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FROM KNOWLEDGE TO INNOVATION: MAPPING POLICOSANOL ROUTES THROUGH GLOBAL SCIENTOMETRIC INDICES

DO CONHECIMENTO À INOVAÇÃO: MAPEAMENTO DAS ROTAS DO POLICOSANOL POR ÍNDICES CIENCIOMÉTRICOS GLOBAIS

DEL CONOCIMIENTO A LA INNOVACIÓN: MAPEO DE LAS RUTAS DEL POLICOSANOL A TRAVÉS DE ÍNDICES CIENCIOMÉTRICOS GLOBALES

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DOI: 10.54899/dcs.v22i81.3193
Recibido: 08/07/2025 | Aceptado: 08/08/2025 | Publicación en línea: 14/08/2025.

ABSTRACT

This study presents a comprehensive scientometric protocol designed to analyze six principal biorefining routes for Policosanol (Pc) extraction. By integrating experimental parameters, publication metrics, and patent indicators, the research reveals asymmetries and convergences across methods such as saponification, solvent extraction, ultrasonic-assisted techniques, molecular distillation, transesterification, and supercritical CO_2. A cross-meta-analysis of articles, reviews, and patents was conducted using Scopus, Web of Science, Intellectual Property (IP) Business Intelligence modality of Orbit® seekers (version 1.9.8) and SciFinder databases. An innovative set of five scientometric indices was applied to the literature as an analytical method, combined with the Technology Readiness Levels (TRL - NASA) and Maturity Readiness Level (MRL - Embrapa) metrics. Completing the methodology, the structured pyramid protocol enabled advanced mapping of international scientific networks and technology readiness levels. Notably, ultrasonic-assisted extraction and transesterification exhibit strong alignment between academic output and industrial interest, while saponification and solvent extraction show marked dissociation—especially within the Ibero-American context. This framework offers a replicable model for assessing innovation dynamics and technological convergence in Pc research, supporting future developments in cardiovascular-relevant bioproducts.

Keywords: Policosanol. Biorefining Routes. Scientometric Analysis. Technology Readiness. Cross-Meta Analysis. Patent Dynamics.

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RESUMO

Este estudo apresenta um protocolo cienciométrico abrangente projetado para analisar seis principais rotas de biorrefino para extração de Policosanol (Pc). Ao integrar parâmetros experimentais, métricas de publicação e indicadores de patentes, a pesquisa revela assimetrias e convergências entre métodos como saponificação, extração por solvente, técnicas assistidas por ultrassom, destilação molecular, transesterificação e CO_2 supercrítico. Uma Meta-Análise Cruzada de artigos, revisões e patentes foi conduzida usando as bases Scopus, Web of Science, a modalidade Business Intelligence de Propriedade Intelectual (PI) do Orbit® seekers (versão 1.9.8) e a SciFinder. Um conjunto inovador de cinco índices cienciométricos foi aplicado à literatura como um método analítico, combinado com as métricas Technology Readiness Levels (TRL - NASA) e Maturity Readiness Level (MRL - Embrapa). Completando a metodologia, o protocolo piramidal estruturado permitiu o mapeamento avançado de redes científicas internacionais e níveis de prontidão tecnológica. Notavelmente, a extração e a transesterificação assistidas por ultrassom apresentam forte alinhamento entre a produção acadêmica e o interesse industrial, enquanto a saponificação e a extração por solvente apresentam dissociação acentuada — especialmente no contexto ibero-americano. Esta estrutura oferece um modelo replicável para avaliar a dinâmica da inovação e a convergência tecnológica na pesquisa em PC, apoiando desenvolvimentos futuros em bioprodutos relevantes para o sistema cardiovascular.

Palavras-chave: Policosanol. Processos de Biorrefino. Análise Cienciométrica. Maturidade Tecnológica. Meta-Análise Cruzada. Propriedade Industrial.

RESUMEN

Este estudio presenta un protocolo cienciométrico integral diseñado para analizar seis rutas principales de biorrefinación para la extracción de policosanol (Pc). Mediante la integración de parámetros experimentales, métricas de publicación e indicadores de patentes, la investigación revela asimetrías y convergencias entre métodos como la saponificación, la extracción por solventes, las técnicas asistidas por ultrasonidos, la destilación molecular, la transesterificación y el CO_2 supercrítico. Se realizó un metaanálisis cruzado de artículos, revisiones y patentes utilizando las bases de datos Scopus, Web of Science, la modalidad de Inteligencia Empresarial de Propiedad Intelectual (PI) de Orbit Seekers® (versión 1.9.8) y SciFinder. Se aplicó un conjunto innovador de cinco índices cienciométricos a la literatura como método analítico, combinado con las métricas de Niveles de Preparación Tecnológica (TRL - NASA) y Nivel de Madurez (MRL - Embrapa). Para completar la metodología, el protocolo piramidal estructurado ha permitido un mapeo avanzado de redes científicas internacionales y niveles de preparación tecnológica. Cabe destacar que la extracción asistida por ultrasonidos y la transesterificación muestran una fuerte correlación entre la producción académica y el interés industrial, mientras que la saponificación y la extracción por solventes muestran una marcada disociación, especialmente en el contexto iberoamericano. Este marco ofrece un modelo replicable para evaluar la dinámica de la innovación y la convergencia tecnológica en la investigación de PC, lo que respalda el desarrollo futuro de bioproductos con relevancia cardiovascular.

