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International Agri-Food Trade, Europe's Seasonal Import Dependence and Supply Vulnerability: A Unit Value Decomposition Analysis of Fresh Oranges

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Abstract

International agri-food trade and climate change interact in ways that have significant implications for supply chain resilience and food sovereignty, yet these interactions remain insufficiently understood at the level of specific traded commodities. This paper analyses European fresh orange imports over 2012–2022 using a unit value decomposition applied to FAOSTAT and Eurostat bilateral trade data, alongside a seasonal supply analysis of monthly import flows from the main exporting regions. The analysis documents a pronounced geographic reorientation of global orange production toward developing and emerging economies in North Africa, Southern Africa, and South America, many of which face documented climate-related stressors. The unit value decomposition identifies how exporter-level unit values and import share reallocations contribute to changes in regional import unit value indices. The seasonal supply analysis shows that the European orange supply depends on a tight sequence of regional exporters operating in largely non-overlapping seasonal windows, leaving limited redundancy if disruptions occur in any single supplying region. These findings provide a descriptive, origin-disaggregated account of Europe's trade-side exposure in fresh orange supply chains. They underscore the need for product-specific monitoring tools and policy approaches that consider seasonal import dependence, supplier concentration, and the climate vulnerability of major origin regions, while recognising that the present analysis does not estimate causal climate effects.

Keywords: food sovereignty; supply chain resilience; citrus trade; unit value decomposition; seasonal supply dependence; European imports

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1. Introduction

Global agri-food trade has expanded substantially over the past two decades, with import volumes nearly doubling and import values more than tripling between 2002 and 2022. This expansion has been shaped by two converging forces: progressive trade liberalisation, which has reduced average import tariffs through bilateral agreements and unilateral measures since the 1990s [1], and growing recognition that climate change is disrupting agricultural production systems in ways that affect both the volume and quality of traded goods [2,3].

Within this context, the concept of Food Sovereignty has gained increasing policy relevance. Defined by Food Secure Canada as a model that prioritises people's food needs over economic profit, promotes sustainable production, and encourages local food economies, food sovereignty does not oppose international trade—rather, it advocates for trade policies that respect people's rights to nutritious, ecologically sustainable food [4]. This principle was reaffirmed at the G7 Agriculture Ministerial meeting held in Syracuse, Italy, in September 2024, where participating nations jointly identified sustainable agricultural practices and climate adaptation as primary priorities for resilient global food systems [5].

These two dynamics—trade liberalisation and climate change—interact in ways that remain poorly understood, particularly at the level of specific agricultural commodities. Trade can affect the environment through at least three channels: a scale effect, whereby increased economic activity raises emissions assuming constant technology; a composition effect, whereby the geographic reorganisation of production based on comparative advantage may increase or decrease emissions depending on whether countries specialise in more or less polluting forms of production; and a technical effect, whereby civil society pressure and public regulation drive adoption of emissions-reducing technologies [6]. Disentangling these channels is complex, and no single analytical framework has yet achieved consensus in the literature.

This paper does not claim to resolve the above-mentioned complexity. Instead, it contributes a focused descriptive analysis of one heavily traded commodity—fresh oranges—that offers exploratory evidence consistent with the broader climate–trade nexus [7]. Fresh oranges are among the most globally traded fruit products. Europe is the world's dominant importing region, accounting for over 53% of global fresh orange imports in 2022. European supply depends on a rotating set of exporting countries across the Mediterranean Basin, Southern Africa, and South America, many of which face documented and increasing climate-related stressors, including drought, heat stress, and water scarcity [8].

The paper pursues three interrelated objectives. First, it documents production and trade trends in global orange markets over the decade 2012–2022, identifying the countries and regions gaining or losing ground [9–12]. Second, it constructs a unit value composition index for European orange imports and decomposes changes in this index into exporter-level unit value effects, import share reallocation effects, and interaction effects [13–17]. Third, it examines the seasonal structure of European orange imports to assess the degree of external supply dependence and the extent of redundancy across supplying regions [18,19]. Together, these objectives provide a descriptive, origin-disaggregated account of Europe's exposure to supply disruption in a fresh fruit market whose major origin regions face documented climate-related stressors [8,20].

The findings are intended to inform the design of complementary trade and agricultural policies that account not only for aggregate food availability, but also for seasonal dependence, supplier concentration, and the resilience of origin country supply systems [20].

2. Conceptual Framework

This paper links food security, food sovereignty, climate vulnerability, and international trade through the concept of trade-side supply exposure. The central premise is that import dependence is not only a question of how much food is available in aggregate, but also where it comes from, when it arrives, how concentrated the supplier base is, and whether alternative suppliers can substitute for one another during seasonal gaps. Fresh oranges provide a useful case because the European supply depends on a sequence of geographically distinct exporters operating in different parts of the crop year.

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Food security and food sovereignty are often used interchangeably in policy discourse, but they refer to meaningfully different concepts. Food security, as defined at the 1996 World Food Summit, exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life [21]. It encompasses four dimensions: the availability of food, physical and economic access to food, dietary utilisation across different consumption patterns, and the stability of food resources over time. No country fully meets all four dimensions, partly because of high dependence on agricultural imports [22,23].

Food sovereignty, by contrast, is a political and governance concept. An early definition, advanced in 1996, described it as the right of communities to manage their food resources with the aim of satisfying the needs of the people, based on sustainable production, respect for the work of food producers, and local economies [24]. More recently, the FAO has endorsed the definition provided by Food Secure Canada, under which food sovereignty is a model of food resource management that prioritises the satisfaction of people's food needs over the maximisation of economic profit, promotes sustainable and respectful food production, and encourages local food economies by reducing the distance between suppliers and consumers, minimising waste, and reducing dependence on geographically distant production systems [24]. Importantly, food sovereignty does not oppose international trade. Rather, it advocates trade policies and practices that serve people's rights to nutritious, healthy, and ecologically sustainable food [4], while accounting for the environmental, social, and economic impacts along the entire food value chain [5].

From this perspective, import dependence matters when it creates exposure to concentrated or weakly substitutable sources of supply. In the case of fresh oranges, such exposure is seasonal as well as geographic. A country may appear well supplied in annual trade statistics while still being vulnerable during specific months if supply depends on a small number of exporters operating in narrow seasonal windows. Therefore, this paper uses origin-disaggregated unit values, exporter contributions, and monthly import flows to describe where and when the European fresh-orange supply is concentrated.

Climate vulnerability enters this framework through the production conditions of origin countries. Climate change can affect agricultural systems through altered precipitation patterns, rising temperatures, more frequent extreme weather events, and shifts in pest and disease pressure [8]. These stressors can affect the quantity, composition, and quality of agricultural output, including in regions that supply fresh oranges to Europe [25–27]. However, this paper does not model climate variables directly and does not estimate the causal effect of climate change on orange markets. Instead, climate vulnerability is treated as contextual information about the resilience of major supplying regions. The empirical analysis focuses on observable trade-side indicators, including unit value composition, supplier concentration, and seasonal sequencing.

Conceptually, food sovereignty motivates attention to stable, resilient, and ecologically sustainable supply relationships; climate vulnerability motivates attention to conditions in origin countries; and trade structure provides the observable evidence used in the paper [6,20]. Within these limits, the analysis examines how Europe's fresh-orange imports are organised across origins, destination markets, and seasonal windows, and how that organisation may create supply vulnerabilities without claiming to identify their causal climate drivers.

3. Materials and Methods

3.1. Data and Scope

This study draws on two primary data sources. Production and trade data at the global level are sourced from FAOSTAT, covering the period 2010 to 2022 for production trends and 2012 to 2022 for bilateral trade flows. Monthly import data for European countries are drawn from Eurostat, covering the citrus crop years 2012/2013 through 2022/2023. All trade values are expressed in thousands of US dollars and quantities in tonnes. Unit values, calculated as the ratio of trade value to quantity, are used as the primary analytical variable. They are interpreted as trade-data indicators of import composition rather than as direct measures of observed prices, product quality, or climate impacts [13–15].

Fresh oranges were selected as the representative commodity following a systematic review of FAOSTAT data on global fruit and vegetable trade. Among major fruit categories, citrus showed particularly dynamic growth in international trade over the study period. Within the citrus group, oranges are the most widely traded product and exhibit the broadest geographic spread of both producers and importers, making them well suited to a comparative analysis across exporting regions [7]. Although the empirical analysis focuses on fresh oranges, the same framework could be extended in future research to other citrus products, such as lemons, mandarins, and clementines, or to other fresh fruit categories with comparable seasonal import structures.

