

GLOBAL TRENDS IN THE WALNUT MARKET AND THE CHANGING COMPETITIVENESS OF HUNGARY

Ferenc APÁTI, Viktória TÓTH-KURMAI, Dóra DOROGI, Marianna SIPOS, Adam CSIHON*
University of Debrecen, Faculty of the Agricultural and Food Sciences and Environmental Management,
Institute of Horticulture, 138. Böszörményi str., Debrecen, H-4032, Hungary

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ABSTRACT

The global walnut market has undergone significant changes in recent years. New countries have emerged among the major producers, leading to a significant increase in production and intensified market competition. This study presents international trends in the walnut market. Hungary's position is analyzed using the Herfindahl–Hirschman index (HHI) and revealed comparative advantage (RCA), supported by cost-benefit and investment efficiency analyses. The results show that the international walnut market has become increasingly diversified, while Hungary's competitiveness has weakened significantly between 2013 and 2024. The revealed comparative advantage has fallen below 1 for both shelled and kernel products, indicating a loss of comparative advantage. According to cost-benefit analyses, traditional plantations (no irrigation, terminal bud-bearing cultivars) have become unprofitable due to low yields and poor quality. In contrast, intensive plantations (high density, irrigation, and lateral-bearing cultivars) show high profitability and return on investment, with earnings before interest, taxes, depreciation, and amortization (EBITDA) reaching 6,400 EUR per hectare and an internal rate of return exceeding 16%. Research highlights that the key to improving the sector's profitability lies in vertical integration and the development of postharvest processes (drying, sorting, packaging). Hungary's future competitiveness depends on increasing the share of intensive plantations, enhancing productivity, and strengthening value-added walnut processing.

Key words: cost-benefit analysis, investment analysis, economic indicators, RCA, HHI

INTRODUCTION

The common walnut (*Juglans regia* L.), also known as the Persian walnut, is one of the world's most important shell fruits. This species is native to Eurasia, from the Balkans to southwest China (Khadivi-Khub et al. 2015; Akca & Sahin 2022). Walnut production occurs at latitudes ranging from 30–55° in the Northern Hemisphere to 30–40° in the Southern Hemisphere, and its cultivation now extends to over 50 countries in the Americas, Europe, Asia, and parts of Africa (Pradhan 2014; Marrano & Neale 2019; Vahdati et al. 2019).

Global walnut production has been continuously increasing in recent decades, both in terms of area and production volume. In 2013, total walnut production reached 2.44 million tons of dried in-shell nuts, rising to 3.99 million tons in 2023. In recent years, new countries have emerged among the leading producers, most notably China, which has gained a dominant role. The previous top producer, the United States, has also seen steady growth in walnut output. Over the past decade, China's walnut production area has increased by approximately 55–60%, and total yields have doubled.

*Corresponding author
e-mail: csihonadam@agr.unideb.hu

In 2012, 720,000 tons of walnuts were harvested from 217,487 hectares, while in 2023, production reached 1.4 million tons from 355,995 hectares. The prominent role of these two countries is evidenced by the fact that China and the United States together account for more than half of global walnut production (FAO 2023). Walnut production in California accounted for a significant portion of global production, 29% in 2017–2018, and has stagnated in recent years. During the same period, China's share increased significantly from 42% to 53%. California's share of the global walnut trade has declined, falling from 68% in 2016–2017 to 44% in 2024, while China continues to expand its market presence (Parsons 2024). Chile has also become an important operator, increasing its share of global production from 5% to 7%. In Europe, the leading producers are Romania, France, Italy, Spain, and Bosnia and Herzegovina (FAO 2023).

In recent years, global walnut cultivation has shifted from traditional low-density orchards to modern high-density systems. Driven by growing demand, technological advances, and climatic challenges, these intensive systems strive to enhance productivity and resource efficiency through mechanization and precision agriculture (Lowenberg-DeBoer 2022; Popa et al. 2023; Kithi et al. 2025). Intensive walnut farming is characterized by high-density plantings and structured canopy systems. Planting design and spacing, which may range from 12×12 meters to 6×6 meters, are determined by production goals, site conditions, and management practices. Intensive systems may reach planting densities of up to 536 trees per hectare, compared with only 100–120 trees per hectare in traditional orchards (Javaid et al. 2017; McNeil 2019). Central leader and open center training systems are commonly used in walnut orchards, but central-leader trees in dense plantings produce fruit earlier and produce higher yields (Lemus 2001; Chen & Qi 2022; Khalil et al. 2023).

