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Mapping the patent landscape of innovations in eggshell waste applications

ABSTRACT – The objective of this article is to analyze patents related to the reuse of solid waste from chicken eggshells. The analysis is based on technological prospection in patent databases. The study focuses on the use of eggshells as raw material or as components in industrial processes. This approach is aligned with the principles of circular economy. To complement the technological prospection, a review of national and international literature was conducted. The goal is to identify innovative technologies and patented processes that support sustainable waste management. The analysis considers environmental, social, and economic dimensions. Findings indicate that eggshell waste remains undervalued. Its disposal continues to pose environmental challenges in many countries. However, between 2000 and 2022, the number of patents related to its reuse increased by 643%. Most filings (91%) are concentrated in Asian countries, which are among the largest producers of chicken eggs. China stands out as the leading applicant. This growth in patent activity reflects the increasing interest of research and development centers in repurposing eggshell waste. The material is gaining recognition as a viable input for new products, especially in agribusiness.

Index terms: added value, circular economy, poultry farming, sustainability.

Mapeando o panorama de patentes das inovações em aplicações de resíduos de casca de ovo

RESUMO – O objetivo deste artigo é analisar patentes relacionadas ao reaproveitamento de resíduos sólidos de cascas de ovos de galinha. A análise baseia-se em prospecção tecnológica em bases de dados de patentes. O estudo concentra-se no uso das cascas como matéria-prima ou como componentes em processos industriais. Essa abordagem está alinhada aos princípios da economia circular. Para complementar a prospecção tecnológica, foi realizada uma revisão da literatura nacional e internacional. O objetivo é identificar tecnologias inovadoras e processos patenteados que contribuam para a gestão sustentável desses resíduos. A análise considera as dimensões ambiental, social e econômica. Os resultados indicam que os resíduos de casca de ovo continuam subvalorizados. Seu descarte ainda representa um desafio ambiental em muitos países. No entanto, entre 2000 e 2022, o número de patentes relacionadas ao seu reaproveitamento aumentou 643%. A maioria dos registros (91%) está concentrada em países asiáticos, que estão entre os maiores produtores de ovos de galinha. A China se destaca como principal depositante. Esse crescimento na atividade patentária reflete o crescente interesse de centros de pesquisa e desenvolvimento em reaproveitar os resíduos de casca de ovo. O material vem ganhando

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reconhecimento como insumo viável para novos produtos, especialmente no agronegócio.

Termos para indexação: valor agregado, economia circular, avicultura, sustentabilidade.

INTRODUCTION

Chicken eggs are widely used in the food industry due to their technological properties (Oliveira et al., 2009). Average per capita egg consumption reached 9.68 kg worldwide in 2018. This represents an increase of 1.14% compared to the previous year, and 9.09% when compared to ten years ago (Helgi Library, 2023). Among the main egg consuming countries are Mexico, Japan, Paraguay and China, where the per capita consumption exceeds 300 eggs per year (Brito et al., 2021). According to the Food and Agriculture Organization of the United Nations (FAO, 2023), in 2021 the world production of table eggs reached 87.60 million tons, an increase of 26.78% compared to 2010, with an additional 18.50 million tons. It is estimated that, by 2030, the world production will reach 95 million tons and there will be a 9% increase in world consumption compared to 2021. China, the U.S., the European Union, India, and Mexico are the major egg-producing countries. China alone produced about 34.4 million tons in 2021, representing 39% of world production (Soares & Ximenes, 2022).

Most eggs are placed on the consumer market as shelled eggs. To meet the demand of a market that is increasingly demanding, the egg production industry has innovated to provide greater safety, economy, and practicality to consumers, creating the processed egg industry (Pastore et al., 2011). Pasteurized whole eggs, boiled eggs, powdered eggs, and other derived products whose main ingredient is eggs are considered egg products (Liobert, 2010 quoted by Gomes, 2011). This type of product presupposes the removal of the peel and membranes and possible separation of its remaining two major components, egg white and yolk, and may also include new ingredients and/or additives, always intended for human consumption. These egg derivatives can be found in liquid, concentrated, dehydrated, crystallized, frozen and deep-frozen forms (Gomes, 2011). Processing is an alternative to prolong the shelf life of eggs, making this food safer and of better economic value in relation to the fresh product, in addition to keeping its chemical characteristics relatively unchanged. Thus, several products derived from fresh eggs have been introduced to the market and, albeit slowly, have been occupying the shelves, making life easier for consumers, and benefiting egg producers (Pastore et al., 2011).

Data from the Brazilian Association of Animal Protein (ABPA) indicate that the Brazilian egg production in 2022 reached 52 billion units, of which 99.56% were destined for the domestic market and 0.44% for the foreign market (ABPA, 2023). Egg exports to the international market totaled 9.47 thousand tons in 2022, of which 5.39 thousand tons were fresh eggs and 4.08 thousand tons were industrialized eggs, a number 15.75% higher than the total amount of industrialized egg products exported by Brazil in 2021, when 3.44 thousand tons were shipped, according to data from ComexStat (Brasil, 2023). International trade of egg products has been driven not only by the search for less perishable products that are easy and quick to prepare, but also by concerns about food safety. In addition, this requires more rigorous monitoring of quality criteria (Pastore et al., 2011).

Regardless of the egg product obtained, generation of waste in egg breaking operations is mainly associated with eggshells obtained from raw material processing (shelled eggs) (Quina et al., 2017). This material represents 3 to 12% of the product's egg mass, depending on the properties of the eggshell (size and thickness) (Russ & Meyer-Pittroff, 2004). Every year, around 6 million tons of eggshells are generated in households and food businesses around the world. Although the industrialization of eggs provides economic advantages, such as extension

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of the product's shelf life, and increased ease of transportation and conservation, on the other hand, it generates a significant number of shells, which are still considered waste (Oliveira et al., 2013). Due to the lack of adequate strategies for the management of this by-product, which is composed of about 94% (w/w) calcium carbonate ($CaCO_3$) (Stadelman & Cotterill, 2013), landfilling has traditionally been used as its final disposal method (Oliveira et al., 2013).

However, possibilities for reusing this waste may include preparation of animal feed or adsorbent materials for the removal of dyes and their incorporation into the soil (Park et al., 2007; Tsai et al., 2008; Mezenner & Bensmaili, 2009). Development of applications with added value for eggshells, generated by agro-industries, would be environmentally and financially beneficial (Quina et al., 2017). That non-biodegradable waste is undervalued, but it represents a potential economic value. In addition, environmental aspects should be considered with regard to the valorization of eggshells, since, in addition to reducing the pollution generated by their disposal directly into the environment, this waste contains considerable protein content, making it an alternative source of calcium carbonate that can reduce the impact on natural reserves of limestone, a non-renewable natural source (Neves, 1998).

