Challenges in the avocado production chain in Latin America: A descriptive analysis

Desafíos de la cadena productiva del aguacate en América Latina: un análisis descriptivo

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ABSTRACT

The avocado market has experienced significant growth in recent decades, with Latin America emerging as a key player in production and export. This article provides an overview of the main challenges facing the avocado production chain in the region, examining crucial aspects such as production trends, supply dynamics, evolving demand patterns, and price fluctuations. By addressing these challenges and capitalizing on emerging opportunities, the Latin American avocado industry can enhance its competitiveness, sustainability, and resilience in the global market. This review provides valuable insights and actionable strategies for stakeholders across the avocado production chain, from producers and exporters to policymakers and researchers, offering key working areas for the sustainable development of the avocado industry.

Key words: agribusiness, agricultural productivity, competitiveness, farm management, *Persea americana* Mill.

RESUMEN

El mercado del aguacate ha experimentado un crecimiento significativo en las últimas décadas, emergiendo América Latina como un actor clave en la producción y exportación. Este artículo ofrece una visión general de los principales desafíos que enfrenta la cadena de producción de aguacate en la región, examinando aspectos cruciales como las tendencias de producción, la dinámica de la oferta, la evolución de los patrones de demanda y las fluctuaciones de precios. Al abordar estos desafíos y capitalizar las oportunidades emergentes, la industria latinoamericana del aguacate puede mejorar su competitividad, sostenibilidad y resiliencia en el mercado global. Esta revisión proporciona información valiosa y estrategias viables para las partes interesadas en toda la cadena de producción del aguacate, desde productores y exportadores hasta formuladores de políticas e investigadores, ofreciendo áreas de trabajo clave para el desarrollo sostenible de la industria del aguacate.

Palabras clave: agronegocios, productividad agrícola, competitividad, gestión agrícola, *Persea americana* Mill.

Introduction

World avocado production has grown rapidly in recent years, increasing from an annual world production of 4.07 million t in 2011 to 8.69 million t in 2021. In the same period, Latin America contributed significantly to global avocado production, with Mexico, Colombia, and Peru adding 1.68 and 4.20 million t in 2011 and 2021, respectively (FAOSTAT, 2022). In 2022, the avocado market was estimated at USD 14.55 billion globally and is projected to reach USD 26.04 billion by 2030 (Grand View Research, 2022).

Latin America is the leading region in global avocado production. Mexico leads both in production and exports, while Colombia, Peru, and Chile are also significant players in the market (Schwartz *et al*., 2018). These countries share three characteristics: (i) expansion of orchards in recent years, (ii) agroclimatic conditions suitable for the crop, and (iii) projected growth in exports (Arima *et al*., 2022; Hass Avocado Board, 2022; OECD & FAO, 2021). Given this situation, the region is expected to maintain its leadership in avocado exports in the coming years (Arias *et al*., 2018). It is estimated that by 2030, 74% of world avocado production will be concentrated in Latin America and the Caribbean (OECD & FAO, 2021).

This rapid growth poses challenges for the avocado market in terms of sustainable production (Sommaruga & Eldridge, 2021). These challenges include the incorporation of small farmers into international markets (Ospina Parra *et al.,* 2023), the role of institutions in supporting agribusiness development (Pérez & Gómez, 2022), the expansion of development of technological applications for the fruit and its subproducts in the food, pharmaceutical, and cosmetics

Received for publication: April 18, 2024. Accepted for publication: July 10, 2024. Doi: 10.15446/agron.colomb.v42n2.113982

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industries (Araújo *et al*., 2018), the growth of new orchards considering environmental and social factors (Denvir *et al*., 2022; Madariaga *et al*., 2021), the adoption of technologies in primary avocado production (Cáceres-Zambrano *et al*., 2023), and the technical challenges related to the crop's phytosanitary and nutritional management (Ramírez-Gil *et al*., 2017). The aim of this article was to describe the main challenges facing the avocado production chain in Latin America. From a competitive perspective, identifying an industry's challenges can lead to strategies to improve business performance (Porter, 1990).

The article is organized as follows: the methodology used for this integrative literature review; an overview of the avocado market, including production, supply, demand, and price trends; the nine key challenges identified for the avocado production chain in Latin America; and, finally, the summary of the main findings, discussing their implications and suggesting directions for future research and industry development.