Palabras clave: Policosanol. Rutas de Biorrefinamiento. Análisis Cienciométrico. Madurez Tecnológica. Meta-Análisis Cruzado. Dinámica de Patentes.

INTRODUCTION

Cardiovascular diseases (CVDs) remain the leading cause of mortality worldwide, accounting for approximately 17.9 million deaths in 2019 - nearly one-third of all global fatalities (World Health Organization, 2021). This alarming prevalence has intensified the search for therapeutic strategies that combine behavioral interventions with nutraceutical and pharmacological solutions. Among emerging bioactive compounds, Policosanols (Pc) - a class of long-chain aliphatic alcohols—have gained prominence due to their lipid-modulating properties and potential cardiovascular benefits (Galletti et al., 2019; Mercurio et al., 2020; Shen et al., 2019; Arruzazabala et al., 1997; Gimmler et al., 2006; Marazzi et al., 2011; Más, 2000a, 2000b; Musto et al., 2010; Primo et al., 2025; Viola et al., 2008).

Despite growing interest in Pc-based bioproducts, the technological and scientific pathways for their extraction remain fragmented across disciplines and regions. This study addresses that gap by applying a cross-track scientometric protocol (Primo et al., 2023; Schiavo, 2019; The PLoS Medicine Editors, 2011) to six major biorefining routes: saponification, solvent extraction, ultrasonic-assisted methods, molecular distillation, transesterification, and supercritical CO_2. By integrating experimental parameters, publication metrics, and patent data, the research aims to identify patterns of convergence and dissociation between academic output and industrial innovation.

Through this approach, the study contributes a replicable framework for evaluating technological readiness and innovation dynamics in Pc research, with particular attention to the Ibero-American context.

The dual objectives of this investigation are: (1) to synthesize key experimental parameters across the six extraction routes, and (2) to map international research networks through temporal scientometric analysis, linking peer-reviewed publications with intellectual property claims.

THEORETICAL FRAMEWORK

Relationships Between Patents, Articles and Reviews: Innovative Five Indexes

The scientometrics analysis assesses the relative importance of articles, reviews and patents, providing insights into technological route maturity and fertility. Considering Technology Readiness Levels (TRL) (ISO 16290:2013 - Space Systems — Definition of the Technology Readiness Levels (TRLs) and Their Criteria of Assessment, 2013; Rodrigues et al., 2021), this scientometric analysis reveals disparities between industrial and scientific activity.

The TRL framework has become a pivotal tool in assessing the maturity of industrial technologies, particularly in guiding research and development (R&D) planning and commercialization strategies. Originally developed by NASA, the TRL scale ranges from 1 (basic principles observed) to 9 (technology proven in operational environment) and has been widely adopted by institutions such as the U.S. Department of Defense and the European Space Agency (EARTO, 2014). As technologies progress through these stages, their proximity to market application increases, prompting a shift in strategic priorities—including intellectual property (IP) protection. The TRL scale not only facilitates internal project management but also serves as a signal to external stakeholders regarding the innovation’s commercial potential and readiness for investment.

Recent studies have highlighted a dynamic correlation between TRL progression and the timing and nature of patent-related actions. At early TRL stages (1–3), innovators typically engage in patent novelty searches and may file provisional applications to secure early rights while continuing development (Kaya, 2024). These stages are characterized by ideation and conceptual validation, where the risk of premature disclosure is high and the need for confidentiality agreements is critical. As technologies advance to TRL 4–6, encompassing proof-of-concept and prototype development, formal patent filings become essential. This phase marks a strategic inflection point where freedom-to-operate analyses are conducted to avoid infringement, and design protections may be pursued to safeguard aesthetic elements. The increasing technical specificity and market orientation of these stages necessitate a robust Intellectual Property (IP) strategy aligned with commercialization goals.

At higher TRL levels (7–9), where technologies are demonstrated in operational environments and prepared for full-scale deployment, the IP landscape shifts toward enforcement, licensing, and portfolio management. Patents filed in earlier stages begin to yield strategic value, enabling firms to negotiate partnerships, attract investment, and deter competitors. The Embrapa model, which institutionalizes TRL / Maturity Readiness Level (MRL) assessments in Brazilian industrial R&D, exemplifies how structured maturity evaluation can enhance technology transfer and business development (Embrapa, 2018). Overall, the interplay between TRL and patent dynamics underscores the importance of synchronizing technological development with IP actions to maximize innovation outcomes and market impact.

In the five index presented below, the logic is to compute the largest expected set in the numerator, but this relationship can be inverted in certain cases and moments, generating positive results less than unity: the *Revision Index* (R-I or ϕ) and *Patent Index* (P-I or ψ) (Equation 1 and 2, respectively); the *Patent-Peer Reviewed Reviews Index* (PR-I or λ) and *Patent-Peer Reviewed Article Index* (PA-I or φ) (Equation 3 and 4, respectively). The ξ it is an indicator of the relationship between the main forms of *New Techno-Scientific Knowledge* and their *Reviews* (NK-I) (Equation 5) (Primo et al., 2023).

$$\phi = \frac{\sum_{i=1}^{m} A_r}{\sum_{i=1}^{n} R_r} \tag{1}$$

$$\psi = \frac{\sum_{i=1}^{m} A_r}{\sum_{i=1}^{q} P_r} \tag{2}$$

$$\lambda = \frac{\sum_{i=1}^{n} R_r}{\sum_{i=1}^{q} P_r} \tag{3}$$

$$\varphi = \frac{\sum_{i=1}^{m} A_r + \sum_{i=1}^{n} R_r}{\sum_{i=1}^{q} P_r} \tag{4}$$

$$\xi = \frac{\sum_{i=1}^{m} A_r + \sum_{i=1}^{q} P_r}{\sum_{i=1}^{n} R_r} \tag{5}$$

where

A = Only article (data paper), article (early access) and article (proceedings paper).