Considering the problem related to the significant volume of eggshells produced around the world and focusing on the reduction of environmental risks, the scarcity of natural resources and the valorization of eggshells as a potential by-product. The objective of this article is to, through the prospection in patent databases, analyze the patents filed related to the reuse of solid waste, such as chicken eggshells, as a source of raw material or as a part of processes in different industries. This type of prospective study, in addition to mapping the main existing technologies through patents, allows for directing research not only to the poultry segment. It also can assist in the monitoring of other economic, social, technological and environmental areas, contributing to the construction of future scenarios for the market, generating opportunities, and demonstrating the ability to develop technologies with various applications that can be protected through patent analysis (Menezes et al., 2018).

LITERATURE BACKGROUND

The circular economy (CE) is a current methodology that aims, among other things, to reintegrate waste as raw material in new production cycles, aiming to reduce the generation of waste intended for disposal (Corsi et al., 2018). Interest in the topic of CE in the world has increased recently, since the 2000s (Abadia et al., 2016). China, although classified as a developing country, was one of the first nations to institutionalize the CE by enacting its specific law in 2008. This legislation positioned circularity as a strategy to balance economic growth with environmental preservation (Yuan & Moriguichi, 2006).

On the international stage, the circular economy has gained prominence in environmental management research, particularly in developed countries such as those in Europe, the United States, and China itself. In contrast, Brazil still shows limited engagement with the topic, although recent studies indicate a growing trend (Corsi et al., 2018). This disparity reveals a gap in national scientific output and underscores the need for research focused on circular applications within the Brazilian context (Ouro-Salim et al., 2021).

Like other developing nations – such as Senegal, Mexico, and India – Brazil adopts practices inspired by circular models from developed countries, but faces challenges intensified by rapid population growth (Ouro-Salim et al., 2021). Despite the political will demonstrated through the creation of environmental laws, solid waste management

remains largely under the responsibility of the private sector (Guérin-Calmettes, 2016).

These countries still face significant challenges in solid waste management. The main issues include lack of political commitment, absence of national guidelines, insufficient regulations, limited financial resources, shortage of educational programs at all levels, and the lack of policies aimed at preserving or implementing the CE (Diaz, 2017).

The concept of circular economy can also be associated with that of industrial symbiosis, since closed systems are the basis of this concept, whose objective is to use waste from one sector as resources for others (Mirabella et al., 2014). Still, for the Ellen MacArthur Foundation (EMF), this approach is not restricted to any scale, and can be applied to large and small businesses, to organizations and individuals, globally and locally (Ellen MacArthur Foundation, 2017).

In this context, eggshells, which are rich in mineral salts, serve as the basis for a wide variety of industries. Despite this, the abundant waste from the egg-based products industry is still not being fully utilized (Oliveira et al., 2009). However, some options have been explored in the literature to provide added value to commercial products. Such alternatives can be grouped into two main categories: raw materials for the manufacture of new products and operational supplies for sorptive and catalytic applications (Laufenberg et al., 2003; Kosseva, 2009; Quina et al., 2017).

Eggshells can be used as raw material in the production of food additives, purified calcium carbonate, cosmetics, biomaterial composites, and animal feed (Oliveira et al., 2009; Mishra & Pathak, 2017; Quina et al., 2017; Faridi & Arabhosseini, 2018). As an operational input for sorptive and catalytic processes, calcium carbonate can be used for dye removal through adsorption and as soil conditioner (Park et al., 2007; Tsai et al., 2008; Mezenner & Bensmaili, 2009; Quina et al., 2017). These uses show that the recovery of this by-product by agro-industries brings environmental and economic benefits (Quina et al., 2017).

The high absorbency of calcium carbonate found in eggshells further reinforces its industrial relevance (Inovação Tecnológica, 2007). However, although these studies offer valuable contributions, they often lack a critical analysis of scalability, economic feasibility, and regulatory challenges for implementing such solutions – especially in developing countries like Brazil (Oliveira et al., 2009; Ouro-Salim et al., 2021).

METHODS

A comprehensive review of national and international literature was conducted, addressing circular economy, the properties of eggshell waste, and its industrial applications. In parallel, a quantitative study based on patent analysis aimed to identify technological alternatives for chicken eggshells. For this analysis, the Questel© Orbit Intelligence (Orbit) database was selected due to its extensive global coverage and academic relevance. It is one of the main tools used by the Secretariat of Technological Development (Sedetec) at the Federal University of Rio Grande do Sul (UFRGS).

Orbit is a paid database developed by Questel that has been utilized since the 1970s (Moura et al., 2019). UFRGS maintains an active subscription to this platform. The choice was also based on its efficient system for searching, selecting, analyzing, and exporting patent data. Orbit provides access to over 100 million patents registered in more than 100 countries and patent offices (Questel, 2023). The research was conducted using the Patent Family feature of the Orbit database (FamPat)[1].

The database search was based on specific keywords. The terms used included

[1] FamPat is a family grouping tool within the Questel Orbit database that organizes patents by sharing the same priority number within a single family (Nutels, 2018).

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eggshell, egg-shell, “egg shell”, waste, and residues (Table 1). This search resulted in 2,091 patent records. The database was generated on April 27, 2022. Data collection was carried out between April and September of the same year. To standardize, validate, and analyze the results, Microsoft Excel® was used.

Regarding the legal status of patent documents, it was decided not to apply it as an exclusion criterion. The proposal aims to offer a comprehensive view of the technological development related to the topic, taking into account both active and inactive records. This approach enables capturing accumulated technical knowledge and identifying solutions with potential for commercial exploitation, including those suitable for public use or adaptation.

Table 1. Patent database search strategy.

Patent database	Terms	Patent families
Orbit Intelligence (Orbit)	Search field: TI/AB/CLMS	
	((eggshell and waste) or (eggshell and residues) or ((egg w shell) and waste) or ((egg w shell) and residues) or (egg-shell and waste) or (egg-shell and residues))	2,091

Initially, the abstracts of 2,091 patents were reviewed. Of this total, 1,223 records were selected. These documents specifically addressed the reuse of chicken eggshells and the separation of the eggshell membrane. Patents related to eggshells from other animals – such as quail, duck, goose, fish, and ostrich – were excluded. Records involving egg production processes or inventions unrelated to waste reuse were also disregarded. For the selected patents, various data were analyzed, including publication history, filing countries, main inventors, applicants, and the International Patent Classification (IPC).