Europe was selected as the focal import market for two reasons. First, it is the world's dominant importing region for fresh oranges, accounting for 53.6% of global import volumes in 2022. Second, European import data from Eurostat provide monthly breakdowns by origin country, enabling a seasonal analysis that is not available at the same resolution for other major importing regions.

The analysis focuses on six European importing countries: three orange-producing countries—Spain, Italy, and Greece—and three non-producing or predominantly import-dependent countries—Germany, France, and The Netherlands. These countries were selected because they combine large import volumes, contrasting domestic production capacity, and distinct market roles within the European orange supply system [9–12]. Spain, Italy, and Greece allow comparison between imports and domestic-season production, while Germany and France represent major consumer markets with limited or no domestic orange production. The Netherlands is included because of its role as a major entry and re-export hub for European fresh fruit trade. For each importing country, the three most active exporting countries within each geographic supply region are identified and grouped accordingly.

3.2. The Unit Value Composition Index: A Shift-Share Decomposition

To analyse the structural dynamics of European orange imports, this study constructs a unit value composition index and decomposes changes in that index using an exact shift-share framework. Trade unit values are widely used in the agri-food trade literature as indicators of import composition and, in some settings, as imperfect proxies for product differentiation or quality [13–15]. In this paper, however, unit values are interpreted more cautiously as trade-data indicators of import composition rather than as direct measures of product quality or climate impacts.

The choice of a shift-share decomposition follows from the objective of the analysis. Standard price indices, such as Laspeyres, Paasche, Fisher, and Törnqvist indices, are designed primarily to summarise aggregate price change between two periods using alternative weighting schemes. The present study asks a different question: which exporting countries contribute to changes in a regional import unit value index, and through which channel? A shift-share decomposition is therefore appropriate because it provides an exact additive attribution of index changes to exporter-level unit value changes, import share reallocations, and the interaction between the two. This approach is consistent with the unit value decomposition logic used by Khandelwal, Schott, and Wei [16] and with applications that use unit values to examine trade composition [13–17].

For a given destination market and supply region g, let c index exporting countries within that region and let t denote the year. The destination market subscript is suppressed for readability, but all calculations are performed separately for each destination market and supply-region block. The unit value of imports from exporter c is defined as follows:

$$p_{tgc} = \frac{V_{tgc}}{Q_{tgc}}, \tag{1}$$

where V_{tgc} is the bilateral import value and Q_{tgc} is the bilateral import quantity. The import quantity share of exporter c within region g and the corresponding regional unit value index is defined as follows:

$$s_{tgc} = \frac{Q_{tgc}}{\sum_{c \in g} Q_{tgc}}, \qquad PQ_{tg} = \sum_{c \in g} s_{tgc} p_{tgc}, \tag{2}$$

where $\sum_{c \in g} s_{tgc} = 1$ in every period. Define changes between $t-1$ and t as $\Delta p_{tgc} = p_{tgc} - p_{t-1,gc}$ and $\Delta s_{tgc} = s_{tgc} - s_{t-1,gc}$. The change in the regional unit value index can then be decomposed exactly as follows:

$$\Delta PQ_{tg} = \sum_{c \in g} s_{t-1,gc} \Delta p_{tgc} + \sum_{c \in g} p_{t-1,gc} \Delta s_{tgc} + \sum_{c \in g} \Delta p_{tgc} \Delta s_{tgc}. \tag{3}$$

The first term in Equation (3) is the unit value, or within-effect. It measures the contribution of changes in exporter-level unit values to the change in the regional index, holding prior period import quantity shares fixed. The second term is the composition, or between, effect. It measures the contribution of changes in exporters' import quantity shares, holding prior period unit values fixed. The third term is the cross, or interaction, effect. It captures the additional contribution that arises when exporter unit values and import shares change simultaneously.

To express the decomposition in proportional terms, each component is normalised by the prior period regional unit value index, $PQ_{t-1,g}$:

$$\frac{\Delta PQ_{tg}}{PQ_{t-1,g}} = \Delta P_{tg} + \Delta C_{tg} + \Delta X_{tg}, \tag{4}$$

where ΔP_{tg}, ΔC_{tg}, and ΔX_{tg} denote the normalised unit value, composition, and cross effects, respectively. These three components sum exactly to the proportional change in the regional unit value composition index. The decomposition is therefore an accounting identity, not an econometric estimate or approximation.

At the exporter level, the total normalised contribution of exporter c is as follows:

$$E_{tgc} = \Delta P_{tgc} + \Delta C_{tgc} + \Delta X_{tgc}. \tag{5}$$

Exporter-level total contributions sum exactly to the proportional change in the regional unit value composition index:

$$\sum_{c \in g} E_{tgc} = \frac{\Delta PQ_{tg}}{PQ_{t-1,g}}. \tag{6}$$

Appendix A provides the derivations of Equations (3) and (4), together with the exporter-level formulas for the unit value, composition, and cross effects. This decomposition allows changes in the regional unit value composition index to be attributed to three distinct mechanisms: changes in exporter-level unit values, changes in the geographic composition of imports, and the interaction between unit value and import share changes. For example, the regional index may increase because existing suppliers ship at higher unit values, because import shares shift toward suppliers with higher prior period unit values, or because suppliers simultaneously increase both their unit values and their import shares. The country-level decomposition identifies which exporters drive aggregate movements and through which mechanism, making it possible to compare the relative contributions of Egypt, Morocco, South Africa, Argentina, and other major suppliers to European import unit value dynamics over the study period.

3.3. Assumptions and Limitations

The index relies on two core assumptions that require explicit discussion. The first is that oranges traded within a given hemisphere and geographic region are sufficiently homogeneous in varietal and commodity characteristics for unit value comparisons to be meaningful. This assumption is standard in the agricultural trade literature using unit values [13–15] and is most plausible when comparisons are made within, rather than across, supply regions. It is less defensible when comparing, for example, Mediterranean navel oranges with Southern African Valencia varieties, which differ in seasonality, skin characteristics, and typical end use. The analysis therefore groups exporting countries by geographic region rather than pooling all origins, which limits but does not eliminate this concern.

The second assumption is that changes in unit values and import shares provide useful descriptive information about the composition of trade flows. This does not imply that higher unit values necessarily reflect higher product quality, greater sustainability, or climate-related effects. Observed unit values may also reflect differences in production and logistics costs, bilateral exchange rate movements [2,3], market power exercised by large trading firms, packaging and certification requirements of destination markets [14], contract terms, shipment composition, and the product mix within the orange category. The present analysis does not control for these factors directly. Observed index variation should therefore be interpreted as descriptive evidence of unit value composition in climate-exposed supply chains, rather than as causal evidence of product quality, sustainability, or climate impacts.

Several limitations of the approach should be noted. Unit values can be constructed consistently from bilateral trade values and quantities, but they may reflect changes in prices, product quality, varietal mix, packaging, logistics costs, exchange rates, contract terms, or shipment composition. Consistent with Khandelwal, Schott, and Wei [16], who treat unit values as prices and adjust for quality separately, and with Bojnec and Fertő [13], who note the limitations of unit value as a quality proxy, the index is interpreted here as a descriptive measure of unit value composition rather than product quality. First, unit values cannot be disaggregated below the country-of-origin level in this dataset, so within-country heterogeneity in production practices is not captured. Second, the analysis is descriptive: it identifies how exporter-level unit values and import shares contribute to movements in the regional index, but it does not establish the causal drivers of those movements [18,19]. Third, monthly Eurostat data for some smaller trade flows contain gaps or suppressed values for confidentiality reasons, which may affect the seasonal analysis for minor origin countries. Finally, the ten-year study window, while appropriate for identifying medium-term trends, may not be sufficient to isolate long-term climate change effects from normal inter-annual variability in agricultural production [24].