R = Review.

P = Patent. Each patent record is computed, and the same technology can be protected in different offices.

Subscript "r"= Technological route.

The λ and ψ disaggregating (and φ aggregate) the relative importance of *A* and *R* studies in relation to P, respectively. The ϕ is a metric usual in the Scopus, WOS basis and others. The calculation of five indices for six technological routes is summarized in Table 1.

Globally, λ index values < 1 indicate a stronger emphasis on intellectual property claims over publishing reviews, particularly in saponification, supercritical, and solvent extraction. This trend is more pronounced in Ibero-America, where reviews are scarce.

Table 1

Five indexes of claims of intellectual and industrial property in the Policosanol extraction routes.

	PR-SD*						Extraction Patent (Fullpat)		Index									
	World			Iberoamerican					World					Iberoamerican				
Route	**Total**	**A**	**R**	**Total**	**A**	**R**	**World**	**Ibero-American**	ϕ	ψ	λ	φ	ξ	ϕ	ψ	λ	φ	ξ
PC in General	801	635	121	231	213	9	102	69	5.25	6.23	1.19	7.41	6.09	23.67	3.09	0.13	3.22	31.33
Saponification	14	13	1	2	2	0	27	20	13.00	0.48	0.04	0.52	40.00	n.a.	0.10	0.00	0.10	n.a.
Solvent Extraction	19	17	2	6	6	0	66	38	8.50	0.26	0.03	0.29	41.50	n.a.	0.16	0.00	0.16	n.a.
Molecular distillation	9	8	1	4	2	2	3	0	8.00	2.67	0.33	3.00	11.00	n.a.	n.a.	n.a.	n.a.	n.a.
Transesterification	7	6	1	8	8	0	1	1	6.00	6.00	1.00	7.00	7.00	n.a.	8.00	0.00	8.00	n.a.
Supercritical CO2	33	29	4	2	2	0	29	21	7.25	1.00	0.14	1.14	14.50	n.a.	0.10	0.00	0.10	n.a.
Ultrasonic-assisted	56	35	21	10	10	0	19	13	1.67	1.84	1.11	2.95	2.57	n.a.	0.77	0.00	0.77	n.a.

* PR-SD - Peer-Reviewed Scientific Document: article (new search), review, meeting abstract, editorial material, correction, letter, proceedings paper, article (data paper), article (early access), article (proceedings paper) and news item. Thus, Total can be greater than or equal to A + R.
n.a. - Not applicable.

Notably, ultrasonic extraction showed balanced research interests and intellectual property reinforcement. In contrast, supercritical extraction exhibited low λ values, indicating limited review publication despite converging research and intellectual property interests. Transesterification displayed academic study prominence over reviews and patents, suggesting an experimental rather than technological focus.