In modern walnut orchards, late-leafling cultivars are favored for their high lateral bud fruitfulness, drought tolerance, and resistance to major diseases such as walnut blight and anthracnose (Ramos et al. 2001; Aslamarz et al. 2010; Ertürk & Akça 2014; Botu et al. 2019; Hassani et al. 2020). Lateral-bearing cultivars typically produce higher yields of $1.7\text{--}4.1 \text{ t}\cdot\text{ha}^{-1}$ of dried nuts compared to terminal-bearing cultivars with yields of $1.5\text{--}2.6 \text{ t}\cdot\text{ha}^{-1}$ (Botu et al. 2010). Nevertheless, lateral-bearing walnut cultivars typically start blooming the year after planting and reach full yield about five years later (Bai et al. 2020).

In Hungary, based on the territory data, walnut is currently the third most important fruit crop after apple and sour cherry. Its production area is continuously expanding. In 2013, walnuts were cultivated on 5,800 hectares, and by 2023, the area had exceeded 9,600 hectares. Annual total yield ranges from 9,000 to 12,000 tons (in raw, undried, shelled nuts). However, average domestic yields are relatively low compared to those of competing countries, at around $1\text{--}1.5 \text{ t}\cdot\text{ha}^{-1}$. It can be attributed to the large number of extensive, neglected old orchards and the high proportion of young plantations. Intensively managed, irrigated orchards in Hungary can also achieve yields of $4 \text{ t}\cdot\text{ha}^{-1}$. Nevertheless, only about 3,000 of the existing 9,600 hectares of walnut production area are characterized by intensive cultivation systems (8×6 m spacing, lateral-bearing cultivars, regular pruning, and irrigation). This means that about two-thirds of Hungarian walnut orchards do not meet these criteria for intensive production (FruitVeB 2024).

The quality of Hungarian walnuts has been appreciated worldwide for decades, with local cultivars often achieving premium fruit grade categories. Hungarian walnut cultivars have a shell diameter of 32–35 mm, a kernel share of 42–50%, and a thin, papery shell. Their value is further enhanced by the attractive, light shell color and smooth, even surface (Bujdosó et al. 2005; Bujdosó & Cseke 2021; Kithi et al. 2023).

Over the past 10 years, the advantage of domestic walnuts has been their precocity, which meant they reached the market at the beginning of the ripening season. Still, with the rise of Chilean and Argentine walnuts, this advantage has been lost (FruitVeB 2024).

This research aims to analyze global trends in the walnut market and assess Hungary's position in walnut production. The paper examines the role of economic, structural, and technological factors in shaping the domestic position of the walnut sector.

MATERIALS AND METHODS

This study uses the Herfindahl–Hirschman index (HHI) and the revealed comparative advantage (RCA) to assess the global market position of Hungarian walnut products. To evaluate the profitability and competitiveness of domestic production, cost-benefit and investment analyses were conducted for orchards with varying production intensity.

The Herfindahl–Hirschman index (Hirschman 1945; Herfindahl 1950) is one of the most widely used measures of market concentration, expressing the level of competitiveness or concentrated of a market, i.e., the number of dominant economic entities. The index is calculated based on the sum of the squares of the market shares of individual operators or, in the case of exports, countries and ranges from 0 to 10,000. The higher the HHI, the greater the concentration, meaning that fewer operators control a significant portion of the market.

For export markets, the HHI shows the distribution of the share of a given product among exporting countries. A value of the HHI below 1,500 indicates low concentration, between 1,500 and 2,500 indicates moderate concentration, and above 2,500 indicates high concentration or even monopoly. The index is therefore suitable for analyzing the structure, competitiveness, and dependence of export markets. The analysis is based on foreign trade data from the UN Comtrade database, using HS (Harmonized System) codes, focusing on two main categories of walnut products: walnuts in shell (HS 080231)

and walnuts shelled (HS 080232). All countries ($n = 129$) were included in the analysis to reflect the study's global market perspective. No missing data were identified for 2023 or earlier years, although not all countries had yet met their reporting obligations for 2024. Therefore, each country was evaluated based on the latest available data.

This method has previously been used, among others, to analyze the concentration of global export of corn, soybean, and wheat (Zulauf et al. 2021). In EU agri-food reports, the HHI values are used to examine the diversification of export partners of Member States and product groups (EC 2023). It is also used to quantify the dependence and risk of export markets (Montes Ninaquispe et al. 2024).

