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Probiotic and Prebiotic Activity of Pineapple (*Ananas comosus*) and By-Products: a Bibliometric Review

Atividade Probiótica e Prebiotica do Abacaxi (*Ananas comosus*) e Subprodutos: uma Revisão Bibliométrica

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Abstract
Given the growing interest in the health benefits of pineapple, there is a need to investigate its probiotic and prebiotic potential. In view of this, the aim of this study was to carry out a bibliometric analysis of pineapple and its by-products in terms of probiotic and prebiotic activities. Thirty-one papers were selected from the Web of Science, Google Scholar and Capes Journal Portal databases, which evaluated the probiotic or prebiotic action or activity of pineapple and its by-products, with a publication date between 2013 and 2022. The following variables were analyzed: year of publication, part of the pineapple, pineapple by-product, activity, microorganisms and/or compounds evaluated. The results show that scientific production on the subject is spread across several countries, authors and publication outlets, with an increase in the number of articles from 2021 onwards, with the probiotic drink being the most researched by-product, while the pineapple pulp was the most used part, among the probiotic microorganisms Lactobacillus acidophilus stood out, among the prebiotics the antioxidants stood out, in the evaluation of activity the probiotic was the most researched. It can be concluded that scientific studies on the subject are focused on probiotic drinks made from pineapple pulp. Its by-products have functional potential, and both fresh pineapple and pineapple in the form of drinks or powders can be exploited for functional purposes such as probiotics or prebiotics.

Keywords: Pineapple. Microorganisms. Intestinal Microbiota.

Resumo
Dado o crescente interesse nos benefícios do abacaxi para a saúde, surge a necessidade de investigar seu potencial probiótico e prebiótico. Diante disso, o objetivo deste estudo foi realizar uma análise bibliométrica sobre o abacaxi e seus subprodutos em atividades probióticas e prebióticas. Foram selecionados 31 trabalhos nas bases de dados, Web of Science, Google Acadêmico e Portal de Periódicos Capes, que avaliaram a ação ou atividade probiótica ou prebiótica do abacaxi e seus subprodutos, com data de publicação entre 2013 e 2022. Foram analisadas as seguintes variáveis: ano de publicação, parte do abacaxi, subproduto do abacaxi, atividade, microrganismos e ou compostos avaliados. Nos resultados observou-se uma produção científica sobre o tema distribuída por vários países, autores e veículos de publicação, com um aumento no número de artigos a partir de 2021, sendo a bebida probiótica o

subproduto mais pesquisado, enquanto a polpa do abacaxi foi a parte mais utilizada, entre os microrganismos probiótico destacou-se o Lactobacillus acidophilus, entre os prebióticos o destaque foram os antioxidantes, na avaliação da atividade a probiótica foi a mais pesquisada. Conclui-se que os trabalhos científicos sobre o tema se encontram focados na bebida probiótica da polpa do abacaxi, seus subprodutos possuem potencial funcional, tanto o abacaxi in natura como em forma de bebidas ou pó podem ser explorados para fins funcionais como probiótico ou prebiótico.

Palavras-chave: Ananás. Microrganismos. Microbiota Intestinal.

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1 Introduction

Pineapple (*Ananas comosus*) has a global production average of approximately 2.2 million tons. According to the Food and Agriculture Organization of the United Nations (FAO), the harvested area and production of pineapple increase annually by 2% and 1.8%, respectively. It is estimated that by 2030, production will reach 37 million tons (Van Tran *et al*., 2023).

Pineapple can be consumed fresh, in minimally processed products, as frozen pulp and concentrates, or processed into jams, sweets, and other products. Pineapple juice contains important nutrients such as vitamins A (retinol), C (ascorbic acid), B3 (niacin), B6 (pyridoxine), and B12 (cobalamin), in addition to many compounds beneficial to human health (Ali *et al*., 2020).

Processing generates a large amount of waste, such as peel, crown, central cylinder, and ends, which can be used for full food utilization. These by-products can yield many useful compounds, such as phenolics, organic acids, and dietary fibers (Meena *et al.*, 2022).

One of the main pineapple by-products is the peel, which shows great potential for use in various products due to its nutritional characteristics, including a mineral content of 4.74% and fiber content of 17.92%, which is considered high (Neres; De Souza; Bezerra, 2015).