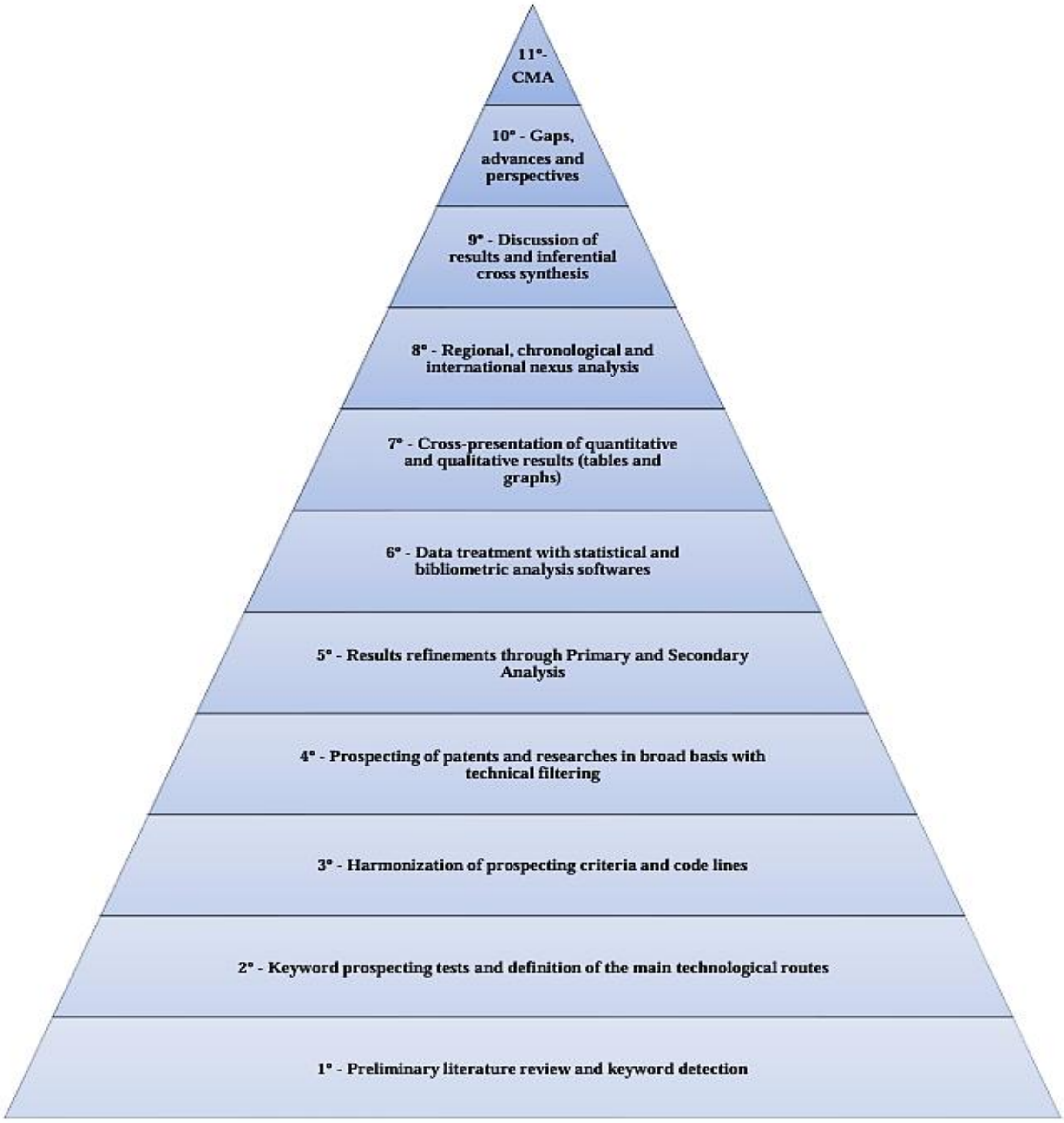
Divergences between peer-reviewed publications (articles and reviews) and patents have been identified. The λ index values < 1 indicate greater interest in intellectual property claims over reviews, particularly in saponification, supercritical extraction, and solvent extraction. This influences ξ index values, reaching extremes in saponification and solvent extraction globally, and in Ibero-American Pc research. Dissociations between industrial (patent-driven) and academic dynamics are evident in: 1. Saponification and solvent extraction (ψ and $\varphi < 1$); 2. Supercritical extraction (low λ values, indicating limited review interest despite converging research and intellectual property trends). Equilibrium and Technological Status: 1. Ultrasonic extraction exhibits equilibrium between article, review, and patent interests (ϕ, ψ, λ); 2. Transesterification is predominantly experimental, with articles outnumbering reviews and patents.~

METHODOLOGY

A systematic review typically begins with three preliminary steps: a comprehensive state-of-the-art review, keyword prospecting tests, and central theme analysis (Hajduk, 2017). These steps defined the six main extraction routes and Ibero-American countries. Following harmonization of prospecting criteria, eight additional steps were undertaken, adhering to the protocol pyramid (Primo *et al.*, 2023, 2025): data treatment with meta-analytic software, analytical depth assessment, identification of advances and gaps, Cross-Meta Analysis (CMA), and expectation evaluation.

Figure 1

CMA Pyramid Process.



Source: Primo *et al* (2023).

Aligned with initiatives such as the International Registry for Prospective Reviews and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses, and aimed at minimizing arbitrary revisions, eliminating redundancy, and fostering collaboration, this framework comprises a clearly defined set of procedures and tools organized into 11 self-explanatory steps, progressing from the base to the apex of a process pyramid (Figure 1).

The research spans the temporal scope from the 1990s to the 2020s, drawing on a diversified set of sources. It employs 35 technology domains through the Advanced Search and IP Business Intelligence modality of Orbit seekers (version 1.9.8), refined by criteria including title, abstract, key information, concepts, claims, descriptions, advantages of the invention, and limitations compared to prior art. Complementarily, the SciFinder platform contributes data in the fields of Organic Chemistry, Biochemistry, and Chemical Engineering, filtered by the same refinement parameters. The study further utilizes the Federated Academic Community (CAFE) of the National Teaching and Research Network (RNP), via the CAPES Portal Periódicos, encompassing 537 referential databases. Additionally, bibliometric insights are derived from international indexes such as the Science Citation Index Expanded (SCI-E) of the Web of Science – Core Collection (Clarivate Analytics) and Scopus (Elsevier) (Primo *et al.,* 2023, 2025).

The procedural design encompasses studies that include patents and peer-reviewed research in final-stage publication specifically addressing Pc extraction. A range of bibliometric tools was employed to support patent and publication analysis. For patent data, the Advanced Search and IP Business Intelligence features of Orbit seekers (v1.9.8) provided a robust set of scientometric functions (Orbit Intelligence, 2021, 2022),, complemented by SciFinder's Knowledge Graph for connection mapping. Statistical tools from Web of Science (WoS) and Scopus were utilized alongside VOSviewer® software (v1.6.15, April 2020) to generate bibliometric visualizations (Van Eck & Waltman, 2020). Additionally, the R-based Bibliometrix package (v4.1.1) and its Biblioshiny interface supported data standardization, duplicate exclusion, and comprehensive science mapping (Aria, 2023; Aria & Cuccurullo, 2017).

