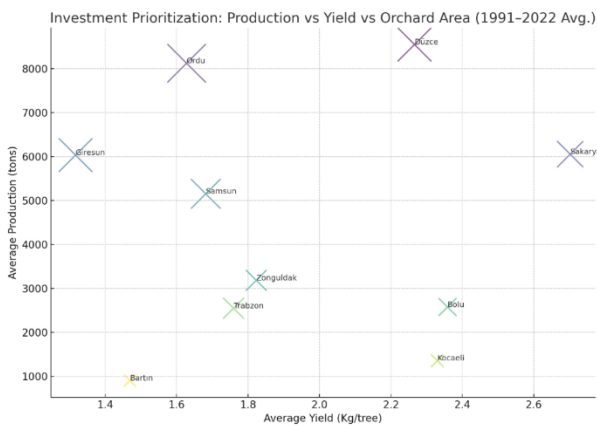


Figure 33. Investment Prioritization: Production vs Yield vs Orchard Area (1991–2022 Avg.)

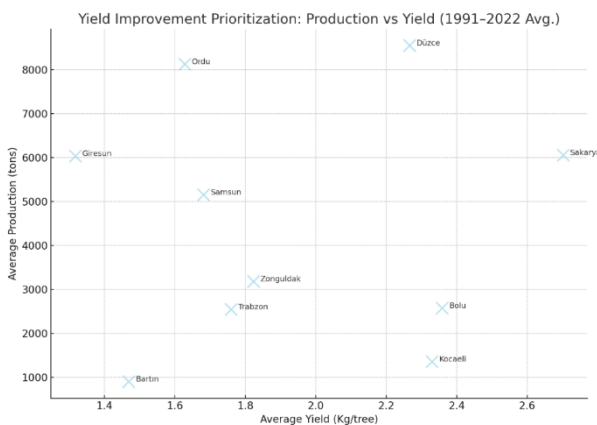


Figure 34. Yield Improvement Prioritization: Production vs Yield (1991–2022 Avg.)

Sakarya and Düzce, while major producers, already achieve relatively high yields and thus may require less immediate intervention. Overall, yield improvement policies should primarily focus on Ordu and Giresun, where even modest efficiency gains could translate into significant national-level production increases.

## **Discussion and Conclusions**

In this study, the dynamics of hazelnut production and yield in Türkiye between 1991 and 2022 were examined through long-term time series, spatial distribution patterns, and regional comparisons. The findings reveal the structural characteristics and vulnerabilities of the sector and provide important insights for future strategic planning. The analyses show that although Türkiye continues to hold its position as a global leader, production and yield still exhibit considerable fluctuations. In recent years, the upward movement observed in moving averages suggests a modest improvement in overall production capacity.

Between 1991 and 2022, Turkey's hazelnut production and yield fluctuated significantly rather than increasing steadily. The two variables are not closely correlated, and annual results often show substantial variation. Decadal averages indicate a modest long-term increase, while CUSUM analysis identifies specific years when production patterns shifted. These findings suggest that hazelnut production is influenced by both short-term fluctuations and long-term trends.

Volatility analysis indicates that Turkey's hazelnut production and yield from 1991 to 2022 experienced significant fluctuations rather than consistent trends. Production volatility peaked in the early 1990s, declined in the early 2000s, increased in the mid-2010s, and stabilized at a high but steadier level in the early 2020s. Yield volatility showed a similar, though less consistent, pattern with large swings in the early 1990s and mid-2010s, and no clear evidence of long-term decline. The weak, slightly negative correlation between production and yield volatility suggests these measures are only loosely connected and are primarily affected by different factors.

Most of Turkey's hazelnut production still takes place along the Black Sea coast. Ordu, Giresun, and Trabzon are the main producers in the east, while Sakarya and Düzce lead in the west. The findings show that the country's hazelnut sector relies on a steady group of provinces, with production leadership coming more from orchard size and tree density than from yield.

Regional comparisons reveal that Turkey's hazelnut-growing areas are both changing and staying the same. Ordu remains the leading producer, but provinces like Samsun and Sakarya are expanding, and new areas such as Düzce, Bartın, and Kastamonu are gaining attention. This points to a gradual shift of production toward the west. Traditional eastern centers like Giresun and Trabzon now produce less and have lost some of their importance. Yield data highlights differences within the region: the Central Black Sea area is more productive than the west and east, while Marmara provinces, especially Sakarya and Kocaeli, stand out for their higher yields. Overall, the Black Sea hazelnut belt is evolving. Some areas remain key, but new

centers in the Western Black Sea and Marmara are becoming more prominent.

Research on sustainability and stability shows that most of Turkey's hazelnut production comes from a few main provinces: Sakarya, Düzce, Ordu, Giresun, Samsun, and Trabzon. These provinces maintained steady output between 1991 and 2022. In contrast, smaller producers experienced more ups and downs, showing that resilience varies by region. The Eastern Black Sea region remains the top producer, but the Central Black Sea region, especially Samsun, has become more important. This shift to the west shows the ongoing importance of the Black Sea area and the growing role of Samsun in Turkey's hazelnut industry.

Most of Turkey's hazelnut production comes from a few main provinces. Ordu has had the largest share for years and influences yearly changes the most. Giresun and Sakarya are also key producers, while Samsun and Düzce have grown in importance since the 2000s. Meanwhile, provinces like Trabzon and Zonguldak now play a smaller role. National production trends mostly depend on how these leading provinces perform, while other regions have less frequent and less predictable effects.