4. Results and Discussion

4.1. Global Orange Production Trends

In the decade from 2012 to 2022, according to FAO statistics (Table 1), global agricultural commodity production increased by 23.5%, rising from 7.8 to 9.7 billion tonnes, while fruit production grew at a faster rate of 29.3%, from 0.5 to 0.7 billion tonnes. Within the fruit category, citrus showed particularly dynamic growth, increasing by 28.5% from 129.4 to 166.3 million tonnes between 2010 and 2022. However, disaggregating citrus production by fruit type reveals an important internal divergence: oranges recorded the lowest growth rate within the citrus group, increasing by only 8.1% from 70.6 to 76.4 million tonnes, and their share within the global citrus total declined from 50.6% to 45.9%. This relative stagnation in orange output occurred despite the continued importance of oranges in global fresh fruit consumption.

Table 1. Global production trends for major agricultural commodity groups for fresh consumption, 2010–2022 (thousand tonnes).

Food Categories	2010		2022		2022/2010
Primary crops	7782.4	100.00	9609.5	100.00	23.48
Fruit growing	507.7	6.52	656.2	6.83	29.26
Fresh Citrus	129.4	25.49	166.3	25.34	28.52
-Lemons and limes	14.7	11.37	21.5	12.95	46.33
-Pomelos and grapefruits	7.6	5.86	9.8	5.87	28.76
-Tangerines, mandarins, clementines	24.2	18.72	44.2	26.57	82.35
-Other citrus fruit, n.e.c.	12.2	9.43	14.4	8.67	18.17
-Oranges	70.7	54.62	76.4	45.95	8.12

Our elaborations from FAOSTAT data.

The geographic pattern of production growth in Table 2 reinforces the broader shift in global orange production toward emerging and developing economies [9–12]. The countries contributing most significantly to orange production growth since the early 2000s include, in descending order of 2022 output: India, China, Mexico, Egypt, Indonesia, Iran, Vietnam, Türkiye, Morocco, Algeria, Argentina, South Africa, and Pakistan (Table 2). Together, these countries accounted for 41.1 million tonnes, 53.8% of global production, in 2022. This contrasts sharply with the trajectory of two historically dominant producers. Brazil, despite a sustained decline from 21.3 million tonnes in 2000 to 16.9 million tonnes in 2022, retains the top global ranking. The United States experienced a more severe contraction, falling from 11.8 million tonnes in 2000 to 3.1 million tonnes in 2022, dropping from second to sixth place globally. European producers, Spain, Italy, and Greece, also recorded net declines over the period, though with considerable inter-annual variability [9–12].

Table 2. Orange production by major producer countries worldwide, 2000–2022 (thousand tonnes).

Producer Countries	2000	2010	2015	2019	2022	2010/2000	2015/2010	2019/2015	2022/2019
Brazil	21,330	18,503	16,953	17,090	16,930	−13.25	−8.38	0.81	−0.94
India	2675	5966	7710	9509	10,198	123.1	29.2	23.3	7.2
China (continent)	1054	5618	8052	7760	7600	433.0	43.3	−3.6	−2.1
Mexico	3813	4052	4516	4737	4850	6.3	11.4	4.9	2.4
Egypt	1611	2401	3351	3068	3393	49.1	39.6	−8.5	10.6
United States of America	11,791	7478	5763	4923	3149	−36.6	−22.9	−14.6	−36.0
Spain	2616	3115	2935	3227	2817	19.1	−5.8	9.9	−12.7
Indonesian	644	2029	1856	2563	2685	215.0	−8.5	38.1	4.7
Iran (Islamic Republic of)	1843	2176	1530	2309	2321	18.1	−29.7	50.9	0.5

Table 2. *Cont.*

Producer Countries	2000	2010	2015	2019	2022	2010/2000	2015/2010	2019/2015	2022/2019
Vietnam	427	729	566	1017	1808	70.9	−22.4	79.7	77.7
Italy	1876	2394	1905	1650	1783	27.6	−20.4	−13.4	8.1
South Africa	1167	1415	1763	1688	1748	21.2	24.6	−4.2	3.5
Pakistan	1328	1505	1680	1592	1605	13.3	11.6	−5.3	0.9
Türkiye	1070	1711	1817	1700	1322	59.9	6.2	−6.4	−22.2
Morocco	870	849	869	1182	1248	−2.4	2.3	36.1	5.6
Algeria	-	582	1005	1200	1210	-	72.5	19.3	0.8
Argentina	787	833	1001	1071	1058	5.9	20.1	7.0	−1.2
Greece	946	905	809	849	874	−4.3	−10.7	5.0	2.9
Ghana	-	580	690	696	697	-	19.0	0.9	0.1
Subtotal	55,847	62,842	64,772	67,831	67,295	12.52	3.07	4.72	−0.79
Other countries	8001	7830	8015	8847	9115	−2.14	2.37	10.38	3.02
World	63,848	70,672	72,788	76,679	76,410	10.69	2.99	5.35	−0.35

Our elaborations from FAOSTAT data.

4.2. European Import Patterns

Europe is the world's dominant importer of fresh oranges, accounting for 3.77 million tonnes and USD 2.94 billion in value in 2022, corresponding to 53.6% of global import volumes and values (Table 3). This share, while slightly lower than the 60.8% recorded in 2010, reflects the relative stability of European demand alongside modest growth in Asian import markets, particularly in the Middle East and South Asia.

Table 3. Global fresh orange imports by continent, 2010–2022 (thousand tonnes and thousand USD).

Continent	2010	%	2015	%	2019	%	2022	%
				1000 USD				
World	4,676,335	100.0	4,919,371	100.0	5,464,279	100.0	5,481,023	100.0
Africa	43,370	0.9	81,707	1.7	46,436	0.8	66,846	1.2
Americas	331,592	7.1	400,755	8.1	449,909	8.2	583,560	10.6
Asia	1,204,317	25.8	1,588,166	32.3	2,029,163	37.1	1,851,826	33.8
Europe	3,056,944	65.4	2,809,268	57.1	2,901,280	53.1	2,938,717	53.6
Oceania	40,112	0.9	39,475	0.8	37,491	0.7	40,075	0.7
				Tons				
World	6,120,249	100.0	7,004,525	100.0	7,269,427	100.0	7,029,937	100.0
Africa	113,672	1.9	249,029	3.6	97,025	1.3	149,282	2.1
Americas	515,977	8.4	537,906	7.7	605,568	8.3	636,516	9.1
Asia	1,732,321	28.3	2,296,397	32.8	145,779	2.0	2,454,291	34.9
Europe	3,722,747	60.8	3,888,897	55.5	3,894,200	53.6	3,766,685	53.6
Oceania	35,532	0.6	32,297	0.5	27,632	0.4	23,163	0.3

Our elaborations from FAOSTAT data.

Within Europe, the leading importing countries by volume are the Netherlands, France, the Russian Federation, and Germany, which together intercepted more than half of Europe's total fresh orange imports (Table 4). Trade route direction is closely linked to socio-economic variables including income, population, and per capita consumption [16]. The Netherlands occupies a distinctive position as the primary transit and redistribution hub for the continent: a significant share of its imports is subsequently re-exported to other European markets, meaning that its import volumes reflect commercial intermediation as much as domestic consumption demand. This hub function is relevant for interpreting the Dutch unit value decomposition results below, because Dutch import unit values may reflect sorting, logistics, re-export strategies, and contractual arrangements rather than final consumer-market conditions alone.

Table 4. Fresh orange imports by major importing countries worldwide, 2010–2022 (tonnes).

Importer Countries	2010	2015	2019	2022
Netherlands (Kingdom of)	537,870	503,667	596,217	567,134
France	457,968	489,987	496,507	496,117
Russian Federation	498,799	463,660	447,805	464,641
Germany	504,658	479,973	461,292	443,175
Saudi Arabia	332,473	400,163	405,375	355,754
Bangladesh	-	150,811	167,577	260,619
United Kingdom of Great Britain and Northern Ireland	275,647	277,867	261,163	251,647
Iraq	-	215,968	130,081	243,435
United Arab Emirates	169,481	250,826	202,305	231,410
United States of America	103,097	158,692	190,359	231,017
China, mainland	-	148,407	432,093	209,716
Italy	94,383	217,037	184,225	193,522
China, Hong Kong Sar	189,635	257,478	330,726	185,996
Canada	200,866	188,493	185,823	182,718
Poland	129,236	164,237	168,681	166,963
India	-	-	-	123,654
Spain	137,010	135,076	146,511	117,298
Malaysia	-	-	103,124	115,416
Portugal	83,902	-	113,433	112,024
Belgium	122,335	120,225	104,213	101,752
Subtotal	3,837,360	4,622,567	5,127,510	5,054,008
Others	2,282,889	2,381,958	2,141,917	1,975,929
World	6,120,249	7,004,525	7,269,427	7,029,937
Europe	3,722,747	3,888,897	3,894,200	3,766,685
Europe/World	60.8	55.5	53.6	53.6

Our elaborations from FAOSTAT data.

