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Original Research

Industrialization potential analysis of citrus waste in Colombia

Análisis del potencial de industrialización de residuos cítricos en Colombia

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Abstract

Citrus production in Colombia is divided into six productive centers, with a total production of 1,450 thousand tons in 2021. The greater entrepreneurial activity stands out in the West and a lower level in the South, which generates 230 thousand tons per year of citrus waste, posing challenges in terms of pollution and wet/semi-solid waste management. This study evaluates the industrial potential of these waste products for strengthening the national citrus industry, considering three aspects: raw materials availability, technological opportunities, and market opportunities. The results indicate that Colombia has a robust citrus production, with an emphasis on oranges, mandarins, and lemons, and significant potential in the industrialization of the peel, which constitutes between 40% and 60% of the total fruit. To industrialization were identified six key research areas of citrus waste in terms of technological opportunities. Regarding market opportunities, there is observed growth both nationally and internationally in products derived from citrus waste, including essential oils, terpenes, dietary fiber, pectin, citric acid, and biofuels. Colombia is considered a country with great potential for the industrialization of citrus waste, supported by its abundant raw materials, promising technological opportunities, and a growing market. However, improvements in infrastructure, investment in research and development, and the promotion of entrepreneurial culture in the citrus sector are needed to fully capitalize on this opportunity.

Resumen

La producción de cítricos en Colombia se divide en seis núcleos productivos con una producción en 2021, de 1450 mil toneladas. Se destaca mayor empresarización en el Occidente y menor nivel en el Sur, lo que genera 230 mil toneladas por año de residuos cítricos, planteando desafíos de contaminación y gestión de desechos húmedos/semi-sólidos. El presente estudio evalúa el potencial industrial de estos residuos para el fortalecimiento de la industria citrícola nacional, considerando tres aspectos: disponibilidad de materia prima, oportunidades tecnológicas y oportunidades de mercado. Los resultados indican que Colombia tiene una sólida producción de cítricos, con énfasis en naranjas, mandarinas y limones, y un potencial significativo en la industrialización de la cáscara, que constituye entre el 40% y el 60% del total de la fruta. Se identifican seis áreas clave de investigación para la industrialización de residuos cítricos en términos de oportunidades tecnológicas. En cuanto a las oportunidades de mercado, se observa un crecimiento tanto a nivel nacional como internacional en productos derivados de residuos cítricos, que incluyen aceites esenciales, terpenos, fibra dietética, pectina, ácido cítrico y biocombustibles. Colombia se considera un país con un gran potencial para la industrialización de residuos cítricos, respaldado por su abundante materia prima, prometedoras oportunidades tecnológicas y un mercado en crecimiento. Sin embargo, se requiere mejorar la infraestructura, invertir en investigación y desarrollo, y promover la cultura empresarial en el sector citrícola para aprovechar al máximo esta oportunidad.

Keywords: biorefinery, Bioactive Compounds, Dietary Fiber, Market Opportunities, Technological Opportunities.

Palabras clave: biorefinería, Compuestos bioactivos, Fibra dietaria, Oportunidades de mercado, Oportunidades tecnológicas.