Next, the records of patent documents filed in the Orbit Intelligence database will be analyzed regarding the technologies for the use of eggshells that refer to the terms eggshells, residues, and waste. The analysis will include identification of the main inventors and applicants, the evolution of the filings over the years and the technological fields of the patents filed, as well as the potential application of this waste in the industry.

RESULTS AND DISCUSSIONS

Based on the information obtained from the database, the main results and corresponding analyses are presented below. Figure 1 illustrates the evolution of patent families from the date of first priority (March 6, 1962 to March 2, 2022), highlighting the growing interest in that technology over time. An increase in the number of patents containing the terms defined in the methodology (eggshell, eggshell membrane, waste, residues) is also observed, especially from 2010 onward, with notable peaks in 2016 and 2018.

This upward trend, noticeable since the 1990s, is linked to advances in nanotechnology, which has influenced various industrial sectors (Dias et al., 2021). From the 2000s, the digitization of patent systems also contributed to this growth, facilitating access to and dissemination of invention-related information across countries (Matias-Pereira, 2011).

On the other hand, between 2020 and 2022, there was a decline in patent filings related to

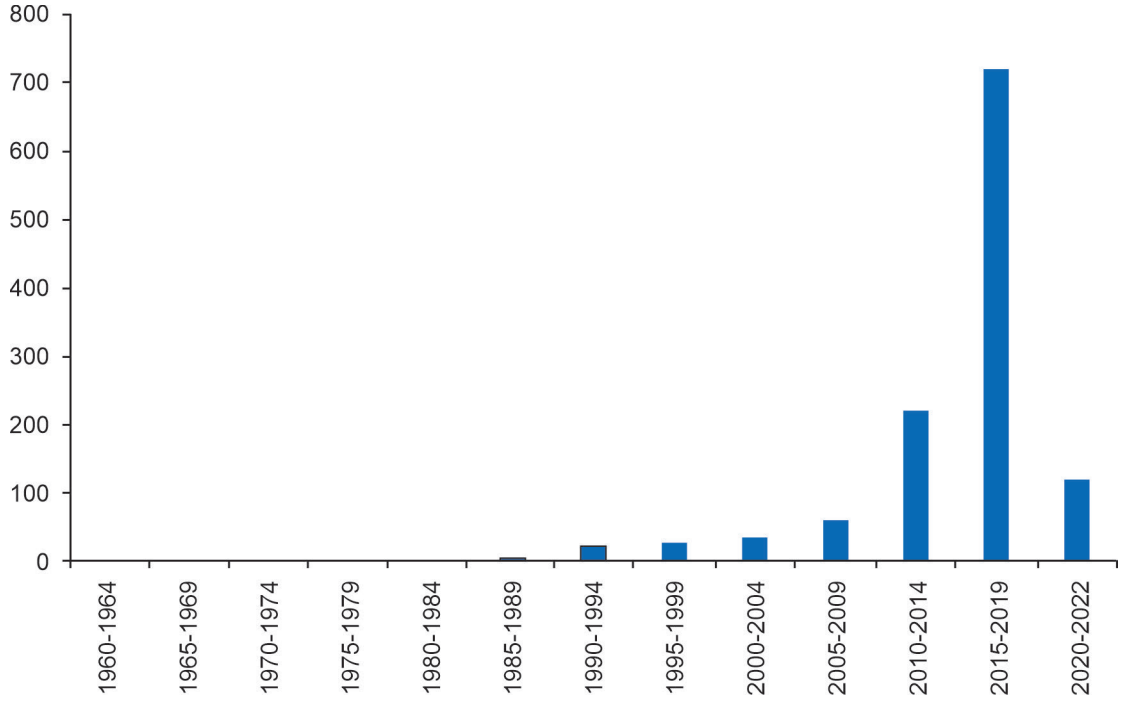

Figure 1. Evolution of patent publications since the first priority date (eggshell, egg-shell, egg shell, waste and residues).

eggshell waste reuse, possibly due to the COVID-19 pandemic. During this period, priorities shifted toward pharmaceutical innovations aimed at combating the disease (Melo & Bonini, 2023). On January 30, 2020, the World Health Organization (WHO) declared the outbreak a public health emergency of international concern. In response to the outbreak, through the Global Research and Innovation Forum, WHO coordinated efforts to fund priority research focused on diagnostics, medical devices, treatments, vaccines, and hospital equipment (WHO, 2020).

In Brazil, the National Institute of Industrial Property (Inpi) implemented an accelerated procedure in 2020 for patent applications related to "diagnosis, prophylaxis, and treatment of COVID-19", aiming to speed up filings in this area (Chwartzmann & Raymundi, 2020).

Figure 2 illustrates the worldwide distribution of patent filings by geographic region, considering only the reuse of chicken eggshells.

Among the countries with the highest number of patent filings (Figure 2), China leads with 973 records, accounting for approximately 80% of the total. Japan follows with 74 applications (6%), and the Republic of Korea with 64 (5%). This concentration can be attributed to two main factors: high egg production and a growing interest – both from industry and academia – in adding value to eggshell waste. This movement reflects a global trend of transforming low-value by-products into profitable and technologically innovative solutions (Ahmed et al., 2021).

China, the world's largest producer in 2019 (Yildiz, 2021), has demonstrated a strong commitment to environmental, economic, and social sustainability. In 2008, China enacted the Circular Economy Promotion Law, which regulates economic development with a focus on sustainable practices. As a result, China holds the highest number of patents related to eggshell reuse.