Several studies have shown that pineapple peel powder (PPP) is a good source of dietary fiber, protein, and minerals, and it can enhance the activity or growth of certain *Lactobacillus* species (Da Luz Silva; Silva; Leal, 2024; Byresh *et al*., 2022). Another study demonstrated the probiotic and antioxidant potential of *Lactobacillus reuteri* LR12 and *Lactobacillus lactis* LL10, which were isolated from pineapple pulp purée (Al-Dhabi *et al*., 2020).

Prebiotic, probiotic, and symbiotic foods are considered functional, as they offer health benefits. These include improved lactose digestion in intolerant individuals, modulation of serum cholesterol levels, anticancer activity, synthesis of B-complex vitamins, and stimulation of the immune system (Trentin; Dos Santos, 2020; Galdeano *et al*., 2019).

The requirements for probiotics to demonstrate safety and health benefits for use in food products

were established by ANVISA's RDC No. 241 of 2018. This regulation covers all products marketed in Brazil with probiotic claims. That is, they may only be sold with a probiotic declaration if their functional properties and survival under gastrointestinal conditions are scientifically proven (Brasil, 2018).

Considering the multiple connections between pineapple and its by-products with probiotic and prebiotic activities, it is essential to analyze the research and scientific production landscape on this topic. In this context, bibliometric research stands out as a study capable of identifying knowledge gaps within a specific subject area, which can be addressed through the analysis of available literature (Marques; Maculan; Souza, 2023).

This study aimed to conduct a bibliometric analysis of pineapple (*Ananas comosus*) and its by-products in probiotic and prebiotic activities, focusing on publications from 2013 to 2022, as a strategy to guide the development of innovative studies and products.

2 Material and Methods

The study is characterized as a bibliometric analysis, and data were collected from the following databases: Web of Science, Google Scholar, and the Capes Journal Portal (Coordination for the Improvement of Higher Education Personnel).

The following keywords were used: abacaxi, Ananas comosus, prebiótico, and probiótico, along with their English equivalents: pineapple, prebiotic, and probiotic. In addition to these keywords, the following search combinations were also employed: abacaxi and prebiótico or probiótico; pineapple and prebiotic or probiotic; Ananas comosus and prebiótico or probiótico; Ananas comosus and prebiotic or probiotic.

A total of 10,500 studies were identified, and inclusion and exclusion criteria were applied to select a final sample of 31 studies.

As an inclusion criterion, only studies published between 2013 and 2022 that evaluated the probiotic or prebiotic action or activity of pineapple and its by-products were selected, as this period was considered suitable for assessing the evolution of studies and innovations on the subject. As for exclusion criteria, literature reviews and editorial papers were excluded.

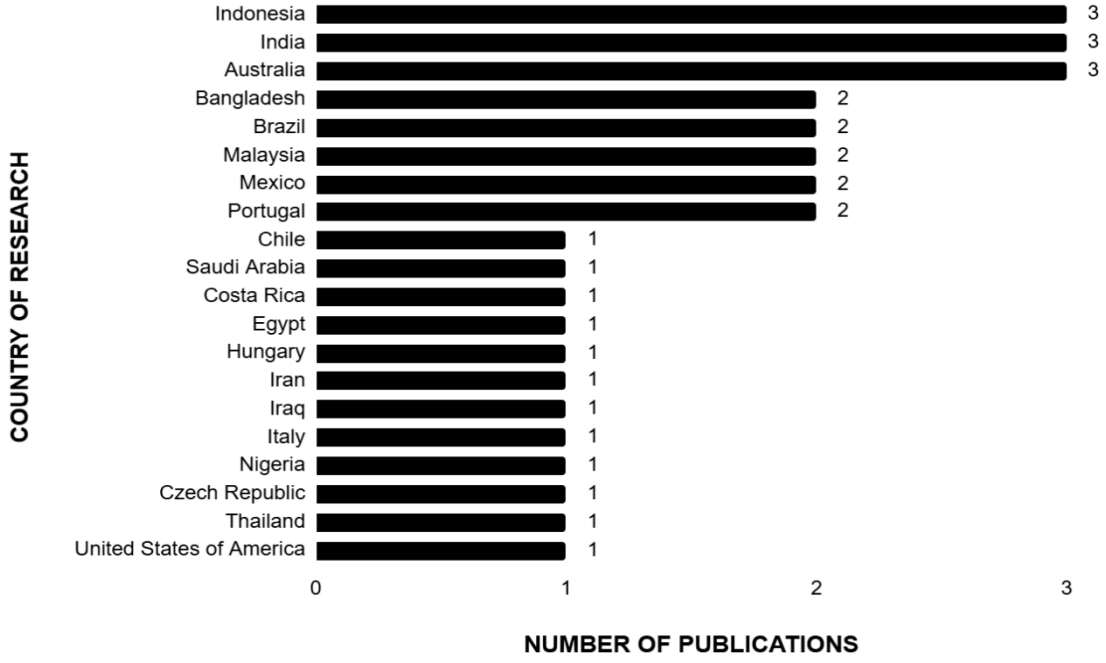
For the bibliometric analysis, the full content of the selected studies was examined, and the following variables were analyzed: country, year of publication, pineapple by-product investigated, part of the pineapple analyzed, microorganisms and/or compounds evaluated, probiotic or prebiotic activity