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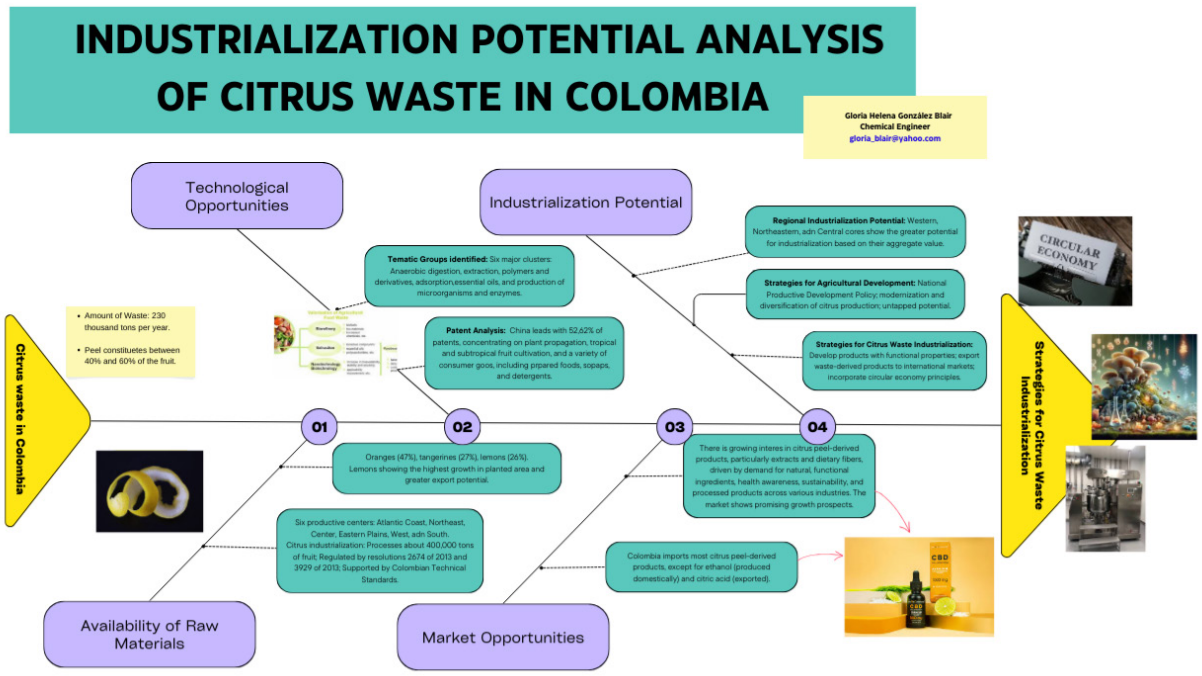
Why was it carried out?
The study was conducted to assess the industrial potential of citrus waste in Colombia with the aim of strengthening the national citrus industry. Three main aspects were considered: raw material availability, technological opportunities, and market opportunities.

What were the most relevant results?
Colombia has a robust citrus production, with emphasis on oranges, mandarins, and lemons.
There is significant potential for industrializing citrus peel, which constitutes between 40% and 60% of the total fruit.
Six key research areas were identified for the industrialization of citrus waste in terms of technological opportunities.
Growth is observed both nationally and internationally in products derived from citrus waste, such as essential oils, terpenes, dietary fiber, pectin, citric acid, and biofuels.

What do these results provide?

The results indicate that Colombia has great potential for the industrialization of citrus waste, supported by its abundant raw materials, promising technological opportunities, and a growing market. These results offer an opportunity to strengthen the national citrus industry, generate added value through waste industrialization, and contribute to the economic and environmental development of the country.

Graphical Abstract



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Introduction

Global economic powers such as Japan, the United States, and Germany sustain their economic growth and high level of employment through the relevance of the manufacturing sector; they are well aware that a decrease in the size of this sector implies a decline in economic growth, an increase in unemployment and a lower trade surplus of goods and services in the economy (1). This pillar is so sensitive that during the first half of 2019, as the weakness of the global economic dynamics persisted, industrial production decreased, and therefore, manufacturing activity decreased (2). In this regard, in Colombia, industrial growth is lagging; it grew, on average, between 2015 and 2019 by 1.4%, while the GDP rose by 2.4%, and the weight of the industry in the economy decreased from 15% of GDP in 2005 to 12.1% in 2019 (3). Furthermore, during this period, it is observed that production was lower than national demand, a deficit that was channeled through imports (4).

On the other hand, the citrus sector in Colombia faces challenges such as the need to generate constant supply volumes with the required quality and in the varieties demanded by the international market and the agro-industry (5); as well as the need to promote value generation processes and develop by-products in the transformation stage (6). This has led to the exploration of various processes for obtaining chemical products from citrus waste, an opportunity that makes sense considering that each Colombian consumes 27 kg of citrus fruits annually and that after consumption, between 40 and 60% of the fruit is discarded as waste, also generating enormous challenges regarding pollution (7). Consequently, this article analyzes the potential for the industrialization of citrus waste in Colombia, taking into account that certain by-products obtained from the processing of citrus juices (such as essential oils, terpenes, and dehydrated peel, among others) have a developing market (8), capable of strengthening the national bioeconomy and reducing negative environmental impacts (9).