The distinction between European orange-producing countries—Spain, Italy, and Greece—and non-producing countries—Germany, France, and the Netherlands—is analytically significant. Producing countries have access to domestic supply during their harvest season, reducing import dependency during those months, while non-producing countries depend entirely on imported supply year-round. This structural difference shapes the seasonal composition of import flows and is reflected in the monthly data examined in Section 4.4 [18,19].

4.3. Unit Value Decomposition Results

Tables 5–9 report total exporter-level contributions to the proportional change in each regional unit value composition index. Positive values indicate that an exporter contributed to an increase in the regional index in that year, while negative values indicate a contribution to a decrease. As shown in Appendix A, these total contributions combine the unit value, composition, and cross effects defined in Section 3.2. Therefore, the tables identify which exporters drove movements in the regional index, while the decomposition framework clarifies the channels through which such movements can occur.

Table 5. Unit value composition index of fresh orange imports into major Central European markets from Mediterranean Basin producing countries, 2012–2022.

Imports from Producing Countries												
	Germany				France				Netherlands			
Years	Egypt	Tunisia	Türkiye	Total	Egypt	Morocco	Tunisia	Total	Egypt	Morocco	Türkiye	Total
2012	-	-	-	-	-	-	-	-	-	-	-	-
2013	0.0501	0.0148	−0.0095	0.0554	0.1464	0.0476	−0.0944	0.0996	0.1705	−0.0103	−0.0190	0.1412
2014	0.0048	−0.0049	0.0020	0.0019	0.0175	0.0678	−0.0569	0.0284	−0.1314	0.0138	−0.0053	−0.1229
2015	−0.2372	−0.0121	−0.0250	−0.2743	−0.0085	0.0427	−0.0670	−0.0329	−0.1219	−0.0011	−0.0014	−0.1245
2016	0.0299	0.0371	−0.0317	0.0353	0.1567	−0.0764	−0.0290	0.0513	0.0043	−0.0321	−0.0085	−0.0363
2017	0.0674	0.0114	−0.0090	0.0698	−0.0735	−0.0834	−0.0107	−0.1675	0.0560	0.0120	−0.0079	0.0601
2018	0.0039	−0.0010	−0.0144	−0.0116	0.1340	−0.0475	−0.0415	0.0450	0.0297	−0.0141	0.0045	0.0201
2019	−0.1209	−0.0042	0.0027	−0.1225	0.0234	−0.0299	−0.0050	−0.0115	−0.0736	0.0094	0.0087	−0.0554
2020	0.3192	0.0043	0.0073	0.3308	−0.0073	0.0171	0.0143	0.0241	0.3362	−0.0521	−0.0515	0.2326
2021	−0.0392	−0.0122	−0.0295	−0.0809	0.0915	−0.0454	0.0047	0.0508	−0.0934	−0.0107	−0.0008	−0.1050
2022	0.0056	0.0285	0.0209	0.0550	0.0521	−0.0652	−0.0080	−0.0211	−0.0432	0.0141	−0.0032	−0.0323

Our elaborations from FAOSTAT data.

Table 6. Unit value composition index of fresh orange imports into major Central European markets from non-producing European intermediary countries, 2012–2022.

Imports from Non-Producing Countries												
	Germany				France				Netherlands			
Years	Netherlands	France	Belgium	Total	Netherlands	Germany	Belgium	Total	Belgium	France	Germany	Total
2012	-	-	-	-	-	-	-	-	-	-	-	-
2013	0.0721	−0.0018	−0.0001	0.0701	−0.0040	0.0116	0.0852	0.0927	0.1452	0.0083	−0.0133	0.1402
2014	−0.0909	0.0001	0.0008	−0.0900	−0.0033	0.0005	−0.1176	−0.1204	−0.0926	0.0010	−0.0075	−0.0992
2015	0.0024	−0.0004	−0.0005	0.0015	−0.0015	−0.0012	−0.0050	−0.0077	−0.0382	0.0100	−0.0125	−0.0407
2016	0.0651	−0.0014	0.0011	0.0648	−0.0004	0.0001	0.0488	0.0484	0.0602	0.0202	−0.0347	0.0457
2017	0.0308	0.0004	0.0001	0.0312	0.0051	−0.0041	0.0962	0.0972	0.0377	−0.0084	0.0032	0.0326
2018	−0.0345	−0.0006	−0.0023	−0.0374	−0.0009	−0.0004	−0.0411	−0.0424	0.0986	−0.0122	−0.0473	0.0391
2019	0.0166	0.0001	0.0036	0.0204	−0.0161	0.0168	−0.1390	−0.1383	−0.0453	0.0564	−0.0233	−0.0123
2020	0.2503	−0.0052	−0.0040	0.2412	0.0034	−0.0044	0.2264	0.2254	0.2659	0.0194	−0.0070	0.2783
2021	−0.0777	0.0005	0.0004	−0.0768	0.0048	−0.0019	−0.0860	−0.0830	−0.1220	0.0022	0.0001	−0.1198
2022	0.0075	0.0383	−0.0306	0.0151	0.0128	−0.0143	−0.0132	−0.0148	−0.0665	−0.0188	0.0071	−0.0782

Our elaborations from FAOSTAT data.

Table 7. Unit value composition index of fresh orange imports into the Netherlands from Southern African producing countries, 2012–2022.

Years	South Africa	Zimbabwe	Eswatini	Total
2012	-	-	-	-
2013	0.1104	−0.0003	0.0001	0.1102
2014	−0.0578	0.0004	−0.0004	−0.0577
2015	−0.0553	−0.0002	−0.0009	−0.0565
2016	−0.0272	0.0004	0.0000	−0.0268
2017	0.1448	−0.0003	0.0001	0.1446
2018	−0.0563	0.0005	−0.0003	−0.0561
2019	0.0056	−0.0003	0.0000	0.0054
2020	0.2080	−0.0011	0.0005	0.2075
2021	−0.1988	0.0007	−0.0008	−0.1989
2022	0.0992	0.0000	0.0001	0.0993

Our elaborations from FAOSTAT data.

Table 8. Unit value composition index of fresh orange imports into the Netherlands from South American producing countries, 2012–2022.

Years	Argentina	Peru	Uruguay	Total
2012	-	-	-	-
2013	0.3085	−0.0362	0.0242	0.2966
2014	−0.0227	−0.0058	0.0042	−0.0244
2015	−0.0613	−0.0185	0.0002	−0.0796
2016	0.0081	0.0350	0.0048	0.0480
2017	0.0878	−0.0095	−0.0027	0.0757
2018	−0.0121	0.0089	−0.0018	−0.0050
2019	−0.1345	0.0009	−0.0311	−0.1647
2020	0.1471	0.0365	−0.0126	0.1710
2021	−0.0668	0.0036	0.0014	−0.0617
2022	0.1082	−0.0185	−0.0093	0.0803

Our elaborations from FAOSTAT data.

Table 9. Unit value composition index of fresh orange imports into major European producing countries (Italy and Spain) from Southern African producing countries, 2012–2022.

	Imports from Producing Countries					
	Italy			Spain		
Years	South Africa	Zimbabwe	Total	South Africa	Zimbabwe	Total
2012	-	-	-	-	-	-
2013	0.1299	−0.0005	0.1294	0.1159	−0.0014	0.1145
2014	−0.0625	0.0002	−0.0624	−0.0543	−0.0007	−0.0550
2015	−0.0611	0.0000	−0.0612	−0.5163	0.5125	−0.0038
2016	−0.0188	−0.0004	−0.0193	−0.0382	0.0202	−0.0180
2017	0.1572	−0.0022	0.1550	0.1030	0.0388	0.1418
2018	−0.0556	0.0012	−0.0544	0.0438	0.0054	0.0492
2019	−0.0189	−0.0001	−0.0190	−0.1652	0.0112	−0.1541
2020	0.2125	−0.0001	0.2124	0.2817	0.0028	0.2845
2021	−0.2154	0.0011	−0.2143	−0.1802	0.0477	−0.1326
2022	0.1045	−0.0011	0.1034	0.2051	−0.0047	0.2004

Our elaborations from FAOSTAT data.