Methodology

This study employed an integrative literature review methodology, following the guidelines proposed by Snyder (2019). The main purpose was to synthesize and classify the challenges facing the avocado production chain in Latin America. The research question focused specifically on identifying and analyzing these challenges. The search strategy was not systematic, allowing for a more flexible and broad exploration of relevant literature. Various sources were included, such as research articles and other published texts related to avocado production, imports, and exports. The analysis of the collected information was qualitative, enabling a deep interpretation of emerging themes. This approach facilitated the synthesis of findings and the identification of nine key challenges affecting the avocado industry in Latin America. The main contribution of this study is a comprehensive classification of these challenges, providing an integrated view of the issues facing the sector and establishing a foundation for future research and sustainable development strategies in the avocado industry.

Overview of the avocado market

The global avocado market has experienced significant growth in recent decades, with Latin America emerging as a key player in production and export. This section provides a comprehensive overview of the avocado market, examining crucial aspects such as production trends, supply dynamics, evolving demand patterns, and price fluctuations. By analyzing these key market indicators, we aim to establish a solid foundation for understanding the context in which the challenges facing the Latin American avocado industry have developed. This market analysis will help to frame the subsequent discussion of specific challenges and provide insight into the forces shaping the industry's future.

The avocado market

World avocado production increased by 920% from 1961 to 2019, growing from 0.71 to 7.3 million t, with Mexico leading the supply (Díaz Castellanos, 2021). Global avocado imports have been determined mainly by consumption in the USA and the European Union, with China emerging as a potential market in coming years (Arias *et al*., 2018). World imports have grown by around 172% in the past decade (Cruz-López *et al*., 2022). The Hass avocado is the most marketed internationally; its dominance has been attributed to consumer preference and the variety's resistant peel, which gives it the ability to survive the transportation process (Chaparro & Janzen, 2022). The average price per ton of avocados in the last two years was one of the highest for the main tropical fruits, reaching a maximum price of USD 3400 per t in March 2022 (FAO, 2023). However, this situation changed over the first nine months of 2023, with the average price dropping to USD 2063 per t, approximately 20% below the average for the same period in 2022 (FAO, 2024).

Supply

Avocados are grown throughout the world in the tropical and subtropical climates (Hurtado-Fernández *et al*., 2018). According to the Agricultural Outlook 2021–2030, avocado production is expected to reach 12 million t by 2030, making the avocado the second most commercialized tropical fruit globally, after bananas, with 3.9 million t exported (OECD & FAO, 2021).

Production

After Mexico, Colombia, and Peru are the primary leaders in production (Fig. 1). Mexico's share of global avocado production in 1961 was 15% and rose to 31% in 2019; in the same period, Colombia and Peru shares rose from 2% and 3%, respectively, to 7% each (Díaz Castellanos, 2021).

By 2021, global avocado exports were estimated to have grown to 2.5 million t, with Mexico the lead exporter, with 60% of the total (FAO, 2022). The country's exports are primarily sent to the USA (85%) and Canada (8%) (Cruz-López *et al*., 2022). Mexican avocado exports grew to USD 3 billion in 2021 (Statista, 2021). Mexico has significantly expanded avocado planting, production, and exportation, increasing from an annual production of 0.11 million t

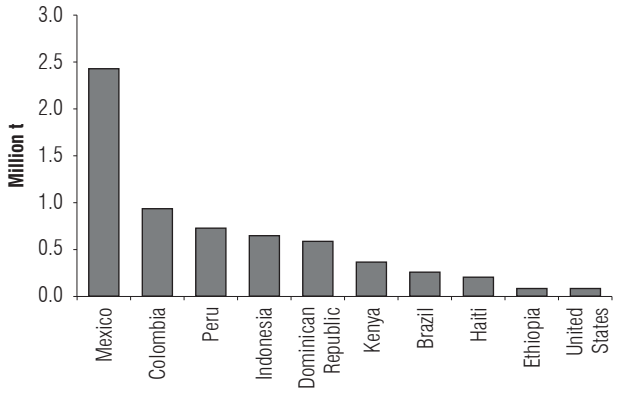

FIGURE 1. Avocado production and primary producing countries. Prepared by the authors using FAO (2022) data.

in 1961 to 2.3 million t in 2019 (Díaz Castellanos, 2021). Mexican dominance can be attributed to its geographic location (proximity to the main import market) and its comparative competitive advantage related to cost efficiency and availability of production factors – labor and capital (Cruz-López *et al*., 2022). Furthermore, Mexico can produce fruits in all seasons, focusing on high-quality Hass avocado production (FAO, 2023).