Methodology

To analyze the potential for industrializing citrus waste in the country, three aspects were evaluated: raw material availability, technological opportunities, and market opportunities. Raw material availability, was established through secondary sources (Ministry of Agriculture and Rural Development; National Administrative Department of Statistics - DANE; Fedesarrollo; Ministry of Commerce, Industry, and Tourism; Citrus Associations; and National Planning Department). Technological opportunities were defined by reviewing databases of scientific literature (Scopus, ScienceDirect, and PubMed) and patents (PATENTSCOPE -WIPO), with the respective assistance of VOSviewer and Gephi programs, following the procedure described by Guzmán (10) and using the keyword "citrus waste" to enhance the dynamics of the field of study and facilitate the visualization of knowledge networks. Market opportunities considered the size of imports, definition of principal actors, and trends of different products, based on databases and reports from consulting firms such as Trade Statistics for Business Development, Markets and Markets, Precedence Research, and Research and Markets, following the methodological principles described by Meléndez (11). The analysis of the aforementioned aspects was integrated with the matrix in Table 1, created to evaluate the industrialization potential in the six citrus centers of the country, using secondary sources and five interval scales defined by DANE (12), following the approach proposed by Posada (13), and employing the qualitative point method (14) to identify areas of strength and opportunity, as well as potential challenges and areas for improvement in each of the analyzed zones.

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Table 1. Evaluation parameters

Regional evaluation parameter			**Criteria for assigning quantitative factors**				
			1	**2**	**3**	**4**	**5**
Raw Material	Production (thousands of t)	6	< 60	61 - 120	121 - 180	181 - 240	> 240
	Added value of the primary sector	12	< 0.6%	0.6 - 1.5%	1.6 - 3.5%	3.6 - 6%	> 6%
	Innovation index	15	< 18	18 – 27.99	28 – 36.99	37 – 59.99	> 60
	Added value of manufacturing industries	12	< 0.1%	0.2 – 0.5%	0.6 – 2.5%	2.6 – 6%	> 6%
	Added value of public service supply and environmental management	12	< 0.1%	0.2 – 1%	1.1 – 2%	2.1 – 5%	> 5%
Market	Competitiveness index	16	< 4.5	4.5 – 4.99	5 – 5.49	5.5 – 5.99	> 6
	Gross Domestic Product (Percentage share at current prices)	12	< 0.5%	0.6 - 2%	2,1 - 5%	5.1 - 20%	>20%
	Gross Domestic Product (Volume growth rates)	12	< 0.1%	0.1 - 5%	5.1 - 7.5%	> 7.5%	N.A.

Results and discussion

Raw Material Availability

Citrus production in Colombia is distributed in six productive centers: Atlantic Coast (Atlántico, Magdalena, Cesar, Bolívar), Northeast (Santander, Norte de Santander, Boyacá), Center (Cundinamarca, Tolima, Huíla), Eastern Plains (Meta, Casanare), West (Antioquia, Valle del Cauca, Caldas, Risaralda, Quindío), and South (Cauca, Nariño); with an average area per farmer at the national level of 5.6 ha., although it is common to find in the western core a higher level of entrepreneurship (from 20 ha. to 600 ha.) and in the South and Northeast cores a lower level (from 1 ha. to 10 ha.). In 2021, the average yield was 15 tons/ ha, the planted area reached 87,638 ha, and production reached 1,450,071 tons (6).