RESULTS AND DISCUSSIONS

Saponification

The countries that stand out the most for their co-authorship in studies related to Pc and saponification methods, mentioned in the progressive chronology of their co-authorship, are, in the first place, Chile, followed by China and India.

A Brazilian patent (PI 0702137-2 A8) uses sugar cane wax as a raw material for the extraction of Pc, optimizing time and simplifying processes in a way that enables it to be produced on a large scale with a high degree of Pc purity. This technological route involves four stages, which can be briefly described as follows: 1) alkaline hydrolysis of the wax with a hydroxide solution; 2) addition of saline solution to the hydrolyzed wax resulting from the first stage, heating, cooling and filtration; 3) addition of ethyl alcohol to the by-product of step 2, heating, cooling, filtration and drying, obtaining the primary Pc and 4) purification of this primary Pc using an organic solvent, obtaining a minimum purity of 92 % (Rozário *et al.*, 2008).

The IN201631013579 extracts Pc by selective and controlled alkaline hydrolysis of lactic wax, obtaining Triacontanol (C30) for the purpose of natural regulation of plant growth (PGR), causing a significantly greater effect compared to commercially available triacontanol formulations (Sanjay *et al.*, 2017).

Of the 18 patents related to Pc extraction and saponification, only two results appear after 2015, in the basic materials chemistry and measurement topic domain; 2004 was the year with the highest number of deposits (8), in the areas of pharmaceuticals (8), basic materials chemistry (3), food chemistry (1) and measurement (1), centered on the Pc source called Chinese white wax scale (*Ericerus pela*), entomological knowledge and atherosclerotic complication, among others. Extraction of Pc from this *Ericerus pela* (native to southern China), is an innovation and is based, in one case (WO2004/069161), on hydrolysis/saponification (in an aqueous or alcoholic solution) in homogeneous phase of the wax isolated from the insect and extract the hydrolyzed with an organic solvent, to obtain a composition of matter with greater purity, resulting in a Pc with singularly high purity (Qi & Ji-Fu, 2004).

Dated after 2015, IN201821003939 refers to a process for the extraction of Pc from raw rice bran wax using ethanol as a solvent. The refined and bleached bran wax has melting point 78-82 % and saponification value 70-120, a commercial alternative by selective removal of oil and resinous matter and simplicity of the process (Ganesh *et al.*, 2019).

Remarkable Parameters of Experiments I

A protocol that provided a fast and viable method for the quality control of Pc products derived from rice bran wax was based on experimental results according to which the extract obtained by dry saponification has the highest levels of octacosanol and triacontanol that dry saponification, in alcohol, in water (neutralized and non-neutralized) or by transesterification (Wang, Lian, Mao, Zhou, Gong, Qian, Fang, Li, Mei-Fei Wang, *et al.*, 2007). The insect wax saponification value reached 208.36 mg KOH/g in experiments that used 300 nm UV light irradiation in two stages, degradation and oxidation, resulting in a shortening of the Pc's long carbon chain (Li *et al.*, 2014).

The insect wax saponification value reached 208.36 mg KOH/g in experiments that used 300 nm UV light irradiation in two stages, degradation, and oxidation, resulting in a shortening of the Pc's long carbon chain (Li *et al.*, 2014). A correlate study on the effect of the saponification on composition of Unsaponifiable Matter (USM) oil concluded that Pc contributed with a high percentage (43.4 % in crude rice bran oil and 28.5 % in refined rice bran oil) (Afinisha Deepam *et al.*, 2012). Has been shown that to extract the crude wax from the bark of *Saccharum spontaneum L.* (wild sugarcane, Kans grass), to obtain the Pc, the saponification value is 112.2 (Murugasan *et al.*, 2016). Pc extraction experiments conducted for three years from tomato seed, using saponification, concluded that the crop year influences the parameters employed, but that hot break and cold break (cheaper) treatments did not significantly influence the physicochemical properties (Giuffre *et al.*, 2017).

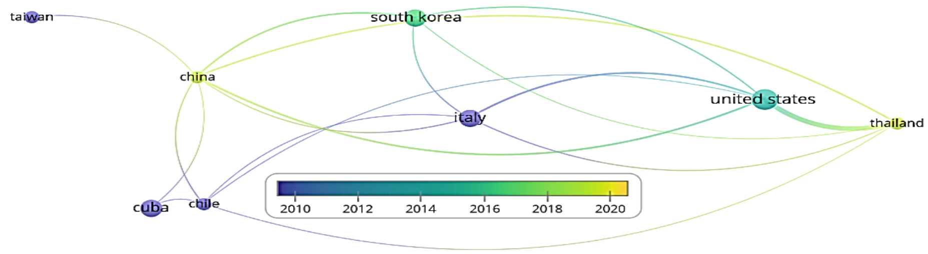
Solvent Extraction

The 75 patents related to Pc extraction and use of solvents are distributed, by technological domain (with respective number of patents), as follows: food chemistry (54), pharmaceuticals (14), organic fine chemistry (10), chemical engineering (7), basic materials chemistry (4) and measurement (1). The highest point in the historical series was 2012, with 25 deposits, followed by 2016, with 12, and 2014, with 9. In 2012, the three most attractive concepts relating to raw materials, in decreasing order of frequency, were bitter orange oil, grape skin extract and gum Acacia Senegal.