Avocado production in Colombia has grown in recent years, from around 490,000 in 2017 to 597,000 t in 2019 (Orrego *et al*., 2021). In terms of exports, about 92% is sent to the European market, mainly the Netherlands, the United Kingdom, Spain, Belgium, France, and, to a lesser extent, to the USA (Hass Avocado Board, 2022). Colombia is poised to become a leading actor in the exportation of Hass avocados, with projections for an increase from 200,000 t in 2022 to 700,000 t by 2030 (Hass Avocado Board, 2022). The value of Colombian exports in 2021 reached USD 204.6 million, making Colombia the world's sixth largest avocado exporter (Statista, 2021). Its export potential is attributed to: (i) the pacification in agricultural production areas, *i.e*., territory that was formerly under the control of illegal armed groups that now is dedicated to avocado production; (ii) the availability of land at relatively low cost; (iii) the country's agroclimatic advantages, including yield potential, year-round production availability, natural soil fertility, and the ability to irrigate avocado crops with rainwater; and (iv) the country's strategic geographic location, which facilitates serving key import markets in Europe and the USA (Hass Avocado Board, 2022).

In Peru, Hass avocado orchards grew from 22,499 ha in 2015 to 50,699 ha in 2021 (ProHass, 2022), positioning the country as the second global exporter by volume, with 26% of global exports in 2022 (FAO, 2023). The export value of Peruvian Hass avocados reached USD 1 billion in 2021 (Statista, 2021). Peruvian Hass avocado exports increased from 74,723 t in 2012 to 483,017 t in 2021; 57% of exports targeted Europe – mainly the Netherlands, Spain, and England, followed by the USA with 18% (ProHass, 2022).

Chile is the third largest avocado exporter in the world. The value of the country's exports was USD 213.8 million in 2021 (Statista, 2021). The main destinations for Chilean avocado exports were the Netherlands with 46.83%, Argentina with 13.97%, the United Kingdom with 12.38%, and Spain with 8.87% (Oficina de estudios y políticas agrarias, 2022). Its strong export capacity has been attributed, in part, to the role that institutions have fostered in meeting import market requirements, mainly for the USA, Europe, and more recently, China, as well as to favorable international prices and exchange rates offered (Guevara *et al*., 2021; Schwartz *et al*., 2018).

Yield

Avocado yield is typically measured as production per ha (Ramírez-Gil *et al*., 2017), though it can also be quantified by total fruit weight, fruit count, or individual fruit weight (Rojas-Rodríguez *et al*., 2023). In Latin America and the Caribbean, the Dominican Republic's performance was superior among the evaluated countries (Fig. 2). Some elements that may explain this behavior are the country's institutional effort via extension services, support for technology adoption and phytosanitary protection capacity building, and favorable agroclimatic conditions (González *et al*., 2009). It is necessary to investigate whether the strategies implemented by this country could be implemented in Latin American countries to improve productivity. Following the Dominican Republic, Brazil showed the second

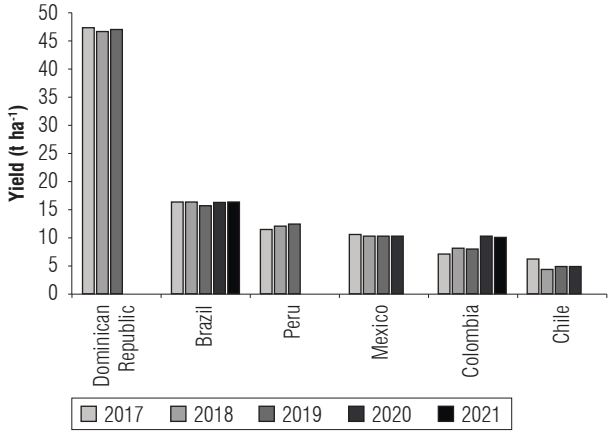

FIGURE 2. Avocado yield (t ha^{-1}) in Latin America and the Caribbean. Prepared by the authors using Statista (2021) data.

highest performance in avocado production, which may be related to the efforts underway to face technological and technical production challenges (Moraes *et al*., 2022). Peru's performance has been attributed to the implementation of best practices in production (ProHass, 2022). In the case of Mexico, despite some productive areas showing high performance levels, others have been held back by high production costs (Cruz-López *et al*., 2022). In Colombia, efforts have been made to improve production; however, low levels of competitiveness have also been evident, particularly in productivity (Hass Avocado Board, 2022). Additionally, Chilean production has been reported to be losing efficiency (Guevara *et al*., 2021).