Revealed comparative advantage is a commonly used indicator in international trade to analyze foreign trade specialization and a country's relative competitiveness (Balassa 1965). The indicator measures whether a country's share of a given product in its exports is larger or smaller than its share in world exports. In other words, the value of RCA indicates whether a country has a comparative advantage in the production and export of a given product compared to other countries in the world.

The competitiveness analysis of Hungarian walnut production is based on foreign trade data from the UN Comtrade database by HS codes, focusing on the two main product categories: walnuts in shell (HS 080231) and shelled walnuts (HS 080232), as well as total global product exports and Hungary's exports. Calculations are based on export values (USD), and global trade data include both domestic exports and re-exports. When interpreting the RCA indicator, a value greater than 1 indicates comparative advantage, while a value less than 1 indicates comparative disadvantage. If the RCA exceeds 2, the country has particularly strong foreign trade in the given product. Analyzing the RCA over time enables the identification of competitiveness trends and Hungary's share of the global walnut export market over the past decade.

Using this indicator, Sharma et al. (2023) examined the competitiveness of fresh and processed fruit and vegetable products. Jagdambe (2019) analyzed the competitiveness of Indian agriculture, and Naing et al. (2021) assessed the comparative advantage of various fresh fruits available in the market using the RCA indicator.

In addition to describing global market trends, the authors of this study also aimed to conduct an organization-level cost-benefit analysis based on a methodology developed and subsequently refined at the Debrecen School of Economics. The calculations used cost and income ratios of well-managed, extensive (terminal bearing) walnut plantations using traditional cultivation methods, as well as intensive (lateral bearing) walnut plantations and their associated postharvest processes.

The total area under walnut cultivation in Hungary is approximately 9,600 hectares, of which,

according to expert estimates, approximately 2,000–2,500 hectares are used for commercial production. Even in these commercial orchards, extensive cultivation technology dominates, accounting for approximately 60% of plantations. However, over the past 5–8 years, new orchards have been established, where both the cultivar selection and production technology used are considered intensive, covering approximately 1,000 hectares.

The sampling procedure was purposive, with data collection sites selected by cultivation technology, and data were collected in cooperation with producers. Although the survey is not representative of the entire cultivation area, it focused on commercial production areas, where data were collected representatively for both cultivation technology levels. The study covered approximately 50% of intensive and 20% of extensive cultivation areas. The parameters for the analyzed orchard and drying plant types are summarized in Table 1.

Table 1. Parameters of the analysis of walnut plantations

Parameter	Traditional	Intensive
Rootstock	seedling	seedling
Cultivar	‘Milotai 10’	‘Milotai Bőtermő’
Plantation life cycle	10–35 years	10–35 years
Canopy	globous	central axis canopy
Tree height	6–8 m	5–6 m
Row spacing (m)	10	8
Plant spacing (m)	10	6
Number of plants per hectare	100	208
Irrigation	unequipped	microspraying
Achievable yield level	2 t·ha ⁻¹	4–5 t·ha ⁻¹
Harvest method	machine, manual	machine, manual
Type of product sold	1. raw walnut; 2. dried walnut (using an external dryer); 3. dried walnut (using own dryers)	
Drying investment cost	EUR 4,571.58 per ha	
Drying efficiency	200–220 tons per season	

Source: own data collection and processing

The investment cost for the dryer includes construction costs, process equipment (washing, drying, delivery, packaging), and all additional infrastructure. The dryer’s capacity is 200–220 tons per season, sufficient for processing and drying approximately 50–60 hectares of walnut plantations (intensive production system), and the total cost is 261,233 euros

This study is based on the collection and compilation of inputs for all production technology on commercial farms, by breaking down each work operation into its basic components and determining the inputs for materials, labor, and machinery. Inputs collected from 10 production farms were converted into costs at market prices. Price lists from four leading domestic trading companies were used to determine material prices. Machine operating costs were derived from calculations by 40 production organizations and machine rental rates. Manual labor costs were based on current wage conditions.

To study the revenue side, data on yields and selling prices were obtained from producing farms. Sales prices were also collected from trading companies and numerous secondary sources. Data from producing organizations was collected through personal visits and professional consultations. During the cost-benefit analysis, cost and performance indicators (sales revenue, income), the income situation (contribution margin, EBITDA), and production efficiency (income level, cost level, cost-to-income ratio, prime cost) were also evaluated.