Considering the whole set of 75, the order of the main three becomes grape skin extract, mango extract and rice protein solubility, whose density of protections, under geographic perspective, covering strategic markets in the Americas, Europe, Asia and Australia, especially by Coca Cola (46) and Purecircle (41), which together accumulate more than eight times the strength of any of the other intellectual property rights applicants in this segment.

Figure 2

Chronological distribution, by country, among relationships of main studies regarding the Pc and solvent methods, (2010 to 2020).



To the modalities of Pc extraction with solvents, a network of bibliographic and chronological coupling can be observed in Figure 2. Conversely, solvent extraction with hexane, used as a processing method for wheat germ oil (WGO), source of Pc, was compared with a mechanical extraction process (heavy-duty screw press), allowing us to infer that, although the free fatty acids, peroxide value and p-anisidine value of the oil obtained by mechanical pressing were lower than by solvent extraction, the bioproduct is rich in essential fatty acids and tocopherols (Al-Obaidi *et al.*, 2013). Another comparison found that hexane solvent extraction of perilla oils from roasted perilla seeds contained significantly lower levels of tocopherols, sterols and Pc than those obtained by supercritical CO_2 (Jung *et al.*, 2012). Examining eight sugarcane cultivars, it was inferred that, by solvent extraction, the composition and content of Pc vary from cultivar to another, as well as in relation to the specific part of the analyzed sugarcane and its degree of ripeness. Its increased up to 72% during sugarcane maturation from October to January (Asikin *et al.*, 2012).

Among the patents filed in the last seven years, in English or Ibero-American languages, is the extraction of Pc from raw rice bran wax (IN201821003939), after the removal of wax and wax oil, using alcohol, with the advantages mentioned above when discussing saponification (Ganesh *et al.*, 2019). The second (IN201617022160) offers a process for extracting Pc from sugar cane vinasse, a process that comprises the supply of a concentrate of cane vinasse to produce an extract and a refine, performing a concentration step on that refined to produce a permeate and a retentate and performing a separation step on this retentate to produce a new retentate containing Pc (Aerts *et al.*, 2016).

A Brazilian patent (PI 0701341-8 A2) is clean and use non-toxic extractants, mitigating residual in the extract; in addition to being carried out in an airtight extraction environment, preventing degradation occurring in the extraction process by steam distillation or hydrodistillation, as well as by subtracting the solvent evaporation step (Meireles & Shintaku, 2008). The patent IN201617022160 indicates that the retentate (penultimate biorefined) will contain a usefully high concentration of policosanol and that the level of compounds other than policosanol will be low, and that the desirable separation of Pc can be accomplished by familiar purification methods such as solvent exchange (Aerts *et al.*, 2016).

Remarkable Parameters of Experiments II

Solvent extraction with hexane, used as a processing method for wheat germ oil (WGO), source of Pc, was compared with a mechanical extraction process (heavy-duty screw press), allowing us to infer that, although the free fatty acids, peroxide value and p-anisidine value of the oil obtained by mechanical pressing were lower than by solvent extraction, the bioproduct is rich in essential fatty acids and tocopherols (Al-Obaidi *et al.*, 2013). Another comparison found that hexane solvent extraction of perilla oils from roasted perilla seeds contained significantly lower levels of tocopherols, sterols and Pc than those obtained by supercritical carbon dioxide (Jung *et al.*, 2012). Examining eight sugarcane cultivars, it was inferred that, by solvent extraction, the composition and content of Pc vary from cultivar to another, as well as in relation to the specific part of the analyzed sugarcane and its degree of ripeness. Its increased up to 72% during sugarcane maturation from October to January (Asikin *et al.*, 2012).

Molecular Distillation and Transesterification

The transesterification / acetylation of long-chain fatty alcohols was used to obtain Pc by passing through a microcolumn filled with solid NaOH, generating rice bran alcohols with 24-34 acetylated carbon atoms successfully (Kaewkool & Krisnangkura, 2010). The results, in terms of patents referring to Pc extraction and molecular distillation, were discarded for the purposes of this study, after content analysis determined that they refer to the distillation modality useful for solvent recovery.

It is worth noting about molecular distillation and transesterification, although the patent EP3110781 B1 does not provide quantitative and explicit information on the performance of final bioproducts with alternative raw materials, this technological route is scrutinized as an economical process for the production of large quantities of aliphatic alcohols with a chain length of 20 to 36 carbon atoms, in particular for the production of policosanol (Pellati *et al.*, 2018), from animal or vegetable waxy material in two steps, using microwaves, as well as solvents widely recovered by distillation.

The remarkable patent on the extraction of Pc using transesterification (Pellati *et al.*, 2018) starts from waxy material, in particular wax, from animal or vegetable origin and benefits from two steps using microwaves, as well as solvents widely recovered by distillation, comprising the following steps: (1) microwave-assisted transesterification of the waxy material; (2) washing the transesterified material with water to remove salified water-soluble fatty acids; (3) microwave-assisted hydrolysis to purify the transesterified material from unreacted fatty acids and esters; (4) purification with non-polar organic solvents.

Regarding molecular distillation and the number of citations, the chronological order of the most prominent countries is Thailand, Italy and Taiwan, very close to each other at the beginning of the second decade of the 21st century, followed by Indonesia with fears of the same decade and, more recently, by China. Regarding transesterification and the bibliographic coupling, the chronological order is Thailand, China and Italy.