Although Brazil does not stand out quantitatively in this segment, it has registered eight patents (Figure 2). Most of these filings come

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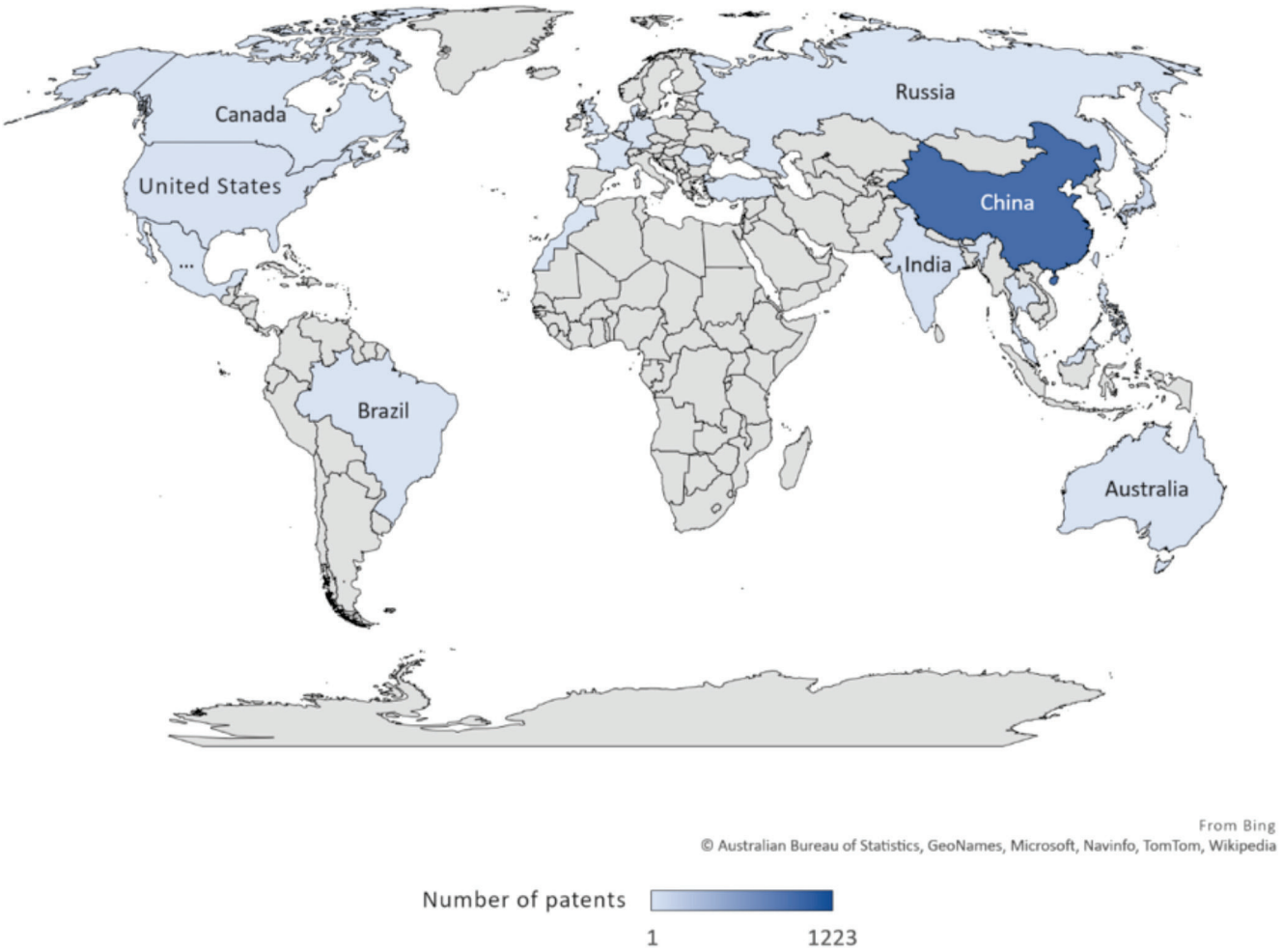

Figure 2. Distribution of patent filings worldwide between 1962 and 2023 (based on first priority date) for the reuse of eggshells, egg-shells, egg shells, waste and residues.

from academic institutions, including five federal universities (located in states of Rio Grande do Sul, Pelotas, Paraná, Pará, and Lavras) and the State University of the North Fluminense Darcy Ribeiro (Uenf, located in state of Rio de Janeiro). The patent applications cover a range of uses, including health, fertilizer production, and materials for fluorescent lamps.

Despite being on a smaller scale, these Brazilian initiatives reveal alignment with the principles of circular economy, which is based on three essential pillars: eliminating waste and pollution, preserving product and material value, and regenerating natural resources (Ellen MacArthur Foundation, 2017). These pillars support practices such as product reuse through repair and refurbishment, component recovery through remanufacturing, and material recycling, enabling reintegration into new production cycles (Zink & Geyer, 2017).

This approach aims to close the material loop by increasing the use of biological nutrients and reducing waste generation (Zhijun & Nailing, 2007; Ellen MacArthur Foundation, 2017). The logic of circularity strengthens its connection with the bioeconomy, especially through recycling, which allows the replacement of non-renewable resources with sustainable alternatives, reduces energy and material consumption, and encourages clean technologies in sectors such as agriculture (Pires et al., 2019). In this context, the valorization of by-products

becomes a key strategy, enabling the conversion of organic waste into energy or new materials and promoting integration between industrial chains to optimize resource use (Ellen MacArthur Foundation, 2017).

Within the scope of this investigation, several patents illustrating the intersection between circularity principles and technological innovation were identified. Notable initiatives include the substitution of raw materials, such as using eggshells as an alternative source of calcium and nitrogen in animal feed, fertilizers, and biomaterials. Relevant applications were also observed in the bioeconomy and health sectors, including the development of pharmaceutical, nutraceutical, and biomedical products. In the field of material recycling, there are records related to calcium carbonate extraction for use in cement, paper, plastics, and cosmetics. Circular design emerges as a strategy for creating biodegradable packaging incorporating eggshells, especially in plastic-based materials. Finally, it is worth highlighting energy recovery through the conversion of eggshells into biofuels or their use in thermal and catalytic processes that enable energy reuse.

To facilitate analysis, the International Patent Classification (IPC) was prioritized due to its broad acceptance and global standardization. Figure 3 presents the subclasses with the highest concentration of filings (more than 20), selected to improve data interpretation. This choice is justified by the wide variety of existing subclasses and the dispersion of information, which could compromise analytical clarity.

The analysis of the subclasses shows that a large portion of patent filings is concentrated in agribusiness-related areas, such as animal nutrition (A23K, A23L), fertilizers (C05G, C05F), and agricultural activities (A01G), reflecting the predominant use of eggshells as raw material in these sectors. This waste has been used in the development of various solutions, including animal feed, dietary supplements, cosmetics, bioceramics, and bone implants (Murakami et al., 2007).

Figure 4 shows the temporal evolution of the 30 IPC subclasses with the highest average number of filings per year, based on the date of patent applications related to the use of eggshells.