Demand

The world import volume of avocados increased from 0.0021 million t in 1961 to 2.7 million t in 2019, an increase of 128,571% (Díaz Castellanos, 2021). By 2019, world imports rose to USD 7.2 billion (Orrego *et al*., 2021). In 2022, world imports were 2.3 million t (FAO, 2023). The increase in consumption of this fruit has been attributed to its health, nutrition, and flavor benefits (Ballen *et al*., 2022). Additionally, Cheikhyoussef and Cheikhyoussef (2022) stated that the fruit's properties enable it to be used not only in the food industry but also in the pharmaceutical and cosmetics industries. The main import markets for avocados are the USA and the European Union.

The USA has been the main global importer of avocados since 2005, displacing the dominance held by France from 1970 to 2000 (Díaz Castellanos, 2021). In 2021, the USA accounted for 46% of global avocado imports (FAO, 2022). In 2022, the USA imported approximately 1 million t (FAO, 2023). The US market is supplied mainly with avocados from Mexico and Peru, along with local production from California (Chaparro & Janzen, 2022). Ballen *et al.* (2022) stated that the USA demand for avocados grew from 0.53 million to 1.14 million t from 2009 to 2018, with the Hass variety constituting around 97% of the total avocado supply in the country. Ambrozek *et al.* (2018) indicated that per capita consumption increased 344% from the 1990s to the 2014–2016 period, increasing from 0.73 to 3.2 kg. This increase in demand has been attributed, in part, to Hass Avocado Board promotional activities/programs related to the nutritional and health benefits of avocado consumption.

The European Union is the second most important avocado market in the world. In 2021, it accounted for 27% of global imports, equivalent to 0.8 million t (FAO, 2023). According to the Centre for the promotion of imports from developing countries (CBI) of the ministry of foreign affairs of the Netherlands, imports increased from 0.52 million t in 2017 to 0.8 million t in 2021, with an average per capita consumption in Europe in 2021 of 1.4 kg (CBI, 2023), led by Norway (2.87 kg) followed by the Netherlands (2.85 kg) and Denmark (2.65 kg) (Statista, 2023). The Netherlands is the main importer in the European Union, with 9% of global imports (Guevara *et al*., 2021). The value of exports for the Netherlands was USD 1.2 billion in 2021, which places it as the second largest exporter in monetary terms (Statista, 2021). This is because the country basically operates as a re-export platform to other markets in the region (Arias *et al*., 2018).

Xiong and Song (2018) stated that China is becoming a significant avocado importer; from 2012 to 2016, the value of imports was equivalent to USD 60 million per year. These authors found that the increase in imports to China responded to the country's economic growth and changing consumption preferences (growing interest in avocados). Despite the potential growth of the Chinese market, its share of avocado consumption in the Asia–Oceania region is 12%, below that of Indonesia, which accounts for around 50% of consumption. China's per capita consumption is the lowest in the region at 0.2 pounds (Huang *et al*., 2023).

Price

The average price of a t of exported avocado was one of the highest for tropical fruits, reaching a peak of USD 3400 per t in the 2020–2022 period (FAO, 2023). International avocado prices have shown an upward trend in the past few years, which is attributed to demand being higher than supply (Arias *et al*., 2018). However, this trend may reverse if production surpasses demand, leading to a drop in prices (Huang *et al*., 2023). In fact, prices experienced a significant decline in 2023, primarily due to a substantial increase in global supply, which outpaced demand (FAO, 2024).

International avocado prices are sensitive to multiple factors, including climate, pests, seasonal supply from some countries, the degree of intermediation, fruit size, and the target market (Arias *et al*., 2018). Avocado prices in importing markets vary significantly compared to prices in countries of origin. In Mexico, a kilo of avocados destined for the USA costs between USD 1.00 and 2.50 (Herrera-González *et al*., 2020). The average prices in Colombia and Peru for Hass avocados paid to the producer were around USD 0.97 per kg and USD 0.99 per kg, respectively (Orrego *et al*., 2021). Conversely, in the USA, the average price is around USD 3 per kg, with prices as high as USD 8 per kg (FAO, 2023).