Cost-benefit analysis is used in many areas of agribusiness to evaluate the cost-to-income ratio in specific sectors. This method was previously used in dairy production by Hingyi (2002), in the poultry sector by Szöllősi (2008), in the beef cattle sector by Szabó (2009), in the sheep sector by Cehla (2011), in the tobacco sector by Bittner (2011), and by the Agricultural Economics Research Institute to analyze the cost and incomes of major agricultural products (Béládi et al. 2017). Cost-benefit analysis is also regularly used in scientific research on fruit production (Jalić et al. 2022; Vasuki & Soundariyan 2022; Ravalomanana 2023).

Investment profitability analysis is typically used to qualitatively assess the expected profitability of an investment, compare it with alternative risk-free investments, and support informed decisions about the optimal use of resources. Cost-to-income ratios for the bearing years and the economic efficiency of plantation investments were calculated for four production variants: traditional cultivation system of raw and dry shelled walnuts

(1–2) and intensive cultivation system of raw and dry shelled walnuts (3–4).

Dynamic investment efficiency metrics provide more accurate economic results (Horváth 1997; Pfau 1998; Szöllősi 2008). This analysis is based on four dynamic indicators as these account for the time value of money, thus enabling sound economic decisions: net present value, profitability index, discounted payback period, and internal rate of return. Economic efficiency is a relative concept, so it is common practice in business economics to compare the profitability of an investment with the rate of return on an alternative, risk-free investment. Such a reference could be a bank deposit, the interest rate of which is currently 3–7%. In this analysis, the calculated interest rate was set at 6.5%. Economic analyses of investments are suitable for a comprehensive economic evaluation of the useful life of the plantation (Castle et al. 1992; Akçay & Uzunöz 2005; Brealey & Myers 2005; Apáti 2007; Nábrádi & Szöllősi 2007; Sojková & Adamicková 2011; Szöllősi & Szűcs 2013; Badiu et al. 2015; Szabó 2016; Singh & Nandi 2020).

RESULTS AND DISCUSSION

The global nut market is rapidly changing and moderately concentrated, with competitive intensity varying by product and season. Table 2 shows the global market concentration for nut kernels and shelled nuts from 2013 to 2024, based on the HHI. Both products had HHI values around 2,000 or below, indicating moderate market concentration. Walnut kernels show a slight downward trend from 2013 to 2024, indicating increased market competition and diversification among producers and exporters. In contrast, the HHI for shelled walnuts declined significantly from 2013 to 2023, before rising again in 2024. This may indicate market reconcentration, as confirmed by research by Aksoy and Kaymak (2021) and Zhang and Fan (2024), who reached similar conclusions. Fluctuations in the HHI can likely be explained by changes in the structure of production or trade (e.g., the entry or exit of new, major exporters).

The structure of global shelled walnut exports (Table 2) showed significant structural changes during the examined period (2013–2024). At the beginning of the period, the United States was the dominant trader with a 59% market share. However, by 2024, this share had declined to 27%, indicating a gradual weakening of its former dominance. According to Padilla et al. (2023), the US competitive position in the global walnut market is threatened by factors such as climate change, water shortages, and forest fires in the main producing regions. At the same time, China is experiencing dynamic growth. While China played no role in the global shelled walnut trade in 2013, by 2024 it accounted for 34% of global exports, becoming the leading exporter of this product group. Chile's market share stabilized at 14–20% during this period, indicating sustained competitiveness. In contrast, the market share of Mexico and France has continuously declined from 10–13% to below 5–6%.

The previously single-centered walnut kernel market has also undergone a restructuring. In 2013, the United States accounted for 44% of global exports, but by 2024, this share had fallen to 33%. At the same time, Mexico significantly strengthened its export position, increasing its share from 8% to 21%. China has expanded its market share from 3% to 16%, indicating the greater importance of walnut processing and the production of value-added products. Several studies emphasize that the development of processed walnut products and the establishment of an export-oriented processing industry may even be key to a successful future for China (Chen et al. 2017; Chen & Qi 2022). Chile's export share has stabilized at around 9–10%, confirming the sustained market competitiveness of this South American country. All of the above suggests that a regionally diversified, multipolar competitive environment has developed in the global walnut kernel market (Table 3).