Over time, a clear trajectory of diversification and technological sophistication can be observed. Prior to the 2000s, patent applications were concentrated in broader and

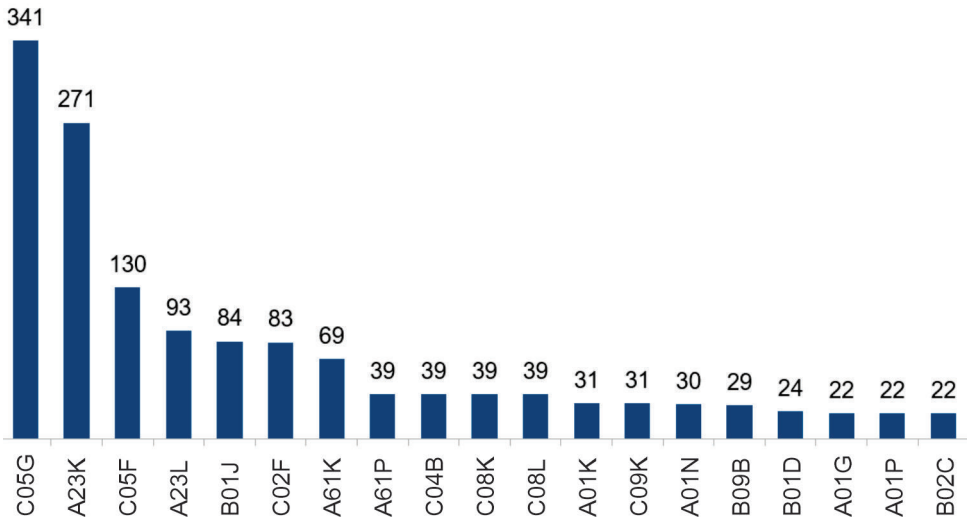

Figure 3. Main subclasses according to the International Patent Classification (IPC) of patent filings between 1962 and 2023 (eggshell, egg-shell, egg shell, waste and residues).

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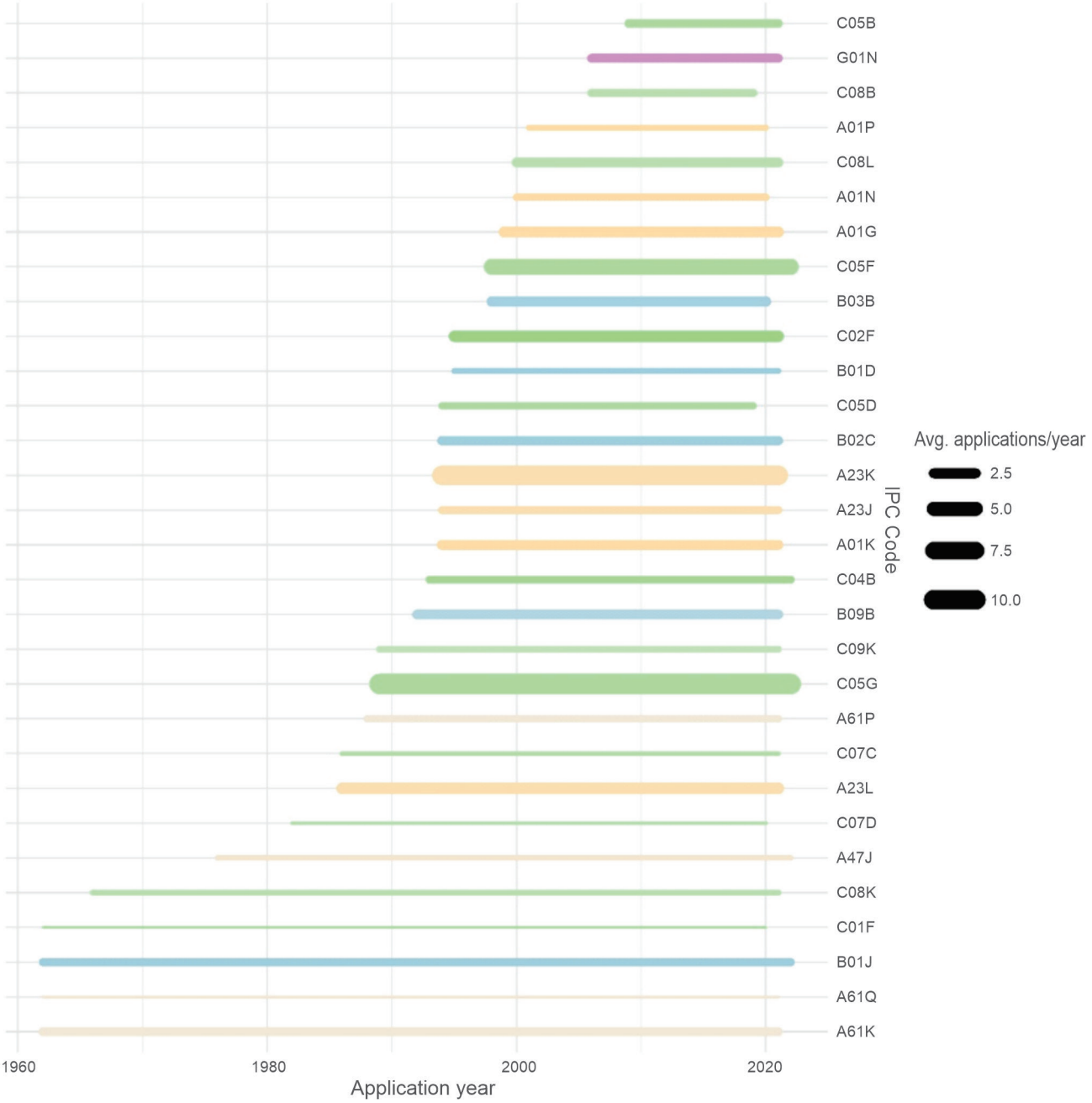

Figure 4. Temporal evolution of the 30 IPC subclasses with the highest average number of filings per year, based on the date of patent applications related to the use of eggshells.

more generic classes, such as B01J (catalytic processes), C01F (inorganic compounds), C08K (polymeric additives), and A61K (medicinal preparations), reflecting traditional applications. From 2010 onward, there was a notable expansion into emerging areas, with emphasis on classes such as C05B (fertilizers), G01N (analytical instrumentation), and C08B (biopolymeric materials), highlighting the advancement of technologies focused on waste functionalization and the development of new materials.