A review of historical and current trends in the global avocado market, as reported by the FAO (2024), reveals a significant shift in price dynamics. In contrast to the upward price trends observed over the previous decade, the current market situation suggests a potential stagnation or even decline in international avocado prices. This reversal is primarily attributed to the substantial growth in global supply, with Mexico playing a pivotal role. The FAO report highlights those Mexican avocado exports are expected to reach approximately 1.5 million t in 2023, a 27% increase from the previous year. This surge in supply, outpacing demand growth, has exerted downward pressure on prices, resulting in the lowest average export unit values seen in nearly a decade. This development underscores the need for careful consideration of market dynamics in planning future avocado production expansions.

Likewise, the avocado market is experiencing significant shifts in global trade patterns. While Mexico remains the dominant supplier to the USA market, there have been notable changes in the role of other exporters. Chile, once a major supplier to the USA, has been redirecting its exports to the European Union and China, diversifying its market presence. This shift presents opportunities for other producing countries to fill the supply gap in the USA market.

Simultaneously, there is a growing trend in organic Hass avocado production and trade. According to USDA Foreign Agricultural Service's Global Agricultural Trade System (GATS) data, imports of organic Hass avocados have been increasing in both quantity and value. Specially, USA imports of organic Hass avocados grew from about 49,000 metric t valued at more than USD 138 million in 2019 to more than 60,000 metric t valued at approximately USD 164 million in 2023, indicating promising growth in demand for organic avocados (USDA, 2024).

Challenges for the avocado production chain

The avocado market is experiencing significant growth, driven by relatively favorable prices that have spurred both the production and exports of the fruits. Latin America stands out as the dominant region for avocado supply. However, this favorable scenario also poses a series of challenges throughout the production chain that must be addressed to guarantee business sustainability. These challenges were identified from a market analysis and literature review, which are described in this section of the article. These challenges start with the need for sustainable production and industrial transformation of the fruits, extending to the complexities of commercialization in international markets, and the need for consumption markets to adapt in response to sustainability efforts in the productive chain.

Strengthening management capacity among producers

Access to external markets is a challenge for avocado producers, especially in terms of developing management capacity that would enable them to take advantage of these opportunities effectively. The management capacity of farmers can be defined as (i) possessing suitable personal characteristics and (ii) decision-making ability to face problems and opportunities in a timely and sound manner. In other words, it is the ability to run the farm business in an efficient way to obtain desired farm outcomes (Rougoor *et al*., 1998). It is expected that a farmer with high management capacity will obtain better farm results in terms of productivity, profitability, and efficiency (Taramuel-Taramuel *et al*., 2023).

Changes in the global avocado market stemming from rapid growth in demand, the expansion of orchards in Latin America, and quality and food safety requirements imposed by food and non-food markets in Europe and the USA necessitate a transition from a traditional farming approach to sustainable farming management. In this change, the producer must see him or herself not only as a farmer but also as a manager, treating production as a business involving not only the technical aspects of farming but also strategic and commercial management, innovation, and social and environmental responsibility. For this, public and private interventions targeted at strengthening the management capacity of avocado producers must be promoted, as they could improve business productivity and profitability (Taramuel-Taramuel *et al*., 2023).

Greater government involvement in agribusiness development

Most countries in Latin America are middle-income, and the state can play an essential role in the development of the avocado production chain. First, R&D investment in the avocado sector needs to be strengthened, given that this expense is associated with increases in agricultural productivity (Fuglie *et al*., 2020; Taramuel *et al*., 2021). Second, it is indispensable to strengthen public technical extension and farm management programs since they are positively correlated with better technical crop performance (Mariano *et al*., 2012). Third, the role of the state in providing infrastructure is essential in strengthening the avocado export industry, for example, in the development of logistics from avocado production sites to the port of export (Hass Avocado Board, 2022). Fourth, the promotion of associativity has been recognized as a mechanism for rural

development, especially for small farmers, to gain greater market advantages (Gutiérrez, 2014). Fifth, access to public subsidies can also sustain avocado business development, particularly when prices fall, or adverse climatic events cause problems. Pérez and Gómez (2022) emphasized the critical role played by institutions, including government agencies and trade unions, in the consolidation of the avocado export chain via (i) negotiation of avocado access to international markets, (ii) promotion of small and medium producer associations and cooperatives, and (iii) provision of public agricultural extension services.

Integration of small avocado producers into global markets

Higher prices in import markets are an opportunity that could potentially be leveraged by small and medium avocado producers from Latin America. However, admission to these markets may be conditioned on quality standards, food safety, and other technical requirements which contrast to national markets (Amare *et al*., 2019). To face this challenge, strategies could include (i) strengthening organizing processes, (ii) providing technical assistance, (iii) adopting certifications, (iv) improving fruit quality, and (v) using contract-based agricultural schemes (Ospina Parra *et al*., 2023). In addition, tools for market management, including digital tools, can improve farmer's marketing activities (Romero-Sánchez & Barrios, 2022).