Table 2. Concentration of the world walnut market (Herfindahl–Hirschman index)

Product	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Walnut kernel	2,187	2,193	2,545	2,390	2,011	2,101	1,901	2,017	1,922	2,054	1,845	1,888
Walnut in shell	3,679	2,866	2,562	2,905	2,245	1,994	1,808	1,973	1,906	1,973	1,747	2,313

Source: own editing based on data from Comtrade (2025)

Table 3. Shares in export of walnut products on the world market (%)

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Walnuts in shell (HS 080231)												
USA	59	50	46	48	41	36	32	36	32	33	24	27
China	0	0	0	0	3	5	14	15	20	15	22	34
Chile	7	9	14	8	17	18	13	16	19	21	20	18
United Arab Emirates	1	2	2	2	6	8	10	7	8	12	11	n.d.
Mexico	7	12	13	21	11	15	15	11	6	5	9	6
France	10	11	10	9	9	8	5	6	6	5	5	4
Other countries	16	16	15	12	13	10	11	9	9	9	9	11
Total	100	100	100	100	100	100	100	100	100	100	100	100
Shelled walnuts (HS 080232)												
USA	44	43	47	43	38	37	33	37	35	38	30	33
Mexico	8	10	12	19	19	24	25	22	21	20	26	21
China	4	4	3	2	3	4	5	5	9	9	12	16
Chile	10	10	10	8	11	9	10	9	10	9	9	9
Other countries	34	33	28	28	29	26	27	27	25	24	23	21
Total	100	100	100	100	100	100	100	100	100	100	100	100

Source: own editing based on data from Comtrade (2025)

The development of RCA indicators (Table 4) confirms these trends. In the case of shelled nuts, the comparative advantage of the United States gradually weakened. In 2013, the RCA value was 6.89, and by 2024 it had fallen to 2.77, indicating persistent but decreasing foreign trade specialization. In the case of China, on the other hand, no comparative advantage was observed in 2013 ($RCA \approx 0$). Nevertheless, by 2024, the country reached a value of 2.02, indicating increased competitiveness and a transformation in its export structure. Bai et al. (2025) also pointed to a growing comparative advantage for China. RCA values in Chile were consistently exceptionally high (20–50), confirming the country's strong export-oriented specialization in nut production, although slight declines were observed after 2020.

A similar, but more balanced, trend can be observed for shelled walnuts. Although the RCA for the United States declined from 5.12 to 3.34, the country remains the leading exporter. Mexico's RCA increased from 4.13 to 9.82 in 2019 and then declined to 7.15, reflecting a stable, high level. Chile's RCA values ranged from 18 to 28, indicating persistent and prominent specialization, while China's RCA increased from 0.32 to 0.94 (Table 4).

From 2013 to 2024, significant structural and competitive changes took place in the global walnut products market. Both market shares and RCA values show that the previous leading position of the United States has steadily declined, while the role of China, Chile, and Mexico has considerably strengthened.

Thus, the sector has shifted toward a multipolar, highly competitive global market, where production efficiency, processing levels, and export diversification play an increasingly important role in creating and maintaining comparative advantages.

Foreign trade in Hungarian walnut products has undergone significant restructuring over the past decade, both in exports and imports. Based on Eurostat data (Table 5), the foreign trade position of the Hungarian walnut sector has weakened significantly. Hungary continued to record a significant export surplus in shelled walnuts between 2013 and 2017, meaning that domestic production was able to supply not only the domestic market but also foreign markets during this period. Exports were mainly directed to neighboring countries – Slovakia, Austria, and Germany. After 2018, exports values declined continuously, while imports gradually increased, especially in 2023–2024, when imports exceeded exports. As a result, by 2024, a negative foreign trade balance occurred, and the Hungarian shelled walnut market became partially dependent on imports. This trend is even more pronounced for shelled walnuts (a processed product). The foreign trade balance remained positive between 2013 and 2017, but since 2019, exports have declined sharply, while imports have risen sharply. Shelled walnuts originate mainly from Ukraine, Romania, and China, while significantly lower exports to Western Europe – primarily Germany and Austria. The foreign trade market for the analyzed Hungarian walnut products has gradually transformed from an export-driven market to an import-driven market.

Table 4. Revealed comparative advantage indicators for walnut products

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Walnuts in shell (HS 080231)												
USA	5.12	4.94	5.06	4.68	4.21	4.18	3.72	4.42	4.38	4.33	3.36	3.34
Mexico	4.13	4.62	5.05	8.05	8.22	10.10	9.82	8.99	9.05	8.15	9.72	7.15
China	0.32	0.28	0.20	0.13	0.25	0.28	0.39	0.34	0.61	0.56	0.82	0.94
Chile	24.45	25.50	25.75	21.95	28.06	23.71	26.45	21.22	22.16	21.86	21.43	18.36
Shelled walnuts (HS 080232)												
USA	6.89	5.68	4.90	5.20	4.60	4.06	3.64	4.32	3.91	3.74	2.73	2.77
China	0.00	0.00	0.00	0.01	0.19	0.41	1.06	0.97	1.28	1.00	1.50	2.02
Chile	16.74	23.28	36.49	20.02	42.12	46.48	35.23	36.00	43.86	50.66	47.82	38.32
United Arab Emirates	0.47	1.32	1.27	1.06	3.34	3.73	4.83	3.82	4.13	5.66	4.52	n.d.
Mexico	3.40	5.61	5.31	8.69	4.44	6.33	6.15	4.46	2.59	2.02	3.27	2.16
France	3.35	3.46	3.15	2.88	2.82	2.62	1.76	2.02	2.37	1.89	1.68	1.46