In Colombia, the main citrus products are oranges (47%), tangerines (27%), and lemons (26%), with the latter showing the highest growth in planted area and a greater export vision (6). Regarding prices, producers receive approximately 40% of the costs reported in the wholesale market of Abastos (6), while supermarkets offer the product at prices between 2.24 and 3.69 times the price set by wholesale markets. The citrus industrialization

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process reaches approximately 400,000 tons of fruit (9); it is regulated by resolutions 2674 of 2013 and 3929 of 2013, and is supported by Colombian Technical Standards as listed in Table 2. (15,16)

Chemically, these peels contain a wide variety of secondary products with antioxidant nativity (17): eriocitrin, narirutin, naringin, hesperidin, neohesperidin, poncirin, neoponcirin (18). In orange peel, the most important components are of terpenic nature (19): limonene (76 - 94.5%), linalool, myrcene, carvone, and aldehydic compounds such as octanal, nonanal, and decanal, whose concentrations generally increase with ripeness. Citrus peels, in general, show variations in total polyphenol content, inhibition coefficient IC_{50} against DPPH and $ABTS^{+}$ radicals (17), and the amount of protein with antioxidant activity (20). Common tangerine, grapefruit, Rio Oro tangerine, Cleopatra tangerine, tangelo, Valencia orange, and Tahiti lime peels are potential sources of natural antioxidants with anticancer, anti-inflammatory, antiviral, antiallergic, and antibacterial properties. They are capable of protecting against heart diseases and damage caused by ultraviolet rays, environmental pollution, and some chemicals present in food (21).

Table 2. Colombian Technical Standards that strengthen the development of the national citrus chain.

NTC	Object
4086:1997	Establishes the requirements that Valencia oranges must meet for fresh consumption or as raw materials for processing. It includes definitions, classification and size, packaging, and labeling.
1268-3:1995	Establishes the necessary conditions for preserving oranges during storage.
1268-4:1995	Establishes conditions for the transportation of oranges.
1330:1977	Establishes the terminology and requirements that must be met by tangerines intended for fresh consumption.
1272:1994	Establishes definitions, minimum requirements, classification, size, tolerances, presentation, and labeling of grapefruit.
4087:2012	Establishes the requirements that Tahiti lime (Citrus aurantifolia Swingle) must meet for fresh consumption or as raw material for processing.
5468:2012	Establishes the requirements and test methods that must be met by fruit juices, pulps, fruit nectars, and their concentrates, for direct consumption or further processing.

Technological opportunities

The review of databases using the VOSviewer tool allowed us to establish six major thematic groups (clusters): Anaerobic digestion; extraction; polymers and derivatives; adsorption; essential oils; production of microorganisms and enzymes (Table 3); identify a higher density of co-occurrence of the descriptors: Citrus sinensis, industrial waste, hydrogen ion concentration, plant extracts, fermentation, and animals; recognize infrared spectroscopy analysis, HPLC chromatography, scanning electron microscopy, and thermogravimetry as the most widely used instrumental tests in the studies conducted; and visualize trends in the development of biorefineries, green extraction technologies, and waste management.

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Table 3. Identification of research and development clusters

Cluster	Items
Anaerobic digestion	Biogas, ethanol, fermentation, biodiesel, bioethanol, biorefinery, biofuel, bioconversion, methane, anaerobiosis, bioreactor
Extraction	Bioactive compounds, antioxidant activity, carotenoids, hesperidin, limonene, flavonoids, phytochemicals, polyphenols, phenolic compounds, naringin or aurantiin, monoterpenes, terpenes, green synthesis, essential oils, pigments
Polymers and their derivatives	Polysaccharides, pectin, prebiotics, enzymatic hydrolysis, cellulose, lignin, degradation, dietary fiber, encapsulants, sugars, hemicellulose
Adsorption	Adsorption, biosorption, activated carbon, particle size, pyrolysis, biosorbents
Essential oils	Essential oils, antifungal activity, antibacterial activity, and antimicrobial activity
Production of microorganisms and enzymes	Fungi, microorganisms, pectinase, polygalacturonase, enzymatic activity, metabolism, aspergillus, Aspergillus niger

Source: Cluster map constructed with VOSwiever using Scopus, ScienceDirect, and PubMed as databases