Pérez and Gómez (2022) discussed two strategies – vertical integration and associativity – targeting avocado export markets. Vertical integration is usually adopted by large organizations that implement actions such as (i) export-type (Hass) avocado production, (ii) fruit packaging, (iii) international commercialization, (iv) diversification of agricultural production and investments, and (v) implementation of sustainable production practices. Associativity consists of collaboration among small and medium avocado producers, focusing on entry into national and external markets by strengthening the commercialization of agricultural products via certifications and a supply chain infrastructure that grants access to international markets.

An emerging opportunity for small avocado producers lies in the growing demand for organic avocados in global markets. While this transition requires initial investments and certification processes, it can lead to premium prices and access to niche markets. Cooperatives and associations can play a crucial role in helping small producers navigate the organic certification process, achieve economies of scale in production and marketing, and connect with international buyers seeking organic avocados. By tapping into the organic market, small avocado producers can potentially increase their competitiveness and profitability in the global marketplace.

Incorporating technological innovations to improve business operations

One strategy for improving productivity and profitability is the adoption of agricultural innovations (Fuglie *et al*., 2020). In the avocado sector, joining forces to improve efficiency in production and commercialization is essential to contributing to the business's continuity in the market.

It is critical to promote the incorporation of cutting-edge innovations to improve productivity. First, technologies are needed to optimize communication with customers; marketing via digital tools could benefit business operations. Romero-Sánchez and Barrios (2022) propose the adoption of e-commerce in the fruit and vegetable sector as an opportunity to decrease intermediaries in commercialization, lower operational and transactional costs, improve producer–consumer communication, and increase consumer satisfaction and loyalty. Second, López-Pimentel *et al*. (2022) highlighted the importance of strengthening the traceability of the avocado supply chain using blockchain, a key element in reaching international markets. Blockchain, a distributed ledger technology that creates an immutable and transparent record of transactions, offers several benefits for the avocado industry: (i) it enhances traceability by enabling detailed product tracking from farmer to end consumer, (ii) it increases transparency across the supply chain, reducing the risk of fraud and improving consumer trust, and (iii) it facilitates quick and accurate verification of certifications and quality standards (Granillo-Macías *et al*., 2023). The implementation of these innovations is directly related to increasing trust from the end consumer, which could significantly contribute to expanding the avocado market.

The adoption of emerging technologies in avocado agribusiness is an opportunity to improve efficiency throughout the production chain. However, low adoption of technologies has been reported in avocado production systems in Latin America (Cáceres-Zambrano *et al*., 2023; López-Pimentel *et al*., 2022). Therefore, it is necessary to continue implementing policies/programs that integrate emerging technologies in avocado farms, addressing technical and management aspects to foster sustainability and profitability in the avocado sector.

Expansion of industrial applications for the avocado

Avocado pulp and oil have applications in the food, cosmetics, and pharmaceutical industries. Duarte *et al.* (2016) reviewed the fruit's main attributes: (i) high nutritional value due to its containing lipid-soluble vitamins, proteins, potassium, and unsaturated fatty acids; (ii) health benefits due to the bioactive components of the fruits, including omega fatty acids, phytosterols, tocopherols, and squalene, with phytosterols helping lower cholesterol and prevent cardiovascular diseases; and (iii) avocado oil uses in developing perfumes, producing avocado oils commercially, and preparing flour for baked goods.

Despite considerable development of industrial applications for pulp and oil, there is potential to take advantage of waste, such as pits and leaves. Cheikhyoussef and Cheikhyoussef (2022) reported that typically 50-80% of the fruit is used after processing, with the rest considered waste, including the pit, peel, and unprocessed pulp, leading to around 40% of the fruit being discarded or wasted. Avocado waste can be used in the production of animal feed, oil, microbiological crop media, starch, biodiesel, fuel, biopolymers, and other value-added products (Araújo *et al*., 2018). Thus, it is necessary to continue exploring the nutraceutical and medicinal applications of fruits that may contribute to strengthening the production chain.