assessed, and evaluation results. The data were tabulated and analyzed using absolute frequency in Google Sheets.

3 Results and Discussion

Figure 1 shows the number of publications by country, with Indonesia, India, and Australia being the countries with the highest number of studies (n=3), followed by Bangladesh, Brazil, Malaysia, Mexico, and Portugal (n=2).

Figure 1 - Number of publications by country on the use of pineapple and its by-products in probiotic and prebiotic activities from 2013 to 2022

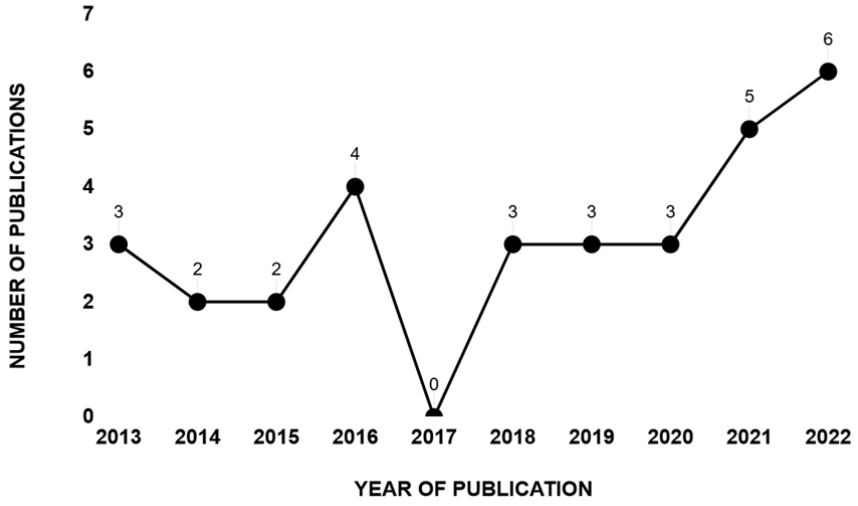


Source: research data.

Pineapple has a significant economic impact on trade and is among the most exported fruits, being extensively cultivated in various parts of the world (Campos *et al.*, 2020). It is widely grown in several tropical countries such as Brazil, Indonesia, Malaysia, Thailand, and India, among others, with the Asian region accounting for 46.7% of global pineapple production (Van Tran *et al.*, 2023). However, no single country stood out as a reference in terms of publications, although there appears to be a correlation between pineapple cultivation and the number of publications.

A chronological analysis was carried out for the period between 2013 and 2022 regarding the number of academic publications (Figure 2).

Figure 2 - Number of publications per year on the use of pineapple and its by-products in probiotic and prebiotic activities from 2013 to 2022.



Source: research data.

Significant changes in the number of publications per year were observed, suggesting that certain factors may have influenced the number of studies.

Figure 2 shows a low level of interest in research on the prebiotic and probiotic activity of pineapple in recent years, with no publications found in 2017. Only from 2021 onward was an increase in interest observed, which continued into 2022, indicating that this is a relatively underexplored topic that has only recently begun to attract more attention from the scientific community.

The increase observed from 2021 may be related to the COVID-19 pandemic, as research lines focused on immunity experienced a surge in output during and after the pandemic. Probiotics became a topic of interest, including studies evaluating their potential role in supporting treatment for clinical cases or preventing the progression of COVID-19 to more severe stages (Kurian *et al.*, 2021).