According to the patent analysis, China produced 52.62% of the patents, followed by a distant second, the Republic of Korea (9.57%), and in terms of research and development, over the last five years, the sectors with the greatest impact have been agriculture, waste management, and manufacturing. Chinese patents are oriented towards plant propagation; the cultivation of tropical and subtropical fruits; the production of prepared foods; the manufacture of soaps, detergents, cleaning and polishing preparations, perfumes, and toiletries; and the manufacturing of machinery and equipment for special use (irrigation, fertilization, harvesting, and post-harvest). Korean patents prevail in the manufacturing of pharmaceutical products, medicinal chemicals, botanical products for pharmaceutical use, and the preparation of prepared foods for human consumption. Meanwhile, those from Germany and Japan have directed their studies towards polystyrene recovery. Countries such as Australia, Canada, Mexico, the United States, India, Israel, and Czechoslovakia are investing their efforts in the production of prepared animal foods, confectionery, beverages, plastic products, packaging, cement, textiles, and basic chemicals. Regarding waste management, patents are showing interest in waste collection, treatment, and disposal, as well as material recovery.

Regarding production processes, there is abundant literature focused on pectin and essential oil extraction (22, 23, 24, 25), activated carbon production (26, 27), recovery of bioactive compounds (18, 28, 29), and enzymatic hydrolysis of cellulose for biofuel production (30, 31). This information allowed us to construct Table 4, grouping the different operations according to the stages of the production processes.

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Market opportunities

According to Trade Statistics for International Business Development, Colombia is a net importer of almost all citrus peel-derived products, except ethanol, which it produces for domestic consumption, and citric acid, a substance it exports. In the past five years, annual import growth rates have been high for pectic materials, pectinates, and pectates (7.37%); vinegar and vinegar substitutes (9.35%); and lemon essential oil (12.62%). Regarding national supply and export demand, it is observed that markets for denatured ethyl alcohol with a volumetric alcohol content equal to or greater than 80% vol, and for vinegar and vinegar substitutes are expanding markets with sustained growth and possibilities for diversification. These products are innovative, in high demand, or have a competitive advantage in terms of quality or price. Established markets with consolidation opportunities include aromatic aqueous distillates, aqueous dilutions of essential oils, and preparations based on synthetic carotenoids, thanks to maintaining market share and effectively adapting to market changes. Emerging market niches, with the potential to capture part of the declining market, include businesses in orange essential oils and other essential oils that offer innovative products or services and effective differentiation from competitors. Markets offering opportunities for improved management, innovative spaces, and market differentiation include activated carbon, candied peels and citric acid. Therefore, it is necessary to identify and correct their deficiencies and adapt to the changing market demands. Finally, markets with the possibility of strategic reorientation and opportunities for cost reduction include markets for pectic materials, pectinates, and pectates. This implies the need to identify new market niches and seek strategic alliances.

Table 4. Stages of production processes

Stage	Operation	Alternative Operations
Analytical or collection	Reception	By weight, by origin, by quality parameters, by nature.
	Cleaning	Manual, immersion or soaking, with foam, y spraying, in situ.
	Separation	Manual.
	Storage	Refrigeration, freezing.
Synthesis or	Drying	In the sun, by hot air, by contact, by infrared, by freezing, in a fluid bed, dielectric.
	Grinding / Crushing	Dry, wet, cryogenic (with liquid nitrogen or dry ice).
	Extraction	Solvent extraction, cold pressing, hydrodistillation, steam distillation, steam explosion, microwave extraction, solid-liquid extraction, sonication-assisted extraction, supercritical fluid extraction.
	Hydrolysis	Acidic, alkaline, enzymatic.
	Pyrolysis / carbonization	At temperature and heating speed low, at temperature and heating speed high, vacuum, flash, fast.
	Activation	Acidic (phosphoric, sulfuric, nitric acid), basic (potassium hydroxide, sodium hydroxide) or oxidative (hydrogen peroxide).
	Fermentation	Aerobics, anaerobic
	Packaging	Primary, secondary and tertiary.
	Storage	Conventional, compact, dynamic, mobile, automatic, load-bearing.
	Distribution	Direct, indirect.

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To obtain a comprehensive view of the market and help make informed decisions about investments, market strategies, and product development, tables 5 and 6 relate, for different forecast periods, the expected market value, the Compound Annual Growth Rate (CAGR), demand drivers, dominant markets, key players, and dominant product classification.