Planning for new orchards

Favorable prices and the upward trend in avocado consumption have driven the creation of new groves to meet this demand. However, in some regions, the expansion of avocado has not been organized, neglecting key factors, including climate, soil, infrastructure (access roads), and the exclusion of orchards in protected areas, such as reserves and natural parks (Anacona Mopan *et al*., 2023).

In Latin America, Grüter *et al*. (2022) assessed the appropriate distribution of avocado production, considering climatic conditions and biophysical and soil requirements. Their analysis revealed that there are highly suitable regions in Honduras, Venezuela, Bolivia, and Brazil. In the case of Mexico, the Dominican Republic, and Peru, the suitability of avocado orchards is limited by climatic factors and, to a lesser extent, by soil requirements. The analysis also shows that in the climatic conditions of 2050, rising temperatures could be beneficial for avocado orchards in the USA, Brazil, Uruguay, Paraguay, and Argentina. In Mexico, future climatic conditions are expected to favor avocado production, while in Peru and the Dominican Republic, changes in climatic conditions could reduce the zones suitable for avocado crops. Ramírez-Gil *et al.* (2018) also called for establishing new orchards in Colombia to respond to suitable conditions, noting that orchards in highly suitable regions with greater levels of technology use had better yields.

The viability of new avocado orchards hinges critically on future price trends. Recent market developments, characterized by significant price declines due to substantial increases in global supply, particularly from Mexico, raise concerns about the economic feasibility of new orchard investments. This situation underscores the importance of careful market analysis and strategic planning in the expansion of avocado production, especially considering the long-term nature of orchard investments and the time lag between planting and full production capacity.

Likewise, a critical challenge for the avocado industry in Latin America is the implementation of sustainability practices throughout the production chain. To address this, the industry should adopt a Triple Bottom Line (TBL) approach, which balances economic, environmental, and social aspects of the business (Elkington, 1998). This holistic strategy not only mitigates the risk of market restrictions but also enhances long-term viability and consumer trust. Successful implementation of TBL in the avocado sector requires transparent practices, rigorous environmental stewardship, and proactive engagement with local communities, ensuring that economic growth aligns with ecological preservation and social well-being.

Responsible water management in primary production

The unplanned expansion of orchards is associated with forest fragmentation, loss of biodiversity, and imbalances in land use and hydrological systems (Denvir *et al*., 2022). In terms of the avocado's water footprint, Sommaruga and Eldridge (2021) estimated that, on average, 849 m^3 of rainwater and 237 m^3 of surface and ground water per t are needed. These levels of consumption are higher than those reported for the average of all fruits (727 and 147 m^3 t^{-1} for rainwater and surface and ground water, respectively).

In some regions of Latin America, crop expansion has been associated with water scarcity. Panez-Pinto *et al.* (2018) found that water use for avocado production has been far higher than water use for regional human consumption. Madariaga *et al.* (2021) argued that the influence of avocado producers has allowed the expansion of the crop despite demands from communities that have experienced insufficiency in water availability.

Deforestation is a significant consequence of avocado crop expansion, particularly in Mexico's main avocado-producing region Michoacán. Cho *et al.* (2021) attributed 17% of total deforestation in the region to avocado plantation growth between 2001 and 2017. This environmental impact is largely driven by the growing demand for avocados in the USA, facilitated by complex supply chains lacking transparency and environmental accountability. The study employs innovative methods to map these supply chains, linking the USA retailers to Mexican producers and revealing a disconnect between actual environmental damage and industry perceptions. To address the deforestation associated with avocado production, the authors suggest implementing improved supply chain governance, increasing transparency, and developing multi-stakeholder initiatives. Projected crop expansion will contribute to further degradation of hydrological ecosystems (Arima *et al.*, 2022).

Although avocado crop expansion leads to economic opportunities, such as new sources of income (agricultural diversification) and job creation for farmers in Latin America, avocado production needs to be promoted based on balancing the production system with its surroundings, involving responsible use of water and natural resources.

Social impact stemming from crop expansion

To maintain Latin America's leadership in avocado production, it is important for the business to be socially sustainable. Some authors have drawn attention to the social costs of crop expansion. Vega-Rivera and Merino-Pérez (2021) reported that the rapid expansion of the business has had social consequences, some of which include: (i) land seizures, (ii) changes in subsistence livelihoods, including the loss of peasant farming of staple foods, (iii) land use conflicts, (iv) increased violence (armed groups use the avocado as a platform for money laundering), and (v) increased income inequality (a few large agribusiness concentrate profits along the production chain).