The classes with the highest annual average of filings – such as C05G (fertilizer mixtures with organic and inorganic components), C09K (functional materials), B09B (processing and reuse of solid waste), C07D (heterocyclic

compounds), and A61P (therapeutic uses) – demonstrate strong technological activity and continuous innovation. This evolution reveals a trend toward specialization: older classes cover broader fields, while newer ones target specific technical applications and functional properties. Sectoral diversity is also significant, with patents distributed across agriculture, medicine, waste treatment, and materials industries.

In this context, eggshells have emerged as a versatile raw material, with applications that go beyond their conventional use in fertilizers. Recent studies highlight their potential in areas such as sensors, environmental adsorbents, and pharmaceutical products. Despite their economic value (Oliveira et al., 2009), eggshell waste remains underutilized, and improper disposal – estimated at around 7.2 million tons annually worldwide (Cortés López et al., 2016) – can lead to environmental impacts and public health risks (Cardoso, 2017).

Conversely, reusing eggshells as a substitute for conventional calcium carbonate helps preserve natural limestone reserves, a non-renewable resource (Neves, 1998). Additionally, they can be used to produce electroceramic materials such as calcium titanate ($CaTiO_3$), widely applied in sensors for automobiles, cell phones, and industrial equipment (Callister & Rethwisch, 2012). The notable presence of subclasses linked to circular economy principles – such as B09B (processing and reuse of solid waste), C05F (waste-based fertilizers), and C05G (fertilizer mixtures with organic and inorganic components) – reinforces a scientific and technological shift toward the valorization of organic waste, aligned with sustainability principles.

To deepen the understanding of patent classes, Table 2 presents the ten detailed patent classes with the highest number of filings according to the IPC classification. This

Table 2. Main types of patents found according to the International Patent Classification (IPC) between 1962 and 2023 (eggshell, egg-shell, egg shell, waste and residues).

IPC	Description of group or subgroup(1)	Patent filings
A23K-010/30	Animal feeding products: derived from plant-based materials, e.g., roots, seeds, or hay; from materials of fungal origin, e.g., mushrooms (obtained by microbiological or biochemical processes, e.g., using yeasts or A23K 10/10 enzymes).	292
C05G-003/00	Mixtures of one or more fertilizers with additives without specific fertilizer activities.	271
A23K-010/26	Animal feeding products: derived from waste material, e.g., feathers, bones, or skin (A23K 10/24 has priority).	203
A23K-010/37	Animal feeding products: derived from waste material (from wood or straw hydrolysates A23K 10/32; from molasses A23K 10/33).	203
C05G-003/80	Mixtures of one or more fertilizers with additives without specific fertilizer activities. Soil conditioners.	160
A23K-050/75	Food products specially adapted for certain animals: for poultry.	156
A23L-015/00	Egg products; its preparation or treatment.	117
A23K-001/18	Food products specially adapted for animals; methods specially adapted for the production.	111
A23K-001/16	Food products specially adapted for animals; methods specially adapted for the production.	106
C05F-017/00	Preparation of fertilizers characterized by biological or biochemical treatment steps, e.g., composting or fermentation.	102

(1) International Patent Classification (IPC) was created in 1971 through the Strasbourg Agreement. Patents can have more than one IPC because representatives or companies that own the technologies can protect them in more than one country (Santos & Rocha, 2018).

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selection was made in light of the large number of existing classifications and the dispersion of data, as well as the fact that a single patent may be associated with multiple codes depending on its claims. These factors justify the adoption of a more restricted methodological scope, enabling a clearer and more objective analysis.

Table 2 highlights the codes C05G-003/00 and C05G-003/80, which focus on fertilizer mixtures containing additives without specific functions. These codes reflect the use of eggshells as a complementary component in agricultural formulations, reinforcing their role as an alternative input.

The relevance of subclass A23K is also evident, with records distributed across several subgroups. A23K-010/30 refers to animal feed derived from plant and fungal sources, while A23K-010/26 covers products derived from feathers, bones, or skin. A23K-010/37 focuses on hydrolyzed wood waste or straw. Additional codes such as A23K-050/75, A23K-001/18, and A23K-001/16 include products tailored for different species, including poultry, expanding the potential applications of eggshells in animal nutrition.

This use also extends to subgroup A23L-015/00, which deals with the processing and separation of eggshells – an essential step for industrial reuse. Complementing this scenario, code C05F-017/00 encompasses patents related to fertilizer production through biological or biochemical treatments, such as composting and fermentation, highlighting the potential of eggshells as raw material in sustainable processes.

This broader applicability is described in Figure 5, which illustrates the temporal evolution of the main complete subclasses – representing the most detailed level of IPC. Figure 5 captures trends based on the annual average of patent applications. The horizontal axis shows the patent filing period, while the vertical axis lists the specific IPC codes. The thickness of the line indicates the intensity of technological activity, measured by the average number of filings per year.

Between 2000 and 2020, there was a remarkable increase in the technological use of eggshells, with increasingly specific and complex applications. Most of the recurring IPC codes during this period belong to subclass A23K, which focuses on animal feed, additives, and nutritional formulations. The most frequent entries – A23K-020/163, A23K-020/142, A23K-010/20, and A23K-010/12 – highlight the use of eggshells as a functional ingredient or nutritional supplement in enriched feeds, leveraging their natural content of calcium, phosphorus, and protein.

Subsequently, subclasses such as C05G-003/80, C05F-017/00, and C05G-001/00 began to appear more frequently, emphasizing the use of organic waste – primarily eggshells – as fertilizer (Rivera et al., 1999). This trend is especially relevant in agriculture, where the high calcium carbonate content of eggshells proves effective in correcting acidic soil pH (Neves, 1998) and serves as a natural source of nutrients (Rivera et al., 1999).

The growing diversity of patent applications reflects not only the functional versatility of eggshells, but also a broader shift toward sustainable technologies based on the reuse of organic waste. These innovations align with the principles of regenerative agriculture and the circular economy, reinforcing the role of eggshells as a renewable and environmentally friendly input.

From the 2010s onward, patent filings began to reflect environmental applications. Codes such as B09B-003/00 and C02F-001/28 point to the use of eggshells in wastewater treatment, pollutant removal, and the development of adsorbent materials. These processes enhance the value of eggshells as a biomaterial with relevant physicochemical properties, such as sorptive and catalytic capacity (Quina et al., 2017).