Table 5. Market Outlook for Citrus Peel-Derived Products

Product	Forecast Period	Market Value (million USD)	CAGR (%)	Demand Drivers
Ethanol (32)	2021 - 2030	155,600 para el 2030	5.2	Increased use as a biofuel and solvent. Growing consumption of alcoholic beverages. Greater use of alcohol-based disinfectants. Government control of environmental pollution.
Vinegar and substitutes (33)	2018 - 2028	1,500 para el 2028	1.6	Increasing demand from emerging economies. Growth in the food and beverage sector. Population growth. Increased investment in research and development activities.
Essential oils, aqueous distillates, and essential solutions (34)	2022 - 2027	15,300 para el 2027	11.8	Growth in major end-use industries (food and beverages, beauty, personal care, and aromatherapy). Growing preference in North America for a healthy lifestyle and ingredient transparency. Population growth. Increased demand for natural and organic products.
Citric acid (35)	2023 - 2028	4,268 para el 2028	2.78	Wide use in various industries (food and beverages, personal care, cleaners, detergents, pharmaceuticals). Advantages (preservatives, flavorings, and colorants). Shift towards organic products. Economic growth and lifestyle changes.
Activated carbon (36)	2022 - 2030	7,730 para el 2030	5.6	Growing demand for products in air and gas purification. Increasing need for clean and safe drinking water. Application of strict regulations and the need to comply with them.
Citrus peels (37)	2019 – 2027	Nd	Nd	Growing interest in citrus peel oil and powder. Growth forecasted in the orange extract market..
Citrus-based dietary fibers (38)	2022 - 2032	550 para el 2032	5.6	Growing need for functional natural ingredients. Food additive to improve the shelf life of many foods. Substitute for banned food additives. Healthy nutrition profile of the fiber.
Pectina (39)	2019 - 2025	1,500 para 2025	6.5	Increasing consumption of convenience foods. Increased awareness of the health and multifunctionality of pectin. Increasing application of pectin to treat diarrheal and gastrointestinal diseases.
	2022 - 2030	700 para 2030	6.6	Increase in industrialization in developing countries. Growth of end-users such as the paper and pulp industry and the food industry. Increasing demand for bio-based products.
Cellulose fiber (41)	2022 - 2030	55,020 para 2030	7.3	Government initiatives for a safer environment. Increase in demand for the use of plant-based sources. Commercial strengthening in the garment, construction, pharmaceutical, and automotive industries. Increased environmental awareness. Use of biodegradable substances for fabric production.
Citrus peel extract(42)	2022 - 2032	11,840 para 2032	4.5	Increased public awareness of the benefits of the extract. Increased disposable income. Higher spending at spas and salons where citrus extract-based products are used in massage oils for relaxation and aroma.

Source: Market Reports

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Table 6. Geographic Domination and Key Players in the citrus Peel-Derived Products Market