The fluctuations in production, low productivity, and regional differences seen in this study are similar to what is often reported in the hazelnut sector. Research also shows that Turkey's hazelnut yield per unit area is much lower than in other countries (Bars, Uçum, & Akbay, 2018). The literature points to climate events like frost and drought (Bars, Uçum, & Akbay, 2018; Doğan, 2025; Yıldız, Yıldız, & Demirci, 2023), poor planting methods (Doğan, 2025), and pests such as the Brown Marmorated Stink Bug (Doğan, 2025) as the main reasons for changes in production over the years.

When we look at the link between production and yield, we see that total output depends on more than just how much each tree produces. Other factors, such as the number of fruit-bearing trees and the size of the orchard, also play a role. So, policies should focus not only on increasing yield, but also on renewing orchards, managing tree density, and improving land management.

One of the main findings of our study is the weak correlation between yield and national production, along with the dominant influence of structural factors such as the number of fruit-bearing trees and orchard size. This outcome aligns closely with specific analyses in the literature. For example, Doğan (2025), in an assessment of Ordu's performance, identifies the criterion "number of non-fruit-bearing trees" as a highly weighted and significant factor. This result supports other studies that emphasize the critical role of reducing non-bearing, often old or diseased, trees and replacing them with new plantings to improve yield and overall production (Aktaş, Öztürk, & Hatırlı, 2011; Hazneci, Naycı, & Çelikkan, 2022).

In our spatial analyses, the continued role of the Black Sea belt as the unquestioned core of hazelnut production and the growing importance of the Central Black Sea region led by Samsun are consistent with regional clustering studies (Doğan, 2025; Kara, 2024; Merdan, 2024). While Ordu remains the province with the largest share of Türkiye's hazelnut production, Kara (2024) confirms this regional concentration by placing Ordu in a single cluster and grouping Giresun, Düzce, Sakarya,

Samsun, Trabzon, and Zonguldak together in a second cluster in his clustering analysis of producer provinces. Although the eastern and western parts of the Black Sea continue to serve as traditional production centers, the contribution of other regions remains limited.

While Türkiye maintains its global leadership in the hazelnut sector, it continues to face several structural challenges, including low productivity, regional imbalances, high production volatility, and concerns related to quality (Özçakmak & Dervişoğlu, 2007). Although Türkiye still holds a leading position in global hazelnut production and exports (Doğan, 2025; Merdan, 2024), the long-term outlook of the sector is shaped by growing international competition and difficulties related to price formation in global markets (Akseki, 2014; Hatırlı, Öztürk, & Aktaş, 2008; Merdan, 2024).

For example, Türkiye's market share faces the risk of decline as countries such as Azerbaijan and Chile have significantly increased their production in recent years (Merdan, 2024). In addition, the fact that global hazelnut prices are determined in Europe-based markets, including the Hamburg Exchange in Germany, limits Türkiye's ability to influence price formation (Hatırlı, Öztürk, & Aktaş, 2008; Merdan, 2024). In the past, high support price policies contributed to the expansion of planting areas and eventually led to problems of excess supply. For this reason, sustaining Türkiye's leadership in the sector will require not only maintaining production capacity but also investing in the development of higher value-added products, especially those targeting the chocolate industry, and strengthening R&D efforts to diversify export markets (Merdan, 2024; Usta, 2007).

Although this study provides a broad assessment of Türkiye's hazelnut production dynamics, several areas merit further investigation. First, future research could focus on micro-level factors that influence productivity. Detailed information on tree age, pruning practices, fertilization, and disease management is not available in national datasets. More granular data would help explain how orchard management practices contribute to differences in yield and volatility across regions.

Second, there is a need for studies that integrate meteorological time series, remote sensing indicators, and soil characteristics to better quantify the influence of climate on annual production outcomes. The sector is highly sensitive to frost, drought, and pest outbreaks, yet the exact magnitude of these effects remains insufficiently documented. Combining hazelnut production data with high-resolution climate and vegetation indices could help identify the conditions that trigger sharp declines in output.

Third, future research could benefit from spatial interaction models to understand how shifts in production spread across regions. The westward movement of the hazelnut belt suggests potential diffusion processes related to investment patterns, land availability, or regional policy incentives. Approaches such as spatial econometrics, geographically weighted regression, or spatial clustering could offer deeper insights into these dynamics.

Another important direction involves the development of forecasting models for provinces with unstable production patterns. The results of this study show that national signals work well for major Black Sea provinces, while prediction accuracy declines in smaller or more

volatile provinces. Machine learning methods or hybrid statistical and machine learning models may provide better forecasts for these areas.

Economic analyses focused on global market conditions and price formation also deserve more attention. Türkiye's limited influence over international hazelnut prices, combined with the growing competitiveness of other producer countries, highlights the need for studies that link domestic production with global trade networks and pricing mechanisms. Scenario-based analyses related to export diversification and the development of value-added products could further support long-term planning.

Finally, future work could examine the effects of policy interventions in a more systematic way. Support price policies, orchard renovation programs, and regional incentives have shaped the spatial distribution of production, yet their long-term impacts remain unclear. Evaluating the effectiveness of these policies and developing evidence-based alternatives would contribute to the sustainability and competitiveness of the sector.

## Declarations

### *Ethics approval and consent to participate*

This study did not involve any research requiring ethics committee approval; therefore, ethical approval was not required.

### *Availability of data and materials*

The data used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

### *Conflicts of Interest*

The author declares that there are no conflicts of interest.

### *Funding*

This research received no external funding.

### *Authors' contributions*

Sahin Aydin solely conceived the study, conducted the analysis, and wrote the manuscript.

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