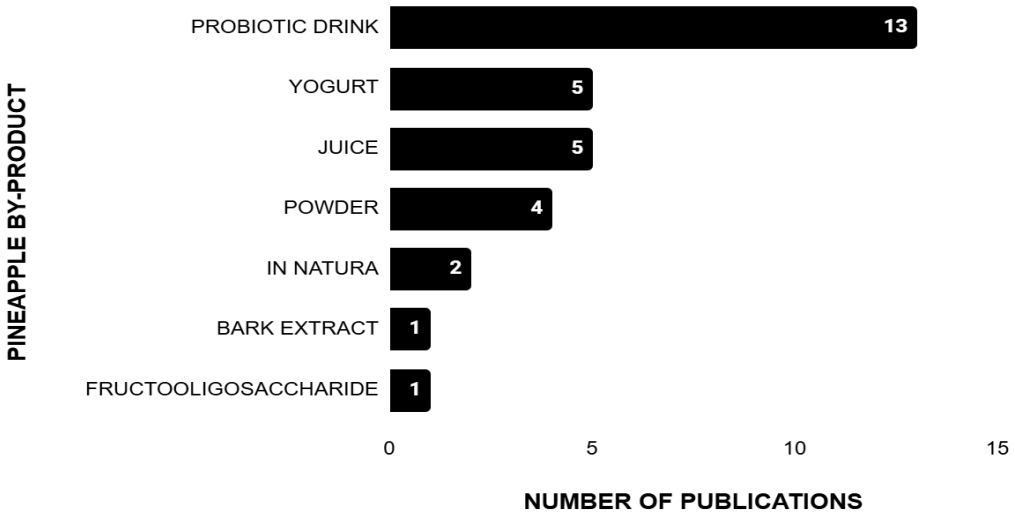
Although no clinical trials have been conducted, there is evidence suggesting potential beneficial effects of probiotics in treating COVID-19. Emerging evidence indicates a link between gut health and microbiota responses to SARS-CoV-2 (Bottari; Castellone; Neviani, 2021).

Several questions arose during the COVID-19 pandemic regarding how to enhance the body's immunity through diet (Tripathy *et al.*, 2021). Research and innovation became a major focus for public policymakers in the face of the global health emergency and resource scarcity (Sharma *et al*., 2022). The food industry has thus focused on producing functional foods with natural compounds that offer health benefits (Tripathy *et al*., 2021).

Analyzing the pineapple by-products based on the reviewed publications, the most frequently studied were probiotic beverages, both dairy and non-dairy (n=13), followed by yogurt (n=5), juice (n=5), and powder (n=4) (Figure 3). This reflects a preference for incorporating probiotics into dairy products

such as yogurt, fermented milk, and others.

Figure 3 - Number of publications by pineapple by-product in probiotic and prebiotic activities from 2013 to 2022



Source: research data.

Dairy beverages are mainly supplemented with healthy food additives such as fruits, which give them high nutritional value. As a result, they are tasty products consumed by people of all ages (Hamad; El_Say; Anees, 2019). Therefore, it is believed that their broad consumer acceptance is a key factor behind their market success.

Since these products are directly associated with the proper functioning of the gut microbiota—which is a complex communication system within the body—the importance of fruit juices enriched with probiotics becomes clear. These juices represent a valuable opportunity for product diversification within the food industry, utilizing a new plant-based matrix (Albuquerque *et al.*, 2021; Naseem *et al.*, 2023). Non-dairy probiotic-enriched foods have increasingly become an appealing option for the food industry (Gao *et al.*, 2021).

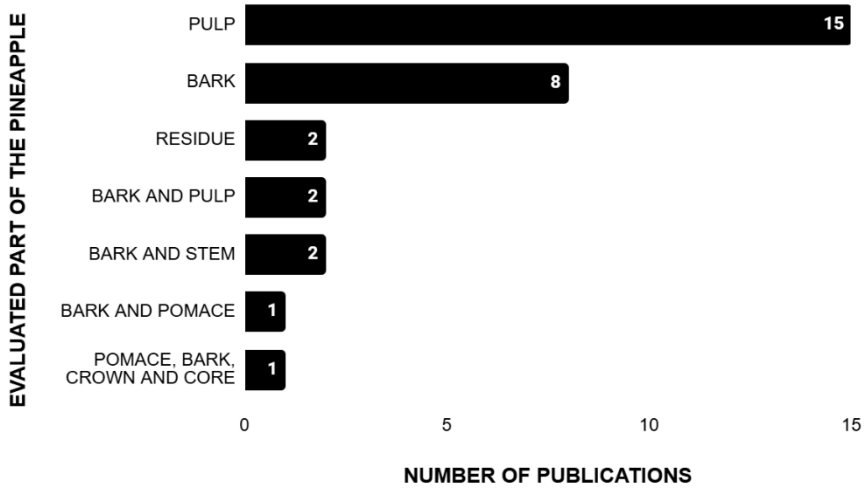
Due to their longer shelf life and lower transportation costs, fermented juice powders are highly desirable. In addition, probiotic fruit and vegetable juice powders can be used in probiotic beverages, ice creams, and other products (Albuquerque *et al.*, 2021).