Product	Dominant Market	Key Players	Dominant
Ethanol (32)	North America. Transportation segment. Denatured alcohol from grains.	Anderson, Archer Daniels Midland, Green Plains, Tereos, Raizen, Pacific Ethano, Sekab Biofuels & Chemicals AB, Corporación Cargill.	Chemistry
Vinegar and substitutes (33)	Europe represents almost 50% of the world share. Vinegars from wine, in the Mediterranean region.	Balneário Acetum; Compañía de vinagre de Fleischmann; Kraft Foods; Ponti SpA; Mizkan América, Inc.; Grupo Burg; Aspall.	Food
Essential oils, aromatic aqueous distillates and essential solutions (34)	The United States dominated the North American market. Natural and organic products. Important development in the lavender oil segment.	Cargill, Incorporated; DSM; Givaudan; International Flavors & Fragances Inc.; Sensient Technologies Corporation; Symrise; Robertet SA; MANE; do TERRA; NOW Foods	
Citric acid (35)	Western Europe represents the largest global consumer, whose main markets are Germany, France and the United Kingdom. Demand for citric acid is mature and relatively saturated in the region, particularly in the carbonated beverage sector.	Compañía Archer Daniels Midland; Cargill, Incorporado; Tate & Lyle PLC; Jungbunzlauer Suiza AG; Cofco Bioquímica (Anhui) Co., Ltd. Huangshi Xinghua Bioquímica Co. Ltd.; RZBC Group Co. Ltd. Weifang Alférez Industry Co., Ltd..	Food Chemistry Aditive
Activated carbon (36)	Asia Pacific due to industrial growth in China and India.	Kuraray Co., Ltd.; Cabot Corporation; Osaka Gas Chemicals Co., Ltd.; Donoy Carbon GmbH; Carbones activados Puragen; Carbotech AC GmbH; Ingevity.	Water and gas treatment. Adsorbents.
Citrus peels (37)	Asia Pacific for personal and home care. Especially in countries like India, China and Japan.	Now Foods Inc.; Vincent Corporation; Active Concepts LLC.; Cifal Herbal Private Ltd.	Natural
Citrus-based dietary fibers (38)	The European market will dominate with the increase in industrial consumption of citrus fiber.	Lemont; Florida Food Products Inc.; Herbafood Ingredients GmbH; CEAMSA; Fiberstar Inc.; CP Kelco	Food Fibers and texturizers
Pectin (39)	Food and beverage segment Production of jams, jellies, spreads, dressings and meat products. High demand in the pharmaceutical sector.	DowDupont; Cargill, Incorporated; Ingredion Incorporated; CP Kelco; Tate & Lyle PLC; Koninklijke DSM NV; Naturex; Lucid Colloids Ltd; Silvateam SpA; Compañia Española de Algas Marinas SA (CEAMSA).	Food Fibers and texturizers
Hemicellulose (40)	North America and Asia Pacific. The polyxylose segment.	Novozymes; Dupont; Enzimas AB; DSM	Food Fibers and texturizers
Cellulose fiber (41)	Asia Pacific	Daicel Corporation; Eastman Chemical Company; Fulida Group Holdings Co. Ltd.	Food Fibers and texturizers
Orange peel extract (42)	In 2022, North America (33.1%) and Europe (27.4%)	Phyto Life Sciences P. Ltd; Cifal Herbal Private Ltd; Ultra Internacional BV; Argenti Lemon S.A.	Supplements and nutraceuticals Cosmetics and perfumery

Source: market Reports

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Which allow us to conclude that there is growing interest in products derived from citrus peels, with emphasis on extracts and dietary fibers (pectin, hemicellulose, and cellulose fiber), and that the need for natural ingredients, the increase in health awareness, sustainability, and demand for processed products in various industries are demand drivers. The above allows us to infer that the market for products derived from citrus peels shows promising growth, driven by the demand for natural and functional ingredients in various industries.

Market opportunities

The National Productive Development Policy in Colombia, according to Document CONPES 3866 (43), aims to promote quality standards for domestic producers and the integration of goods and services into national and international production chains. This drives the modernization and diversification of citrus production, with actions such as pest monitoring, certification in Good Agricultural Practices, innovation, market development, and business strengthening. Despite these advances, the development of this agro-industry has not yet reached its true potential, as it presents significant opportunities in global markets. Table 7 summarizes the results of the matrix defined in Table 1 and allows us to infer that the Western, Northeastern, and Central cores have the greatest potential for industrialization due to their higher aggregate value. Finally, Table 8 relates the economic strengths of the different cores to their industrialization alternatives, giving rise to a management proposal aimed at increasing industrialization, improving income levels in the regions, and reducing environmental pollution.

Table 7. Results of the industrialization potential of citrus waste in Colombia

Evaluated Aspect	**Western**	**Central**	**South**	**Atlantic**	**Northeastern**	**Eastern Plains**
Availability of raw material	4.50	4.00	2.00	2.50	4.50	3.00
Technological opportunities	3.80	3.78	2.50	3.33	4.00	2.33
Market opportunities	6.78	5.17	3.32	4.95	5.92	3.67
Industrialization opportunities	15.08	12.95	7.82	10.78	14.42	9.00

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Table 8. Relationship between economic strengths and industrialization alternatives.