Table 5 presents the unit value decomposition results for orange imports into Germany, France, and the Netherlands from their respective principal Mediterranean Basin exporting countries—primarily Egypt, Morocco, Tunisia, and Türkiye—over the period 2012–2022. In line with the high inter-annual variability typical of agricultural commodity markets [25], the unit value composition index exhibits both positive and negative values across country-destination pairs throughout the decade. These results should be interpreted as exporter-level contributions to changes in regional import unit values, rather than as direct evidence of product quality or climate impacts.

The index values for France and Germany are predominantly positive, while those for the Netherlands are more frequently negative. As noted above, this pattern is partly consistent with the Netherlands' role as a re-export hub, which draws imports across a wider range of origins, shipment types, quality tiers, and price points than countries importing primarily for domestic consumption. The Dutch results should therefore be interpreted with particular caution, as they may reflect sorting, logistics, contractual arrangements, and re-export strategies as well as origin country conditions.

Among exporting countries, Egypt registers the most consistent negative contribution to the index across the three European destinations. Morocco contributes negatively, particularly for France and the Netherlands, while Tunisia shows a similar but more modest pattern for Germany and France. Türkiye records negative values in several years, particularly for Germany and the Netherlands, though these tend to remain close to zero. These patterns indicate that changes in unit values and import shares for Mediterranean suppliers contributed unevenly to the regional unit value composition index. They may reflect differences in production costs, varietal composition, exchange rates, logistics costs, certification and packaging requirements, or contractual arrangements between exporters and European importers. Because the analysis does not control for these factors directly, the results are interpreted as descriptive evidence of unit value composition rather than as causal evidence of product quality, sustainability, or climate effects.

Table 5 shows that Mediterranean suppliers do not form a single unit value pattern across European destinations. Egypt accounts for the clearest downward contribution, while Morocco, Tunisia, and Türkiye vary more by destination market. The result highlights the importance of analysing origin–destination pairs rather than treating the Mediterranean Basin as a homogeneous supply region.

Table 6 extends the analysis to intra-European trade flows, examining unit value composition indicators for imports from non-producing European countries—primarily the Netherlands, Germany, France, and Belgium—acting as intermediary suppliers to the same three destination markets. Negative index values are again frequent. These flows do not identify the original country of production and therefore cannot be interpreted as origin country production effects. They are nevertheless relevant because they capture the role of intra-European redistribution in shaping observed import unit values and may also reflect additional logistics, handling, and intermediation costs associated with multi-stage distribution within Europe [28].

Tables 7 and 8 present unit value decomposition results for Dutch imports from Southern Africa and South America, respectively. For Southern Africa (Table 7), South Africa—the dominant supplier—exerts the largest influence on the regional index, while Zimbabwe and Eswatini, both smaller suppliers in the European citrus trade, contribute only marginally to the aggregate. For South America (Table 8), Argentina, Peru, and Uruguay show alternating positive and negative contributions over the period, with positive aggregate values in several years. The years of stronger positive contribution, including 2013, 2017, and 2020, coincide across Southern African and South American suppliers. This may reflect common market-wide factors, such as international price cycles, exchange rate conditions, logistics costs, or demand-side pressures [13–15], but the present analysis does not identify the causal source of these movements.

Tables 7 and 8 show that the Southern Hemisphere supply is not a single pattern. In Southern Africa, the regional index is driven overwhelmingly by South Africa, making European exposure highly dependent on conditions in one dominant origin. In South America, contributions are more dispersed across Argentina, Peru, and Uruguay, suggesting a less concentrated but more variable supply structure.

Table 9 presents Southern African unit value decomposition results for Italy and Spain, the two major European orange-producing countries that nonetheless import significant volumes from Southern Africa to supplement domestic supply outside their main production season. The patterns broadly parallel those observed for the Netherlands: South Africa accounts for most of the movement in the regional index, while Zimbabwe's contribution remains limited. This reflects South Africa's dominant role in Southern Hemisphere orange supply to Europe and the smaller scale of Zimbabwean exports over the study period. We do not make direct inference here about production practices or environmental performance, since the data do not contain specific information on farm-level production, input-use, or climate variables.

Table 9 links the decomposition results to the seasonal-dependence objective by showing that import exposure is not limited to non-producing countries. Even Spain and Italy rely on Southern African suppliers outside the European production season, indicating that domestic production reduces but does not eliminate Europe's dependence on counter-seasonal imports.

Across all destination-origin combinations examined, the unit value composition index demonstrates its utility as a tool for tracking changes in the composition of import flows over time and across geographic supply regions. The pronounced inter-annual variability in index values is itself informative. It shows that European orange import unit values and origin shares shift considerably from year to year. However, these fluctuations should not be interpreted as direct evidence of climate effects. A more definitive assessment of the climate-related drivers of these movements would require integration of weather, yield, exchange rate, logistics cost, and demand-side data at the origin country and destination market levels. This remains a productive direction for future research.

4.4. Seasonal Supply Structure

The monthly distribution of fresh orange imports into Europe, illustrated in Figure 1, reveals a systematic and highly consistent seasonal pattern across the eleven crop years from 2012/2013 to 2022/2023. Import volumes peak between October and January, when domestic European production is limited or in transition, and show a secondary increase between March and May, when specific high-demand varieties not widely produced in Europe require supplementation. The July-to-November window represents the period of greatest extra-European supply dependence, as domestic production in Spain, Italy, and Greece is largely absent from the market.

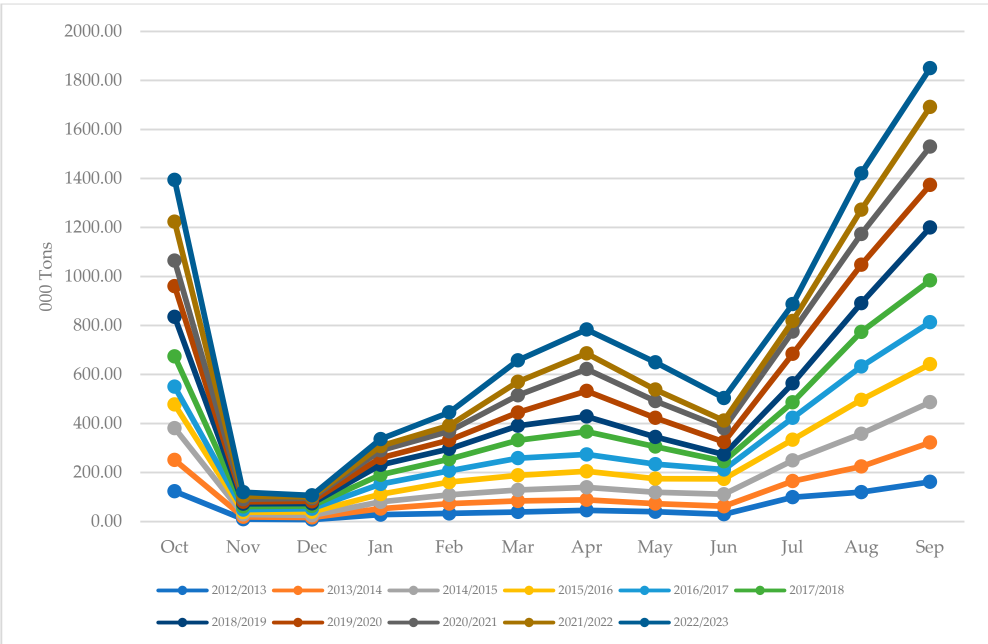

Figure 1. Monthly distribution of fresh orange import volumes into Europe by crop year, 2012/2013–2022/2023 (thousand tonnes). Source: Eurostat.

This pattern shows that European import dependence is not evenly distributed across the year. It is concentrated in specific seasonal windows, especially when domestic production is limited or unavailable. The relevant vulnerability is therefore not simply annual import dependence, but the lack of substitutable suppliers during particular months of the crop year.