Source: own editing based on data from Comtrade (2025)

Table 5. Foreign trade balance of Hungarian walnut products (unit: 1 000 euros)

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Walnuts in shell (HS 080231)												
Export	5,984	7,822	6,646	4,172	6,298	2,997	3,721	1,101	1,221	1,669	841	339
Import	52	10	92	13	18	23	26	37	89	92	98	705
Balance	5,932	7,812	6,554	4,159	6,279	2,974	3,696	1,064	1,132	1,577	744	-366
Shelled walnuts (HS 080232)												
Export	10,760	15,611	15,410	10,242	10,557	3,975	1,883	2,658	1,797	2,021	1,649	1,775
Import	7,460	10,748	11,278	2,831	5,574	3,559	3,455	5,784	6,057	5,861	3,977	5,451
Balance	3,299	4,863	4,132	7,411	4,983	416	-1,572	-3,127	-4,260	-3,841	-2,328	-3,676

Source: own editing based on data from Eurostat (2025)

Table 6 presents the RCA for Hungarian exported walnut products – shelled walnuts and walnuts in shell, from 2013 to 2024. A value higher than 1 indicates a comparative advantage, while a value below 1 indicates a competitive disadvantage in foreign trade for the product. In 2013–2014, a comparative advantage was observed for both walnut products: for shelled walnuts, the value ranged from 1.52 to 1.67, while for walnuts in shell, it ranged from 1.20 to 1.40. This means that Hungary was a competitive exporter of walnut products during this period. However, from 2015 onwards, the indicator showed a continuous downward trend. By 2016, the value of both products had fallen below 1, indicating a competitive disadvantage. In the 2017–2024 period, the downward trend became more pronounced. The RCA of shelled walnuts decreased from 0.79 to 0.08, and of walnuts in shell from 0.91 to 0.03. This indicates a significant deterioration in the export performance of Hungarian walnut products and a loss of the country's previous advantage in foreign markets. The continuous decline in this indicator for shelled walnuts is particularly noteworthy, as processed products are characterized by higher added value. This suggests a deterioration in the competitiveness of processed export products. The RCA for shelled walnuts shows a significant decline, indicating narrowing opportunities for raw-material exports. Between 2013 and 2024, Hungary lost its comparative advantage in walnut exports, and the country now faces a significant competitive disadvantage in both product groups. The persistently low values of RCA indicators warn that walnut production and trade in Hungary require strategic renewal, particularly in terms of production efficiency and quality improvement.

One of the primary explanations for the competitive disadvantage is the drastic decline in domestic commodity pools, driven by economic factors: declining profitability and production efficiency. Therefore, it is necessary to explore how different technological solutions affect cost and income ratios. Accordingly, cost-to-income ratios for production years and the economic efficiency of plantation investments were calculated for four production variants. The first is a traditional cultivation system for raw walnuts in shell. The second is a traditional cultivation system for dry walnuts in shell. The third is an intensive cultivation system for raw walnuts in shell. And the fourth is an intensive cultivation system for dry walnuts in shell, using outsourced drying facilities or own drying machines). What primarily distinguishes dry-shelled walnuts (as an output product) from raw walnuts is their higher production costs (due to investment and operating costs of the postharvest facility) and higher achievable selling price. Raw, shelled walnuts have only limited sales opportunities (primarily with integrators or acquirers with drying facilities). However, the sale of dry walnuts is more flexible because they can be stored for long periods. A comparison of the economic results of the studied cultivation systems was made. It can be clearly stated that intensive walnut plantations are significantly more productive than traditional ones, both in terms of yields and income. Intensive plantations produced $4.5 \text{ t} \cdot \text{ha}^{-1}$, which is 4.5 times the average of $1.0 \text{ t} \cdot \text{ha}^{-1}$ for traditional plantations. Botu et al. (2019) also concluded in an 18-year study that cultivars producing from lateral buds can yield 37% more than those producing from terminal buds, even without irrigation.