The results related to pineapple-derived by-products indicate a preference for the use of dairy-based products in studies. This may be attributed to cultural and market factors, as dairy products are traditionally associated with probiotics (Gao et al., 2021). However, there is growing development of non-dairy alternatives, such as juices and powders. This strategy aims to meet the demand from a segment of the population that avoids dairy products due to dietary restrictions or ideological reasons. Additionally, dairy products tend to have higher costs and perishability, which can impact their scalability (Dutta;

Shrivastava, 2020). Thus, non-dairy options emerge as promising alternatives for research and the development of innovative products.

Regarding the part of the pineapple being evaluated, as shown in Figure 4, the pulp (n=15) stands out, followed by the peel (n=8), while other residues were not studied in isolation.

Figure 4 - Number of publications by pineapple part evaluated in research on the use of pineapple and its by-products in probiotic and prebiotic activities from 2013 to 2022



Source: research data.

Pineapple pulp contains nutrients that enhance the action of starter and probiotic bacteria (Hamad; El_Say; Anees, 2019). It is notably rich in carbohydrates, dietary fiber, potassium, calcium, vitamin C, water, and various minerals that have beneficial effects on the digestive system (Ali *et al.*, 2020).

There are differences in how pineapple waste is generated during processing. The peel represents the largest portion of by-products, followed by the core, while the stem and crown never exceed other residues. Overall, about half of the total weight of the pineapple constitutes both a by-product and a potential source of significant compounds (De Oliveira; Mendes, 2021).

Several studies have shown that lactobacilli were able to accelerate their growth with the addition of pineapple peel powder, which serves as a source of dietary fiber, proteins, and minerals (Byresh *et al.*, 2022; Da Luz Silva; Silva; Leal, 2024).

A study using fructooligosaccharides (FOS) produced from pineapple waste showed increased growth of probiotic bacteria and their metabolites, which inhibited pathogenic bacteria (Ibrahem; Al-Shawi; Al-Temimi, 2022).

Among the specific challenges in using other by-products as prebiotics, the data indicate a preference for using pulp in studies. However, research involving the peel and other pineapple residues has been growing. This strategy aims to make full use of the fruit's potential by transforming what would

be waste into a high-value-added product, thus generating economic gain and contributing to the reduction of waste generated during fruit processing, which also results in a positive environmental impact (Almaraz-Sánchez *et al.*, 2022). Therefore, pineapple peel and residues emerge as promising alternatives for the development of new research and innovative products.

Regarding the analyses on the topic of "microorganisms," the species *Lactobacillus acidophilus* (n=11) and *Lactobacillus casei* (n=7) stood out, while for "components," antioxidants (n=6), peptides, phenolic compounds, and fructooligosaccharides (n=4) were most frequently cited, as shown in Table 1.

Table 1 - Number of publications by microorganisms or substances analyzed in studies on the use of pineapple and its by-products in probiotic and prebiotic activities from 2013 to 2022

Analyzed Microorganisms	**Nº of Publications**	**Analyzed Substances**	**Nº of Publications**
Lactobacillus acidophilus	11	Antioxidants	6
Lactobacillus casei	7	Peptides	4
Lactobacillus paracasei	5	Phenolic compounds	4
Lactobacillus plantarum	5	Fructooligosaccharides	4
Lactobacillus rhamnosus	5	Soluble carbohydrates	1
Lactobacillus spp	4	Carotenoids	1
Pediococcus pentosaceus	4	Inulin	1
Aerococcus viridans	2	Simple sugars	1
Bifidobacterium bifidium	2	Polysaccharides	1
Bifidobacterium spp	2	Minerals	1
Lactobacillus fermentum	2		
Streptococcus thermophilus	2		
Lactic acid bacteria	1		
Bacteroides spp	1		
Bifidobacterium anima	1		
Bifidobacterium lactis	1		
Clostridium leptum,	1		
Firmicutes	1		
Lactobacillus bulgaricus	1		
Lactobacillus delbrueckii ssp. Bulgaricus	1		
Lactobacillus lactis	1		
Lactobacillus reuteri	1		
Lactococcus	1		
Lentilactobacillus parafarraginis	1		
Yeasts	1		
Limosilactobacillus fermentum	1		
Weissella ghanensis	1		
Weissella	1		

Source: research data.