This seasonal structure has a clear geographic logic. As shown in Tables 10 and 11, which disaggregate imports by European producing countries, Italy and Spain, and non-producing countries, France and Germany, imports from Morocco and Egypt are concentrated between December and July, supplying the European market during and immediately after the Northern Hemisphere citrus season. Imports from South Africa and Argentina are concentrated between July and October, bridging the European summer and early autumn supply gap. Counter-seasonal Southern Hemisphere supply is therefore not a marginal supplement but a structural component of European orange availability [26,27].

Table 10. Monthly distribution of fresh orange imports into European producing countries (Italy and Spain) by supply region of origin, 2012/2013–2022/2023 (tonnes).

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Italy from Egypt												
2022/2023	-	-	96.0	99.8	2957.6	11,186.9	7765.6	9485.2	6687.6	373.7	-	-
2021/2022	-	-	96.0	-	277.0	1696.1	4346.1	3214.6	3022.8	804.2	74.2	123.5
2020/2021	-	-	221.4	202.8	647.9	2503.7	4199.0	2036.8	1792.0	383.5	144.8	46.4
2019/2020	-	-	242.1	616.4	575.6	2353.4	13,021.8	9761.7	293.8	629.8	-	-
2018/2019	-	-	352.2	810.1	626.7	1302.4	2687.7	2036.1	433.2	24.0	-	-
2017/2018	-	-	410.5	614.4	792.8	2746.6	3807.3	3581.5	694.6	164.5	192.0	-
2016/2017	-	-	39.0	809.6	1146.4	5762.6	7461.0	3574.5	72.4	24.0	-	-
2015/2016	-	-	287.3	738.1	1294.1	1253.8	1837.3	2117.9	260.3	-	-	-
2014/2015	-	-	453.0	256.0	335.2	960.0	2221.4	4779.8	1215.5	-	-	-
2013/2014	-	-	59.1	365.7	323.1	519.4	1281.4	1018.8	240.5	-	-	-
2012/2013	-	-	-	315.1	145.5	443.2	1650.0	3235.0	1569.9	216.0	-	-
Spain from Argentina												
2022/2023	3485	-	-	-	-	-	-	-	-	241.2	2815.0	6805.7
2021/2022	-	-	-	-	-	-	-	-	-	190.8	2852.8	5866.6
2019/2020	2315	-	-	-	-	-	-	-	48.0	3519.9	1432.9	1606.5
2018/2019	4467	-	-	-	-	-	-	-	-	2461.0	8318.4	13,013.5
2017/2018	4275	-	-	-	-	-	-	-	92.4	347.5	7796.9	15,896.8
2016/2017	6316	-	-	-	-	-	-	-	92.4	3417.0	8228.9	11,836.4
2015/2016	3176	-	-	-	-	-	-	-	329.6	4632.6	11,810.9	9669.3
2014/2015	2499	-	-	-	-	-	-	-	72.0	2345.7	8185.4	13,869.9
2013/2014	2482	-	-	-	-	-	-	-	42.0	1257.8	8957.1	11,577.7
2012/2013	2223	-	-	-	-	-	-	-	177.3	5598.4	9383.3	10,411.5

Our elaborations from FAOSTAT data.

The tight seasonal sequencing suggests limited redundancy across the annual cycle. Each major supply region is active during a relatively specific window, leaving fewer opportunities for one region to compensate quickly for disruptions in another. This is particularly relevant for fresh oranges because perishability, varietal differences, shipping times, and phytosanitary requirements limit the speed with which alternative origins can replace disrupted supply. The seasonal analysis, therefore, complements the unit value decomposition by identifying when Europe is most exposed to origin-specific supply conditions.

Figure 2 presents the monthly average import prices of fresh oranges into Europe across the same eleven crop years. Prices show a consistent intra-annual pattern, with the highest values recorded in the July-to-September window, precisely the period of greatest supply scarcity when Southern Hemisphere imports are the primary available source. The upward drift in prices across recent crop years may reflect a combination of food price inflation, logistics costs, exchange rate movements, demand conditions, and production pressures, including those associated with climate variability in exporting regions, although the present analysis does not isolate these drivers.

Table 11. Monthly distribution of fresh orange imports into European non-producing countries (France and Germany) by supply region of origin, 2012/2013–2022/2023 (tonnes).

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
France from Morocco												
2022/2023	-	-	259.2	223.2	118.7	203.6	159.8	52.6	201.7	243.1	21.8	-
2021/2022	-	-	411.8	762.3	922.3	1488.1	1137.1	1171.6	939.1	1127.2	1369.4	358.5
2020/2021	-	20.8	579.0	323.4	698.2	677.1	892.4	1021.5	1833.4	1830.5	1090.3	93.3
2019/2020	486.4	138.2	147.2	228.2	1218.4	918.1	2622.9	1357.1	1575.2	1200.2	-	-
2018/2019	-	6.8	450.3	502.3	584.5	1046.9	735.5	1387.9	1843.5	2071.1	861.9	1402.9
2017/2018	-	55.8	569.3	476.6	956.8	1929.5	1407.4	2996.5	1419.3	1343.4	644.3	49.1
2016/2017	-	7.9	579.7	541.9	588.8	1409.9	1904.8	3027.4	2299.4	1500.4	280.3	-
2015/2016	-	-	302.9	325.0	255.3	489.6	1638.8	2121.5	1130.8	377.1	-	20.2
2014/2015	-	-	216.0	176.8	372.8	650.1	987.5	1488.6	1547.7	71.3	23.7	22.0
2013/2014	-	-	259.2	223.2	118.7	203.6	159.8	52.6	201.7	243.1	21.8	-
2012/2013	-	-	411.8	762.3	922.3	1488.1	1137.1	1171.6	939.1	1127.2	1369.4	358.5
Germany from South Africa												
2022/2023	327.748	0.447	-	57.000	-	0.002	-	-	151.174	228.864	477.310	880.106
2021/2022	1483.988	80.896	3.000	-	-	6.856	-	0.007	123.716	262.738	458.226	409.368
2019/2020	747.661	-	0.005	-	-	0.001	-	-	188.511	336.208	191.399	1123.834
2018/2019	611.858	-	-	-	-	-	0.696	0.118	295.358	585.365	1197.421	1894.622
2017/2018	898.844	8.900	-	-	-	-	-	-	304.028	686.859	1179.119	3409.877
2016/2017	1320.229	-	12.000	-	-	-	-	-	120.001	351.347	1571.643	1049.914
2015/2016	834.551	14.000	15.620	-	-	-	-	-	79.733	908.306	2771.628	3506.605
2014/2015	700.895	8.241	-	6.687	13.892	-	-	0.650	404.672	1126.476	2600.126	2835.030
2013/2014	507.213	0.980	4.750	3.492	13.052	4.500	-	1.666	201.491	904.080	2440.313	2171.108
2012/2013	327.748	0.447	-	57.000	-	0.002	-	-	151.174	228.864	477.310	880.106

Our elaborations from FAOSTAT data.

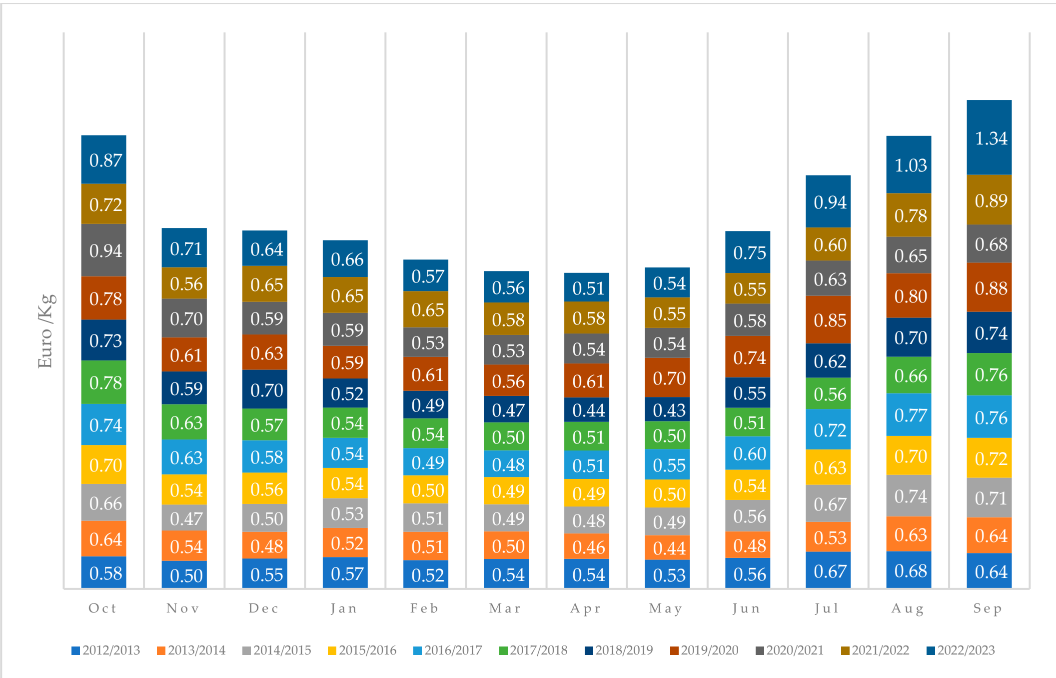

Figure 2. Average monthly import prices of fresh oranges into Europe by crop year, 2012/2013–2022/2023 (EUR/kg). Source: Eurostat.