This difference is due not only to adequate cultivar selection but also to more advanced production technology, denser plant spacing, irrigation, and a higher level of organization in terms of nutrient supply and plant protection. Kithi et al. (2025), Devin and Bujdoso (2022), and Bernard et al. (2018) concluded that intensive and super-intensive walnut orchards require low-vigor cultivars with strong roots, early fruiting, and lateral budding. However, in addition to genetic foundations, modern agrotechnology is also essential.

Sales prices vary significantly depending on the degree of processing: the market price of dried walnuts in shell (EUR 2.74 per kg) is more than twice that of raw walnuts (EUR 1.24 per kg). Consequently, sales of dried products generated higher revenues, confirming the importance of vertical integration and value-added processing. The revenue trend also demonstrates the economic advantage of intensive systems. While the total revenue of a traditional plantation producing raw products was only EUR 1,302 per hectare, the revenue of an intensive plantation producing dried walnuts was EUR 10,497 per hectare. It is worth noting that the rate of direct subsidies to revenues was 20–33% in traditional systems, compared to around 6–10% in intensive systems, indicating that the latter are also commercially viable. Cost analysis shows that the total cost of intensive plantations (5,400–9,500 euros per ha) is about twice that of traditional plantations (4,300–4,800 euros per ha). However, the yield and income surplus significantly exceed this.

The break-even and EBITDA indicators clearly illustrate the income-generating capacity of the studied systems. Traditional systems showed negative break-even points (986 and 692 euros per ha) and EBITDA (669 and 148 euros per ha), indicating their operational unprofitability. In contrast, intensive production systems achieved positive and significant profits: EBITDA reached EUR 3,093 per hectare for raw walnut production and EUR 6,444 per hectare for dried product production (Table 7).

The EBITDA margin in intensive systems ranged from 99% to 159%, indicating outstanding operational efficiency and capital utilization. Cost levels, which represent the ratio of costs to revenues, ranged from 135% to 176% in traditional systems, but only 52–69% in intensive plantations. This means that in intensive plantations producing dried walnuts, only EUR 0.52 of costs were incurred for every EUR 1 of revenue. The levels of income (revenue proportional to income) and direct revenues proportional to costs (31–48% and 46–93%, respectively) also confirm the advantage of intensive systems. At the same time, both indicators were negative in traditional systems.

Investment and economic calculations suggest that each version of the studied investment is worthwhile, but the results of dynamic investment and economic indicators show differences. All calculations presented in Table 8 were performed assuming 100% self-financing. The return on investment for each production system is within the useful life of the plantation. In all the cases studied, the investment can be profitable. Internal rate of return (IRR) values are higher than the calculated interest rate, profitability indices (PI) are greater than 1, and net present values (NPV) are positive. The highest NPV can be achieved by investing in a plantation with a drying plant, exceeding EUR 35,137 per hectare by the end of year 30. It should be noted that this investment result was based on higher investment costs. In the system with outsourced drying, higher revenues are associated only with the intensive costs of establishing the plantation, resulting in an achievable NPV of EUR 31,976 per hectare. The most modest profit can be achieved in a traditional plantation system, where the product sold is only raw, shelled walnuts. In this production system, a NPV of EUR 12,635 per hectare can be realized by the end of the assumed useful life.

Table 6. Revealed comparative advantage indicators of Hungarian walnut products

Product	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Shelled walnuts	1.52	1.67	1.27	0.98	0.79	0.31	0.14	0.18	0.13	0.13	0.10	0.08
Walnuts in shell	1.20	1.40	1.15	0.57	0.91	0.44	0.40	0.16	0.18	0.21	0.10	0.03

Source: own editing based on data from Comtrade (2025)

Table 7. Cost and revenue conditions of the analyzed cultivation systems

Factor	Unit	Traditional plantation (raw walnuts in shell)	Traditional plantation (dried walnuts in shell)	Intensive plantation (raw walnuts in shell)	Intensive plantation (dried walnuts in shell)
Harvested yield	t per ha	1.0	1.0	4.5	4.5
Sold yield	%	0.7	0.56	3.6	3.6
Fresh market selling price	EUR per kg	1.24	2.74	1.24	2.74
Total revenue	EUR per ha	868.60	1,536.05	5,583.86	9,874.61
Indirect subsidies	EUR per ha	434.00	434.00	622.00	622.00
Total income	EUR per ha	1,302.60	1,970.05	6,205.86	10,496.61
Total indirect costs	EUR per ha	2,288.75	2,662.31	4,255.00	5,424.54
Operation costs (current expenditures)	EUR per ha	1,971.78	2,118.07	3,112.52	4,052.95
Break-even amount	EUR per ha	-986.14	-692.26	1,950.85	5,072.06
EBITDA	EUR per ha	-669.18	-148.02	3,093.34	6,443.65
Direct costs	EUR per kg	3.27	4.75	0.95	1.21
EBITDA margin	%	-33.94	-6.99	99.38	158.99
Direct profitability proportional to costs	%	-43.09	-26.00	45.85	93.50
Income level (profitability proportional to revenues)	%	-75.71	-35.14	31.44	48.32
Cost level	%	175.71	135.14	68.56	51.68