Remarkable parameters of experiments III and IV

Sampling carried out at 6 Palm Fatty Acids Distillates (PFADs) refineries to assess their potential as a Pc source, among other bioproducts, using gas chromatography – mass spectrometry (GC-MS) with derivatization method, considering experiments with molecular distillation, did not find Pc (Estiasih *et al.*, 2013). A new procedure for the extraction and purification of Pcs from yellow beeswax using microwave transesterification in one of its three stages, has proved effective in the generation of nutraceutical and pharmaceutical bioproducts (for human use), as well as in the generation veterinary supplements and feed (for animal use) (Venturelli *et al.*, 2019b).

Enzymatic transesterification experiments extracted Pc with recombinant Candida Antarctica Lipase in Aspergillus Niger (CAL-Bn) in reaction medium with toluene, and triacontanol (main component of Pc) was obtained with yields of up to 19 % using isopropanol as an acyl receptor (Ramos-Zambrano *et al.*, 2019a). The transesterification / acetylation of long-chain fatty alcohols was used to obtain Pc by passing through a microcolumn filled with solid NaOH, generating rice bran alcohols with 24-34 acetylated carbon atoms successfully (Kaewkool & Krisnangkura, 2010). The results, in terms of patents referring to Pc extraction and molecular distillation, were discarded for the purposes of this study, after content analysis determined that they refer to the distillation modality useful for solvent recovery.

Supercritical Carbon Dioxide Extraction

The possibilities of using sugarcane residues as a valuable source of lipophilic molecules extracted under supercritical conditions has been highlighted by studies by the Institute of Chemistry of the State University of Campinas (Brazil), of the Molecular Biotechnology Group of the Institute of Physics SC at the University of São Paulo (Brazil) and at the Department of Chemistry at the University of York (United Kingdom) (Attard *et al.*, 2015).

Using supercritical CO_2 for the extraction of Pc with bark, leaves and sugarcane bagasse, substantial amounts of long-chain aldehydes and n-Pc (nutraceutical compounds) were obtained (83 % of the composition) (T. M. T. M. Attard *et al.*, 2015). From cuticular waxes isolated from flax fiber it is possible to obtain Pc, with CO_2 or hexane in supercritical conditions, with more convergent results for C-20, C-22 and C-26 alcohols and more divergent for C-16, C-18 and C-24, according to the extraction method, in these cases with an advantage for CO_2 (Morrison III *et al.*, 2006).

Figure 3

Chronological distribution, by country, among relationships of main studies regarding the Pc and supercritical dioxide carbon extraction method (2010 to 2020).

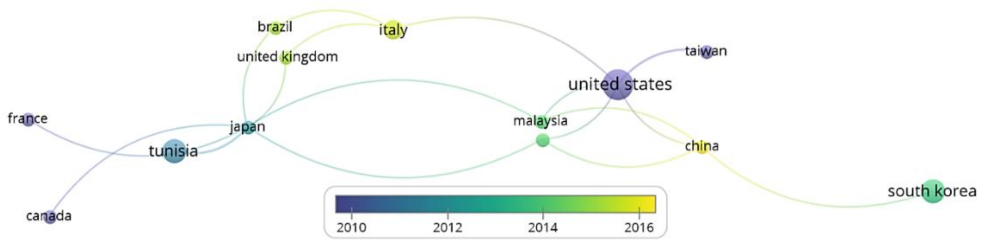
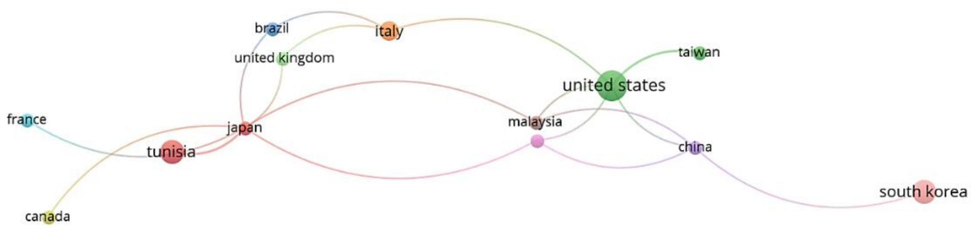


Figure 4

Relationships, by country, between main researches regarding the Pc and supercritical dioxide carbon extraction method (2010 to 2024).



Regarding supercritical CO_2 extraction and the bibliographic coupling the chronological order is EUA, Tunisia and South Korea. Still in relation to supercritical CO_2 method, considering the number of citations (by Scopus), the chronological-national order is displayed in Figure 3 and distributed in different groups of co-citations, in Figure 4.

The main family of the patent of Pc extraction and supercritical fluid is “A method for producing Pc from green tea leaves and its product”, with applicant Sewon C. & S. and publication number KR101492260, 2013, refers to a method of extracting Pc from green tea leaves and an extract of it by a process that includes grinding those leaves and mixing oil obtained by supercritical extraction using a subsidiary solvent, with a solution aqueous solution containing ethanol, sodium hydroxide or potassium hydroxide and water.

The Brazilian patent PI 0701341-8 A2 is not explicit as to the physical productivities in obtaining Pc (octacosanol, hexacosanol, eicosanol, docosanol, tetracosanol, heptcosanol and triacontanol), it represents an effective route to extract them and other attractive compounds for the pharmaceutical and food industries and cosmetics, such as stigmasterol, beta-sitosterol and campesterol phytosterols (Meireles & Shintaku, 2008).