4.5. Discussion

The results support three main observations relevant to the relationship between agri-food trade, seasonal import dependence, and supply vulnerability. First, global orange production has shifted increasingly toward emerging and developing economies, including several countries in North Africa, Southern Africa, and South America [9–12]. Second, the unit value decomposition shows that changes in European import unit values are not uniform across suppliers or destination markets, but are shaped by exporter-specific contributions and by the structure of destination markets. Third, the seasonal analysis shows that Europe's dependence on external suppliers is concentrated in specific months of the crop year, especially during the European off-season. Taken together, these findings indicate that Europe's exposure in fresh orange supply chains is not adequately captured by annual import volumes alone; it is origin-specific, seasonal, and mediated by trade structure.

The findings should not be interpreted as estimating the causal effect of climate change on orange trade. The analysis does not include meteorological, yield, exchange rate, logistics cost, or demand-side variables, and therefore cannot isolate the drivers of observed unit value movements. Rather, climate vulnerability enters the analysis as a contextual feature of the main supplying regions. Many of the countries that now play an important role in European orange supply face documented pressures related to drought, water scarcity, heat stress, and production variability [8,25–27]. Because these pressures interact with trade policy, institutions, and environmental governance, supply resilience cannot be assessed only from the perspective of importing countries [20]. The contribution of this paper is therefore to identify the trade-side channels through which disruptions in such regions could matter for Europe: concentrated supplier windows, limited seasonal redundancy, and reliance on counter-seasonal imports.

Within these limits, the unit value decomposition provides a useful descriptive tool. It identifies which exporters contribute most to changes in regional unit value indices and shows that destination market structure matters. The Netherlands, for example, differs from France and Germany because of its role as a re-export and redistribution hub, while producing countries such as Italy and Spain still rely on Southern Hemisphere suppliers outside the European production season. These patterns show that import dependence is not simply a distinction between producing and non-producing countries. It is shaped by calendar timing, market intermediation, and the availability of alternative origins.

These findings have direct implications for EU agricultural and trade policy. Under the Common Agricultural Policy and related food security strategies, resilience is often discussed in terms of domestic production capacity, farm income stability, and aggregate food availability. The present results suggest that fresh fruit resilience also requires product-specific monitoring of seasonal import dependence. For commodities such as fresh oranges, policy attention should focus on identifying months in which the EU relies on a narrow set of external suppliers, assessing the substitutability of alternative origins, and monitoring origin country risks that could affect supply continuity. Because these risks are mediated by international trade relationships and by the environmental governance capacity of exporting countries, policy responses should combine EU-level monitoring with support for climate adaptation and sustainability in key origin regions [20,28].

Several policy pathways follow from this perspective. First, the EU could develop seasonal import-dependence indicators for perishable products, combining monthly import volumes, origin concentration, and unit value movements. Second, trade and development policies could support climate-adaptation capacity in key supplying regions, especially where European off-season supply depends on water-stressed production systems. Third, contingency planning could identify alternative origins or logistical routes for high-dependence seasonal windows, rather than relying only on annual diversification metrics. Fourth, sustainability and certification schemes could incorporate origin-specific water, climate, and resilience indicators, while avoiding measures that simply transfer adjustment costs to producers in exporting countries.

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From a food-sovereignty perspective, the results underline the tension between year-round consumer availability and dependence on geographically distant production systems. Food sovereignty does not require the elimination of trade, but it does require that trade relationships support resilient, ecologically sustainable, and socially accountable food systems [4,5,24]. In the case of fresh oranges, this means that European policy should consider not only whether imports are available in aggregate, but also when they are available, from where, under what environmental constraints, and with what degree of redundancy.

Future research should extend this framework in three directions. First, integrating country-level climate, yield, and water-stress indicators would allow direct testing of the relationship between climate variability and unit value movements. Second, incorporating exchange rates, tariffs, transport costs, and demand-side variables would help distinguish production-side pressures from market and logistics effects. Third, applying the same framework to other citrus products, such as lemons, mandarins, and clementines, or to other fresh fruits with counter-seasonal trade patterns, would show whether the seasonal vulnerability identified here is specific to oranges or characteristic of broader fresh-produce supply chains [29].

5. Conclusions

This paper examined European fresh orange imports as a product-specific case through which to analyse agri-food trade, seasonal import dependence, and supply vulnerability. Using FAOSTAT and Eurostat data for 2012–2022, the study combined a unit value composition index with a seasonal analysis of monthly import flows. Rather than estimating the causal effect of climate change on orange markets, the study identifies how Europe's fresh-orange supply is structured across origins, destination markets, and seasonal windows, and assesses the potential supply vulnerabilities created by that structure.

Three main findings emerge. First, global orange production has increasingly shifted toward emerging and developing economies, including several countries in North Africa, Southern Africa, and South America [9,12,23]. Second, European import unit value dynamics vary across origin–destination pairs, indicating that supplier contributions differ by destination market and supply region [13–17]. Third, European orange supply depends on a tightly sequenced set of regional suppliers: Northern Hemisphere suppliers dominate part of the crop year, while Southern Hemisphere suppliers become essential during the European off-season [26,27]. Import dependence is therefore not only a question of annual trade volume; it is also seasonal, origin-specific, and shaped by the limited substitutability of fresh fruit suppliers across months.

The study has several limitations. Unit values are descriptive trade-data indicators and should not be interpreted as direct measures of product quality, sustainability, or climate impacts. The analysis does not include meteorological variables, yield data, exchange rates, tariffs, logistics costs, or demand-side controls, and therefore does not identify the causal drivers of observed unit value movements [18,19]. The ten-year study period is also too short to distinguish long-term climate change effects from inter-annual production variability.

For policy, the results suggest that EU resilience strategies should move beyond annual import-dependence measures and incorporate seasonal exposure indicators. This means monitoring monthly import concentration, identifying periods with limited supplier redundancy, assessing the substitutability of alternative origins, and supporting adaptation capacity in key supplying regions. Such measures would align trade policy, agricultural policy, and food security planning more closely with the seasonal realities of fresh-produce supply chains.

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Appendix A

This appendix provides the algebra underlying the decomposition in Section 3.2 and defines the exporter-level unit value, composition, cross, and total contribution terms. The regional unit value index is a weighted average of exporter-level unit values, where the weights are import quantity shares. Therefore, the index can change between two periods because exporter unit values change, import shares change, or both change simultaneously. The decomposition separates these three sources of change.

For a given destination market and supply region g, the regional unit value index is

$$PQ_{tg} = \sum_{c \in g} s_{tgc} p_{tgc} \tag{A1}$$

where p_{tgc} is the unit value of imports from exporter c in period t, and s_{tgc} is exporter c's quantity share within region g in period t.