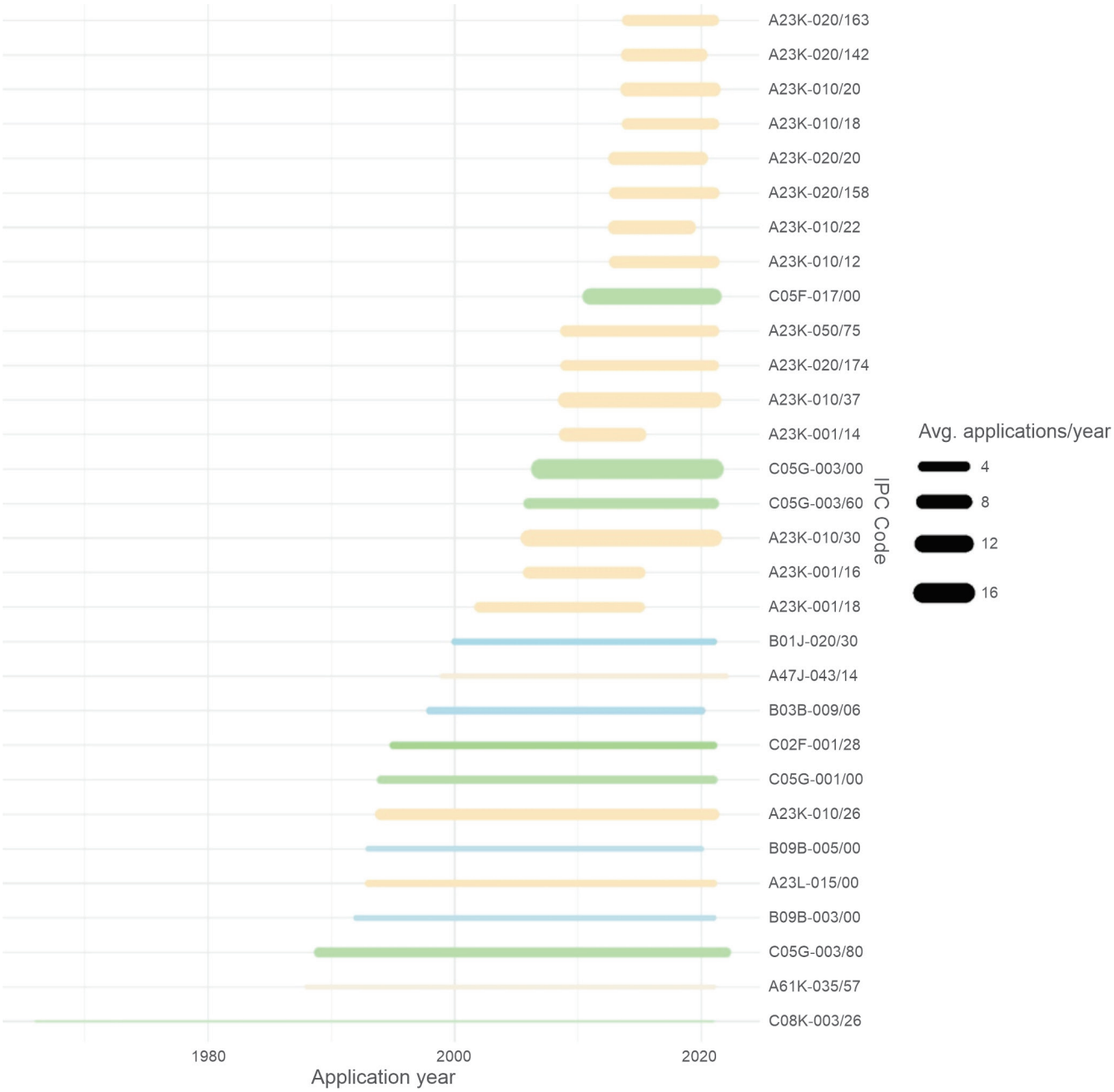

Figure 5. Temporal evolution of the main complete subclasses (the most detailed level of the International Patent Classification), based on the annual average of filings.

Although less frequent, codes such as A61K-035/57 also appear, which are related to pharmaceutical formulations and therapeutic supplements. These entries signal the emergence of health-related applications, further expanding the scope of eggshell utilization.

In summary, the analyzed chart reinforces this trend of diversification. The concentration of records in subclass A23K shows that P&D efforts are primarily focused on animal nutrition. At the same time, the inclusion of subclasses related to water treatment, specialized fertilizers, and urban waste reflects a technological approach increasingly aligned with sustainability.

This dynamic landscape confirms the growing innovation surrounding eggshells,

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particularly in the fields of animal feed, agricultural compounds, and environmental technologies. Their versatility has transformed eggshells from a discarded by-product into a strategic resource with cross-sectoral value.

This trend is further reflected in the inventor landscape, as shown in Figure 4. The analysis reveals a predominance of Chinese inventors, with Yang Dapeng and Liu Minghuan standing out as the most prolific. Both are professors at Quanzhou Normal University, a public institution in Quanzhou, People's Republic of China. Together with their research teams, they have pioneered the development of new nanomaterials derived from eggshells, expanding the material's potential in advanced technological domains.

Figure 6 describes the main inventors of technologies related to the reuse of eggshells between 1962 and 2022.

Other inventors with five or more patents have contributed to a wide range of innovations. Their filings cover applications in agribusiness – including agriculture and livestock – as well as food products, medical and dental technologies, and engineering solutions for the separation and processing of eggshells and their membranes. These contributions also include biotechnological approaches that further enhance the value and functionality of eggshell-based materials.

Given the diversity and volume of filings, it was essential to identify not only individual inventors but also the institutions and representatives responsible for submitting the patents, as they are considered the official holders of the technologies. Table 3 presents the main applicants, listing entities with more than four filings, ranked by volume. The table reveals a mix of individual and institutional holders, predominantly of Chinese origin.

Among the highlights is Quanzhou Normal University, which registered a patent for a compound made from eggshell membrane that promotes the healing of epidermal wounds. The material contains natural active ingredients such as amino acids (glutamic acid, glycine, and proline), glucosamine, chondroitin, and hyaluronic acid (Demir et al., 2024), and has demonstrated hemostatic, healing, and antibacterial properties (Pillai et al., 2023). The university also developed nanocomposites using eggshell particles to detect and remove chemical elements from wastewater, with potential applications as antimicrobial polymers in industry.