Overcoming these challenges requires coordination among social actors. The state should engage in (i) policymaking, in conjunction with avocado producers, to address land concentration through programs for small and medium producers, (ii) greater institutional presence to limit the operation of illegal businesses around avocados, and (iii) regulation of crop expansion in areas with vulnerable populations. In addition, it is necessary to promote corporate social responsibility, in which avocado agribusinesses review their actions towards local communities and implement practices that contribute to society. For example, avocado producing companies should ensure fair and safe labor conditions. These joint actions can minimize the social costs of the crop's rapid growth.

Improving technical crop management

Technical barriers in terms of pests, diseases, and other phytosanitary risks can limit avocado commercialization in international markets. Peterson and Orden (2008) estimated that if the United States had lifted restrictions on the import of Mexican Hass avocados and applied effective phytosanitary measures in 2004, it could have potentially increased net profits for the USA by USD 77.4 million annually.

Technical challenges can negatively impact the economic performance of avocado agribusiness. Ramírez-Gil *et al.* (2017) estimated that the avocado wilt complex generated economic losses of up to USD 420.50 in the nursery stage in a 1-year production cycle, while in the establishment and production stages, these losses could reach USD 2565 per ha in an 8-year period due to plant mortality and decreased production.

Diseases that occur at harvest and postharvest, including anthracnose and stem end rot, can limit commercialization of the fruit in export markets and cause economic losses due to discarded fruit and decreases in the fruit shelf life and quality (Herrera-González *et al.*, 2020). For example, Ramírez-Gil *et al.* (2020) reported that anthracnose and stem end rot cause bruises on the fruits, which leads to the rejection of up to 70.1% of the fruits at export packaging facilities. The cost of discarding fruits due to these diseases is estimated at USD 13.44 per t of production. In summary, crop health issues may limit the production and commercialization of the fruits; therefore, it is necessary to continue working on exploring alternatives to control pathogens, including biological control, to foster avocado production.

One promising strategy is the use of biostimulants in avocado production systems. Recent research by Rojas-Rodríguez *et al.* (2023) has shown that biostimulants can significantly improve yield and preharvest quality in both traditional and organic avocado production systems. Incorporating biostimulants into integrated crop management plans could be a valuable tool for avocado producers to enhance productivity and fruit quality, thereby addressing some of the technical challenges in avocado cultivation.

Conclusions

The avocado production chain has rapidly consolidated in recent decades. The main producers and exporters of this fruit are in Latin America, while imports are driven primarily by the USA and the European Union. The increase in demand is related to the fruit's attributes, making them valuable in the food, pharmaceutical, and cosmetics industries. However, the accelerated growth of the avocado market leads to challenges that must be considered to ensure business sustainability. Nine challenges were identified for avocado agribusiness: (i) strengthening management capacity among primary producers, *i.e.*, strengthening decision-making skills to ensure the business's economic success; (ii) greater government involvement to provide public goods, such as infrastructure, extension promotion, financing, and associativity; (iii) integration of small farmers into global markets to leverage the benefits offered by these markets; (iv) incorporation of technological innovations in business operations, via the adoption of technical and management tools, especially those that are emerging, to increase agricultural income, optimization of resource use, and improvement in commercialization; (v) expansion of industrial applications, in both fruit products and subproducts, to consolidate the business industrial transformation; (vi) planning for new orchards, which involves considering biotic and abiotic factors; (vii) responsible water management in primary production, a key aspect in contributing to production sustainability; (viii) considering social impacts stemming from crop expansion to ensure business viability; and (ix) improving technical crop management, aspects related to crop diseases and pests to prevent limits on its entry into international markets.

The analysis shows that it is possible to achieve sustainable business development by addressing challenges related to social and environmental costs in the primary production of avocados and agro-industrial development in the transformation stage and fostering consumption that supports efforts toward more sustainable agricultural production. Future research should focus on exploring strategies to confront each of the challenges identified, with the goal of the sustainable development of the avocado production chain.

Acknowledgments

The authors thank Professors Liliana Chicaiza and Edison Jair Duque of the Faculty of Economic Sciences at the Universidad Nacional de Colombia for their comments on the earlier version of the paper. This article is part of J. P. Taramuel-Taramuel doctoral research.

Conflict of interest statement

The authors declare that there is no conflict of interests regarding the publication of this article.

Author's contributions

JPTT and DB conceptualized the manuscript. JPTT, IAMR, and DB wrote the manuscript. All authors critically revised the manuscript and approved the final version of the manuscript.

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