Using $p_{tgc} = p_{t-1,gc} + \Delta p_{tgc}$ and $s_{tgc} = s_{t-1,gc} + \Delta s_{tgc}$ writes current period unit values and current period import shares as their prior period levels plus their changes:

$$PQ_{tg} = \sum_{c \in g} \left(s_{t-1,gc} + \Delta s_{tgc}\right)\left(p_{t-1,gc} + \Delta p_{tgc}\right) \tag{A2}$$

Equation (A2) is expanded using the identity $(a+b)(c+d) = ac + ad + bc + bd$. This produces four terms: the prior period index, the unit value-change term, the share-change term, and the interaction term:

$$PQ_{tg} = \sum_{c \in g} s_{t-1,gc} p_{t-1,gc} + \sum_{c \in g} s_{t-1,gc} \Delta p_{tgc} + \sum_{c \in g} p_{t-1,gc} \Delta s_{tgc} + \sum_{c \in g} \Delta p_{tgc} \Delta s_{tgc}. \tag{A3}$$

The first term on the right-hand side of (A3) is the prior period regional unit value index:

$$PQ_{t-1,g} = \sum_{c \in g} s_{t-1,gc} p_{t-1,gc}$$

Subtracting $PQ_{t-1,g}$ from both sides therefore isolates the change in the regional unit value index:

$$\Delta PQ_{tg} = \sum_{c\in g} s_{t-1,gc}\Delta p_{tgc} + \sum_{c\in g} p_{t-1,gc}\Delta s_{tgc} + \sum_{c\in g} \Delta p_{tgc}\Delta s_{tgc}. \tag{A4}$$

Equation (A4) is the core shift-share decomposition. The first term is the price, or within, effect; it measures the effect of unit value changes weighted by prior period import shares. The second term is the composition, or between, effect; it measures the effect of changing import shares weighted by prior period unit values. The third term is the cross, or interaction, effect; it captures the joint effect of unit values and import shares changing at the same time.

Dividing (A4) by the prior period regional index, $PQ_{t-1,g}$, yields the normalised aggregate decomposition:

$$\frac{\Delta PQ_{tg}}{PQ_{t-1,g}} = \underbrace{\sum_{c\in g} \frac{s_{t-1,gc}\Delta p_{tgc}}{PQ_{t-1,g}}}_{\Delta P_{tg}} + \underbrace{\sum_{c\in g} \frac{p_{t-1,gc}\Delta s_{tgc}}{PQ_{t-1,g}}}_{\Delta C_{tg}} + \underbrace{\sum_{c\in g} \frac{\Delta p_{tgc}\Delta s_{tgc}}{PQ_{t-1,g}}}_{\Delta X_{tg}}. \tag{A5}$$

Thus, ΔP_{tg} is the aggregate price effect, ΔC_{tg} is the aggregate composition effect, and ΔX_{tg} is the aggregate cross effect.

The exporter-level price effect is defined as the normalised contribution of exporter c's unit value change, evaluated at its prior-period import share:

$$\Delta P_{tgc} = \frac{s_{t-1,gc}\Delta p_{tgc}}{PQ_{t-1,g}} \tag{A6}$$

Equivalently, define the prior period value share as

$$\omega_{t-1,gc} = \frac{s_{t-1,gc}p_{t-1,gc}}{PQ_{t-1,g}} \tag{A7}$$

Then the price effect can be written as

$$\Delta P_{tgc} = \omega_{t-1,gc}\frac{\Delta p_{tgc}}{p_{t-1,gc}} \tag{A8}$$

This expression shows that the price effect is the exporter's prior period value share multiplied by its proportional unit value change.

The aggregate composition effect in (A5) measures the effect of changing import shares weighted by unit values at their prior period levels. For exporter-level interpretation, it is useful to write this term in centred form. The centred form indicates whether an exporter gained or lost share while having a prior period unit value above or below the regional average.

The exporter-level composition effect is therefore written as

$$\Delta C_{tgc} = \left(\frac{p_{t-1,gc} - PQ_{t-1,g}}{PQ_{t-1,g}}\right)\Delta s_{tgc} \tag{A9}$$

This term is positive when an exporter with an above-average prior period unit value gains share, or when a below-average exporter loses share, and negative in the opposite cases. It is therefore informative about whether European import patterns are shifting toward or away from higher-unit value origins over time [17].

The centred expression in (A9) aggregates to the standard between effect because import shares sum to one in every period. Therefore, the changes in shares sum to zero:

$$\sum_{c \in g} \Delta s_{tgc} = 0$$

Using this identity,

$$\begin{aligned}
\sum_{c \in g} \Delta C_{tgc} &= \sum_{c \in g} \left(\frac{p_{t-1,gc} - PQ_{t-1,g}}{PQ_{t-1,g}} \right) \Delta s_{tgc} \\
&= \sum_{c \in g} \frac{p_{t-1,gc} \Delta s_{tgc}}{PQ_{t-1,g}} - \frac{PQ_{t-1,g}}{PQ_{t-1,g}} \sum_{c \in g} \Delta s_{tgc} \\
&= \sum_{c \in g} \frac{p_{t-1,gc} \Delta s_{tgc}}{PQ_{t-1,g}}
\end{aligned} \tag{A10}$$

Thus, centring changes the exporter-level interpretation but does not change the aggregate composition effect.

The same centring logic is applied to the cross effect. The aggregate cross effect measures the interaction between changes in unit values and changes in import shares. At the exporter level, centring the unit value change around the regional index change helps indicate whether an exporter's unit value changed more or less than the regional index while its share changed.

The exporter-level cross effect is defined as

$$\Delta X_{tgc} = \left(\frac{\Delta p_{tgc} - \Delta PQ_{tg}}{PQ_{t-1,g}} \right) \Delta s_{tgc} \tag{A11}$$

Using $\sum_{c \in g} \Delta s_{tgc} = 0$, this expression aggregates to standard the cross term:

$$\begin{aligned}
\sum_{c \in g} \Delta X_{tgc} &= \sum_{c \in g} \left(\frac{\Delta p_{tgc} - \Delta PQ_{tg}}{PQ_{t-1,g}} \right) \Delta s_{tgc} \\
&= \sum_{c \in g} \frac{\Delta p_{tgc} \Delta s_{tgc}}{PQ_{t-1,g}} - \frac{\Delta PQ_{tg}}{PQ_{t-1,g}} \sum_{c \in g} \Delta s_{tgc} \\
&= \sum_{c \in g} \frac{\Delta p_{tgc} \Delta s_{tgc}}{PQ_{t-1,g}}
\end{aligned} \tag{A12}$$

Therefore, the centred cross effect also aggregates exactly to the cross term in (A5).

The exporter-level total contribution under this centring convention is the sum of the exporter's price, composition, and cross effects:

$$E_{tgc} = \Delta P_{tgc} + \Delta C_{tgc} + \Delta X_{tgc}. \tag{A13}$$

Summing over exporters gives

$$\sum_{c \in g} E_{tgc} = \Delta P_{tg} + \Delta C_{tg} + \Delta X_{tg} = \frac{\Delta PQ_{tg}}{PQ_{t-1,g}} \tag{A14}$$

Thus, exporter-level total contributions add up exactly to the proportional change in the regional unit value index.

The centring terms improve interpretation at the exporter level, but the aggregate decomposition is invariant to centring because the centring terms sum to zero across exporters. For this reason, the country-level tables emphasise total exporter contributions rather than the separate centred composition and cross components.

To see how the centred components combine, substitute

$$\Delta p_{tgc} - \Delta PQ_{tg} = \left(p_{tgc} - PQ_{tg}\right) - \left(p_{t-1,gc} - PQ_{t-1,g}\right)$$

into Equation (A11). This gives

$$\Delta X_{tgc} = \left(\frac{p_{tgc} - PQ_{tg}}{PQ_{t-1,g}}\right)\Delta s_{tgc} - \Delta C_{tgc} \tag{A15}$$

Substituting (A15) into the total contribution definition in (A13) gives

$$\begin{aligned} E_{tgc} &= \Delta P_{tgc} + \Delta C_{tgc} + \left[\left(\tfrac{p_{tgc} - PQ_{tg}}{PQ_{t-1,g}}\right)\Delta s_{tgc} - \Delta C_{tgc}\right] \\ &= \Delta P_{tgc} + \left(\tfrac{p_{tgc} - PQ_{tg}}{PQ_{t-1,g}}\right)\Delta s_{tgc} \end{aligned} \tag{A16}$$

Equation (A16) shows that, under this centring convention, the exporter-level total contribution can be written as the sum of a price component and a combined reallocation component. The aggregate sum of these exporter-level contributions equals the proportional change in the regional unit value index.

At the regional aggregate level, the centring terms sum to zero, so the aggregate price, composition, and cross effects in (A5) are uniquely defined and directly interpretable. At the exporter level, the split between the composition and cross effects depends on the centring convention, but the total contribution E_{tgc} does not; the country-level tables therefore report E_{tgc}.

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