The second most active applicant, Hefei Keyou Biological Science & Technology, focused

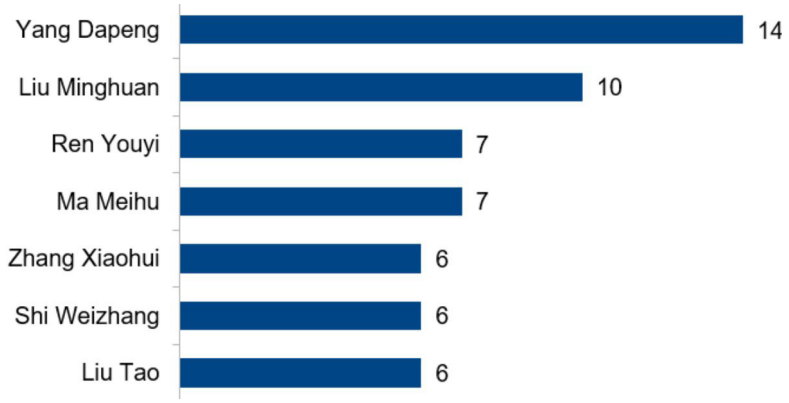

Figure 6. Main inventors of technologies related to the reuse of eggshells between 1962 and 2022 (eggshell, egg-shell, egg shell, waste and residues).

Table 3. Main applicants of technologies related to the reuse of eggshells between 1962 and 2022 – eggshell, egg-shell, egg shell, waste and residues.

Applicant	Number of patents filed
Quanzhou Normal University	18
Hefei Keyou Biological Science & Technology Co., Ltd.	7
Huazhong Agricultural University	6
Quzhou Yikeda Energy Saving Technology Co., Ltd.	6
Hefei Longbin Chemical Technology Co., Ltd.	6
Anhui Lyudi Food	5
Yuan Meifang	5
Quanzhou Xufeng Micro-Powder Materials Co., Ltd.	5
Hefei Xuelixin Agriculture Technology Co., Ltd.	5
Wuwei Guohong Ecological Park	5

on organic and biological fertilizers. Meanwhile, Quzhou Yikeda Energy Saving Technology patented equipment and methods for processing eggshells, emphasizing efficient membrane separation. This enables the reuse of both fractions in food and industrial applications.

The examples presented highlight the growing interest in eggshells as a versatile raw material. Patent data confirm their potential in clinical, cosmetic, nutraceutical, and nanotechnological applications. Previously limited to use in animal feed, dietary supplements, and fertilizers, eggshells are now being explored for more advanced solutions. The increase in the number of patent filings over the past decade reflects this shift and underscores the need for technologies that enable efficient membrane separation.

This progress is supported by studies that analyze the economic feasibility of industrial reuse of eggshells. In Brazil, research identified the potential for establishing processing industries focused on eggshells and their protein membranes, evaluating systems based on three criteria: their profitability compared to the criteria of conventional waste treatment, reduction of environmental impact, and required investment (ranging from less than US$500,000 to over US$1 million) (Oliveira et al., 2009).

Among the models analyzed, the grinding and drying system stands out, producing a powder suitable for use as fertilizer, animal feed, or heavy metal removal. This process yielded economic returns five times higher than the ones obtained by traditional treatment, and it reduced environmental impact by more than 90%, with low implementation costs (Oliveira et al., 2009). Another system, aimed at calcium carbonate production, involves additional steps such as washing and centrifugation to separate the membrane, and also generates positive environmental and economic results within the same investment range.

Despite operational and logistical challenges – such as collection, drying, and transportation (Maziero et al., 2023) – international evidence reinforces the competitiveness of eggshells. A study conducted in Malaysia demonstrated that calcined eggshells are effective adsorbents for phosphorus removal and recovery, with lower costs than conventional limestone-based materials (Lim et al., 2025). These findings strengthen the case for reusing agro-industrial waste in sustainable environmental technologies.

The convergence of technological innovation and economic feasibility reveals a promising scenario for the industrial use of eggshells.

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The expansion of applications – from health to environmental treatment – shows that this previously overlooked waste is being repositioned as a strategic input. The valorization of eggshells opens new market opportunities, drives the circular economy, and reinforces the commitment to more sustainable production practices.

CONSIDERATIONS AND IMPLICATIONS

The results analyzed showed that the number of patents focused on the reuse of eggshell waste has grown significantly in the last ten years, with the vast majority protected in Asian countries and with China as the main patent-filing country. These countries account for the world's largest production of eggshells. Since the adoption of the Circular Economy Promotion Law in 2008 in China, it can be seen that the country has already been seeking environmental, economic, and social sustainability.

The research results indicate that the residues from industrial egg production, the eggshells, have potential applications in various industrial sectors, which highlights not only their economic feasibility, but also the significant environmental benefits associated with their reuse.

In addition, the international subclasses filed by the IPC classification, which are most frequent in the patent portfolio, are related to the areas of chemistry, agriculture and microbiology applied to biotechnology, and the resulting products, animal feed and fertilizer mixtures, were the main innovations in most patents. Thus, the growth in the number of patent filings evidenced in the results of this study demonstrates the interest of study and research centers in reusing this waste as raw material for other products, especially those related to the field of agribusiness science.

It is worth mentioning that, although new uses for this waste obtained from the egg products industry have been studied and patented, the expectation is that the development of technologies in these areas will tend to grow in the coming years. Thus, this type of prospective study, in addition to mapping the main existing technologies through patents, allows for the direction of future research. Therefore, in view of all the findings of the research, it is recommended to conduct this type of analysis for other industrial segments of interest to agribusiness.

In this study, some inconsistencies were identified, which were corrected during the study, especially regarding the names of inventors and patent applicants, since there is no standardization of the data of patents indexed in the Orbit database. In addition, although the IPC is the international classification system for patents adopted in patent offices around the world, there is a lack of standardization in the classification criteria assigned by the patent examiner, which is their responsibility, and this may have an impact on the results analyzed.

Despite these limitations, the study achieved its objectives within the scope of quantitative patentometric analysis. To improve the accuracy and reliability of future research, the use of complementary approaches is recommended. Utilizing public patent databases can expand data coverage and enable cross-referencing, helping to enhance the identification of inventors and technological classification.

Moreover, qualitative methods such as content analysis and case studies provide deeper insights into innovations, revealing aspects that quantitative data alone cannot capture. Together, these strategies strengthen technological prospecting, increase methodological rigor, and contribute to a better understanding of innovation dynamics – especially in emerging areas such as the reuse of agro-industrial waste.

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