Source: own editing based on data from own collection (2025)

Table 8. Economic indicators of investment in the case of the analyzed intensive production system

Indicators	Plantation investment of raw walnuts in shell	Plantation investment with outsourced drying	Plantation investment with its own drying facility
NPV (EUR per ha)	12,635.6	31,976.3	35,137.4
IRR (%)	12.47	17.95	16.14
DPP (year)	14.	10.	11.
PI	6.92	8.14	11.72
Planting costs (EUR per ha)	10,188.1	10,188.1	14,561.3
Useful life cycle (years)	30	30	30

Source: own editing based on data from own collection (2025)

NPV – net present value, IRR – internal rates of return, DPP – discounted payback period, PI – profitability index, calculated interest rate – 6.5%

Investment and economic results are improved by the currently available subsidies for plantation establishment. These subsidies are available in both the short and medium terms. Therefore, analyses were also conducted with a 60% (plantation establishment and infrastructure) and 50% (specifically for the drying facility) investment subsidy. NPVs are higher in all analyzed plantation systems, and return periods are significantly shortened to years 8 and 9, with very favorable IRR.

Economic analyses have shown that in recent years, production on plantations using traditional cultivation methods (cultivars bearing on terminal buds, no irrigation, wide plant spacing, and extensive

cultivation techniques) has become unprofitable under domestic conditions. This is primarily due to low achievable yields and unsatisfactory quality.

According to the calculations in this study, plantations with intensive cultivation systems (cultivars bearing on lateral buds, equipped with irrigation, dense plant spacing, intensive cultivation techniques, and professional plant protection) are profitable and economical. However, because these plantations were established within the last 5–10 years, the amount of the achievable commodity pool is insufficient. The combined effect of these two processes explains why Hungarian walnut products have lost their competitive advantage in the global walnut market.

CONCLUSIONS

Summarizing the study results, it can be concluded that the position of the Hungarian walnut sector in the global market has weakened over the past decade, while the international market becoming more diversified. According to the Herfindahl–Hirschman index (HHI) and revealed comparative advantage (RCA) indicators, the former dominance of the United States has declined. At the same time, the market share of China, Chile, and Mexico has increased, while Hungary has lost its comparative advantage in both shelled and unshelled products. This decline in competitiveness is mainly due to economic reasons, such as low yields, extensive plantation structures, and outdated technology.

Cost-benefit analyses clearly demonstrated that traditional plantations are unprofitable. At the same time, cultivation systems based on intensive, lateral-bearing cultivars and production technologies with irrigation and dense plant spacing are commercially viable. Earnings before interest, taxes, depreciation, and amortization (EBITDA) for intensive plantations ranged from 3,000 to 6,400 euros per hectare. At the same time, the calculated net present value (NPV) ranged from 12,000 to 35,000 euros per hectare, and the internal rate of return (IRR) ranged from 12% to 18%, confirming the return on the investment studied.

Intensive walnut plantations can be economically operated, even without subsidies, due to their high yields and cost-effectiveness. Sales of processed (dried) products especially those further down the processing chain, is key to the competitiveness of the sector.

In general, the example of walnut cultivation illustrates the dynamics of fruit production. Growing international competition is driving down prices, simultaneously demanding high quality and extending the supply season. At the same time, increasingly unfavorable climatic conditions elevate production risks. Consequently, only intensive orchards characterized by high yields and stable, consistent crop volumes can remain competitive. The position of farmers is strengthened by the production of higher-value-added products, which requires both modernization and investment in postharvest technologies.

Therefore, within the framework of the Common Agricultural Policy of the European Union, special emphasis should be placed on irrigation, modern orchard systems, investment support, and instruments that increase supply concentration and promote both horizontal and vertical integration of producers.

Author contribution statement

FA – A – Research concept and design

VTK – B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article

DD – B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article

MS – D – Writing the article

AC – D – Writing the article, E – Critical revision of the article, F – Final approval of the article

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