		Economic strengths	**Products with potential**
Western	Antioquia	Coffee and milk. Processed foods, preserves, beverages, textiles, paper, chemicals, and pharmaceuticals. Health and medical services. Tourism: Route of the Sun and Fruit.	Ecological paper, hesperidin, citrus peel flour, pectin, quercetin, limonene, citrus essential oils. In the tourist route of the Sun and Fruit: Use of citrus peel flour of citrus oils as exfoliants in SPAs.
	Valle Cauca	Pharmaceutical industry cluster. Food and beverages. Paper.	
	Caldas	Coffee and cattle. Industries: textiles and confectionery. Tourism.	
	Risaralda	Coffee and cattle. Industries: food and beverages; textiles.	
	Quindío	Coffee, bananas, and plantains. Tourism: rural accommodations and coffee.	
Central		Coal and salt. Flowers. Dairy, pharmaceutical, textile, and paper industries.	Ecological paper. Activated carbon. Citrus peel flour, limonene, hesperidin, quercetin. Candied and frosted citrus peels. Pectin. Modified pectins.
	Tolima	Coffee, tobacco, rice, and cotton. Aquaculture and textile industry. Tourism.	
	Huíla	Coffee and rice. Hydrocarbons, starch, food and beverage industries. Chemical manufacturing.	
South	Cauca	Agricultural production, fish farming, and livestock. Paper.	Ecological paper. Citrus peel flour. Citrus biopolymers.
	Nariño	Agricultural and livestock production. Diary, flours, and oil.	
Atlantic	Atlántico	Chemical, pharmaceutical, food and beverage sectors, paper.	Ecological paper. Hesperidin. Quercetin. Limonene. Composting. Animal feed. Citrus peel flour. Citrus pickles.
		Agricultural and livestock production. Tourism.	
	Cesar	Cotton, African palm, and rice. Livestock. Dairy and fats.	
	Bolívar	Rice. Petrochemical. Chemical and plastic products. Tourism.	
Eastern Plains	Santander	Tobacco. Poultry farming, fish farming, beekeeping, rabbit farming, and livestock. Medical services. Tourism: a land of adventure.	Citrus peel flour. Citrus snacks (healthy bars).
	Norte de Santander	Agriculture, footwear, textiles, food and beverages. Tourism.	
	Boyacá	Agricultural and livestock production. Metalworking and construction materials.	
	Meta	Agriculture, livestock, and fish farming. Beverages, palm oil extraction and refining, metallurgy, construction materials. Oil and gas extraction.	Citrus peel flour. Essential oil and its derivatives.
	Casanare	Rice and oil palm	

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Likewise, from the previous study, the following strategies can be inferred for strengthening the citrus waste industrialization sector: 1.- develop products with functional properties, such as dietary supplements, functional foods, and cosmetics; 2.- export products derived from waste to international markets; 3.- incorporate the circular economy into the citrus value chain; 4.- strengthen research and development in the field of citrus.

Conclusions

The study reveals significant potential for the modernization and diversification of this sector. There is a clear drive towards improving quality standards, integrating into national and international production chains, and adopting sustainable agricultural practices. However, it is recognized that the maximum possible development has not yet been achieved, especially in terms of seizing global market opportunities.

The identification of cores with greater potential for industrialization and the relationship between economic strengths and industrialization alternatives provide a solid foundation for strategies aimed at increasing industrialization, improving regional incomes, and mitigating environmental pollution. It is necessary to promote innovation, technological development, and collaboration among different actors in the value chain to unlock the true potential of the citrus industry in Colombia.

Three strategic alternatives to boost citrus industrialization in Colombia and generate a positive impact on the economy and the environment, along with their respective market opportunities and applications, are: a.- development of functional and cosmetic products targeting both the domestic and international markets, leveraging the growing demand for natural and sustainable products in sectors such as dietary supplements; b.- exportation of citrus-derived products, capitalizing on international markets that value natural products, such as essential oils, flours, and extracts; c.- integration of the circular economy into the citrus value chain, offering ecological and sustainable products such as ecological paper, biopolymers, compositing, and animal feed, for both the domestic and international markets.

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