Lactobacilli have a long and safe history of being consumed by humans and are important probiotic strains with many health-promoting activities (Miranda *et al*., 2021). For example, *Lactobacillus acidophilus* ATCC 4356 exhibits strong antioxidant activity and the ability to inhibit linoleic acid oxidation. These strains survive and colonize the gastrointestinal tract of the host organism (Khedr *et al*., 2022). The *Lactobacillus casei* group is the most studied among lactic acid bacteria and comprises various subspecies (Hill *et al.*, 2018; Silva *et al*., 2024).

However, there is still a lack of understanding regarding the survival and viability of individual probiotic strains during the fermentation and storage processes of pineapple juice (Nguyen *et al*., 2019).

To provide comprehensive information on the total antioxidant capacity of a tested compound, several different assays must be performed. After testing water-soluble peptide extracts from probiotic yogurt enriched with pineapple peel, these were found to act as potent antioxidant compounds (Sah *et al*., 2015).

After gastrointestinal simulation of the solid fractions of pineapple, it was concluded that pineapple by-product flours are a natural controlled-release system for phenolic compounds with high antioxidant capacity. In the same study, fructooligosaccharides (FOS) were used as a positive control - a well-known and recognized prebiotic. FOS promoted enhanced microbial growth in all phyla except *Bacteroidetes* and *Clostridium*. Thus, pineapple fractions promoted the growth of probiotic microorganisms, indicating they are suitable for acting as prebiotics (Campos *et al*., 2020).

The results related to the microorganisms or substances analyzed in the studies indicate a preference for the *Lactobacillus* genus and substances with antioxidant potential. However, research on various other microbial genera and substances with probiotic and prebiotic potential is also being developed. This expansion of microbial and substance possibilities indicates a promising path for the development of new research and innovative products.

Table 2 shows the number of publications that evaluated a specific activity and whether satisfactory results were obtained. Studies focusing on isolated probiotic activity (n = 19) stood out, followed by those evaluating both prebiotic and probiotic activity simultaneously (n = 11), and studies assessing isolated prebiotic activity (n = 1), which had the least relevance among the publications and was the only one that did not obtain satisfactory results in the activity assessment.

Table 2 - Number of publications that evaluated a specific activity and number of publications with satisfactory results in the evaluations of probiotic and/or prebiotic activities related to the use of pineapple and its by-products in probiotic and prebiotic activities during the period 2013–2022

Activity	Nº of Publications That Evaluated the Activity	Nº of Publications With Satisfactory Results
Probiotic	19	19
Probioti and Prebiotic	11	11
Prebiotic	1	0
Total	31	30

Source: research data.

Pineapple is a good substrate for the growth of probiotic bacteria (Nguyen *et al*., 2019). Pineapple by-products have potential to be used as prebiotic enhancers (Gómez-García *et al*., 2022). However, the analysis of prebiotic activities highlights a lack of satisfactory data. More studies focusing on the impact on the human gut microbiota and how fermentation can specifically shape the intestinal environment in a positive way are needed (Campos *et al*., 2020). It is noted that the effects of prebiotics on the stability of fermented pineapple juice and on the survival of probiotics are still unclear (Nguyen *et al*., 2019).

Data regarding the activity evaluated in the studies show a preference for probiotic activity; however, some studies have demonstrated the prebiotic potential of pineapple components (Gómez-García *et al*., 2022; Nguyen *et al*., 2019). This prebiotic potential of pineapple points to a promising path for the development of new research and innovative products.

4 Conclusion

The scientific literature on the subject is distributed across various countries, with an increase in the number of publications from 2021 onwards, and that probiotic beverages made from pineapple pulp with *Lactobacillus acidophilus* and antioxidants are the most studied items.

Pineapple and its by-products have functional potential; therefore, fresh pineapple, as well as in beverage or powder form, can be explored by the food industry for functional probiotic or prebiotic purposes. Research highlights a shift toward full use of foods; beyond the peels, the use of pulp residues, crown, and core may be viable options.

It can be inferred that current scientific research is focused on the development and evaluation of probiotic beverages made from fruit pulp. A promising path for new research and innovative products would be to explore non-dairy product options, using prebiotic components from residues combined with microorganisms other than the *Lactobacillus* genus.

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