As previously noted, the search for extraction with supercritical carbon dioxide fluid did not present any patent results, which motivated the flexibility of the criterion for the other substances, generating positive results. These patent families fall into these technological domains, in descending order of appearance: Organic fine chemistry and pharmaceuticals with the same number, followed by basic materials chemistry and food chemistry, and, finally, chemical engineering. His most frequent concepts regarding raw materials are, in descending order: rice bran wax, insect wax (including *Ericerus pela*) and sugar cane wax.

Remarkable parameters of experiments V

Using supercritical CO_2 for the extraction of Pc with bark, leaves and sugarcane bagasse, substantial amounts of long-chain aldehydes and n-PC (nutraceutical compounds) were obtained (83 % of the composition) (T. M. Attard *et al.*, 2015). From cuticular waxes isolated from flax fiber it is possible to obtain Pc, with CO_2 or hexane in supercritical conditions, with more convergent results for C-20, C-22 and C-26 alcohols and more divergent for C-16, C-18 and C-24, according to the extraction method, in these cases with an advantage for CO_2 (Morrison III *et al.*, 2006).

Ultrasonic Methods

An admonition should be made regarding the ultrasonic-assisted extraction route: a significant portion of the set of studies is dedicated to its medical or pharmacological applications (and others) and not to the extraction itself, escaping the objectives of this study (Hoksrud *et al.*, 2012) and almost all belong to a single-family patents and do not deal with the extraction of Pc, but with methods to purify steviol glycosides and their uses, being therefore discarded for the purposes of this study.

The 37 patents related to the are distributed among the following technological domains (with their respective deposit numbers): food chemistry (37) and organic fine chemistry (5); 2012 is a peak year, with 25 deposits, concentrated on the following concepts related to raw materials: grape skin extract, mango extract and rice protein.

In Figure 5 the first network of relations, identified in green, between the research on Pc extraction related to the ultrasonic route is in the Asia region, including Japan, Malaysia, Thailand, with which Nigeria is linked externally. The second Asian network is red, including China and South Korea, and Croatia and France are linked to it from the outside; the Euro-American network, strongly coupled to the other bibliography, is shown in blue and the one made up of Cuba and India in yellow, in relative isolation, given their geopolitical dynamics of technological development. In Figure 6 is evident the precedence of the studies of the USA, Cuba, India, Italy and Croatia.

Figure 5

Relationships, by country, between main researches regarding Pc and ultrasonic methods (2010 to 2020).

Figure 6

Chronological distribution, by country, among relationships of main studies on Pc and ultrasonic methods (2010 to 2020).

The 37 patents related to the ultrasonic route are distributed among the following technological domains (with their respective deposit numbers): Food chemistry (37) and Organic fine chemistry (5); 2012 is a peak year, with 25 deposits, concentrated on the following concepts related to raw materials: grape skin extract, mango extract and rice protein. However, they all belong to a single-family and do not deal with the extraction of Pc, but with methods to purify steviol glycosides and their uses, being therefore discarded for the purposes of this study, as initially signaled.

Remarkable parameters of experiments VI

Experiment reached, with the hydrolysis of rice bran, the extraction of Pc by submitting it for 30 min under high-intensity ultrasound either with hexane or without any organic solvent, using a basic aqueous solution instead (Cravotto *et al.*, 2004). Based on samples of 1-octacosanol, rapid generation homologs were achieved by varying the chain length in the alkyl halide through power ultrasound and microwave irradiation (Cravotto *et al.*, 2004).

CONCLUSION

This study offers a comprehensive cross-metric analysis of six principal technological routes for Policosanol extraction, integrating experimental data, scientometric indicators, and patent metrics into a unified evaluative framework. By bridging academic literature and intellectual property claims, the research reveals distinct patterns of technological maturity and innovation alignment. Ultrasonic-assisted extraction and transesterification emerge as routes with strong convergence between scientific output and industrial interest, suggesting readiness for commercialization. In contrast, saponification and solvent extraction display pronounced dissociation, particularly within the Ibero-American context, where review literature and patent activity remain uneven.

The application of a structured pyramid protocol and five scientometric indices enables a nuanced understanding of the interplay between knowledge production and technology transfer. This methodological approach not only enhances reproducibility but also addresses epistemological gaps common in bio-extraction research. By mapping international research networks and correlating them with patent dynamics, the study provides a strategic tool for evaluating innovation ecosystems and guiding future bioproduct development.

Ultimately, the findings underscore the importance of synchronizing scientific inquiry with industrial applicability. The proposed framework may serve as a foundation for comparative regional studies, refinement of biorefining strategies, and policy-making aimed at fostering technological convergence in nutraceutical research.

ACKNOWLEDGEMENTS

To Questel, for the kind permission to use and free training of the Orbit®. To Prof. H. Suzuki, for generously sharing information on patent prospecting. To Dr. Jesús Martín-Gil for the guidelines.

FUNDING

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (Capes) - Finance Code 001: Process: 88887.465369/2019-00 (Capes) - Date: 01/10/2019 to 30/09/2023. In other part, this study was financed by Institutional Internationalization Program – CAPES – PrInt: Process: 88887.468908/2019-00 (Call no. 41/2017); Date: 01/02/2020 to 31/12/2020.

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