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REVIEW ARTICLES

The role of fruit vinegar in food science: perspectives among consumers, the scientific community and patent holders

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Highlights
- The number of articles and patent on fruit vinegar has grown in recent years
- Scientific and technological innovations were revealed
- The main unconventional fruits used recently were identified
- More examinations of the bioactive properties exhibited by vinegars are need

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KEYWORDS:
Acetic acid;
Fermentation;
Fruits;
Intellectual property.

Abstract: Fruits are considered excellent sources of substrate for alcoholic and acetic fermentation and are used to produce food products with higher added value. The aim of this study was to map scientific publications and patents related to fruit vinegars. The methodology used consisted of an advanced search by combining keywords in the scientific databases Pubmed, Scopus, Springer, and Web of Science, while the patent documents were searched in the databases European Patent Office (Espacenet®), Instituto Nacional de Propriedade Industrial (Brazilian Institute of Industrial Property (INPI)), Patent Scope and United States Patent and Trademark Office (USPTO). The search resulted in the retrieval of 73 scientific articles and 293 patent documents. The number of scientific publications on the development of fruit vinegars lags the number of patent documents. Despite technological and scientific development, this present study shows that there is a demand for the development of new methods of vinegar production and points out market trends as well as the use of different raw materials, microorganisms, and enzymes in the production process. Another notable deficiency within this study pertains to the need for more comprehensive examinations of the bioactive properties exhibited by products crafted from various raw materials.

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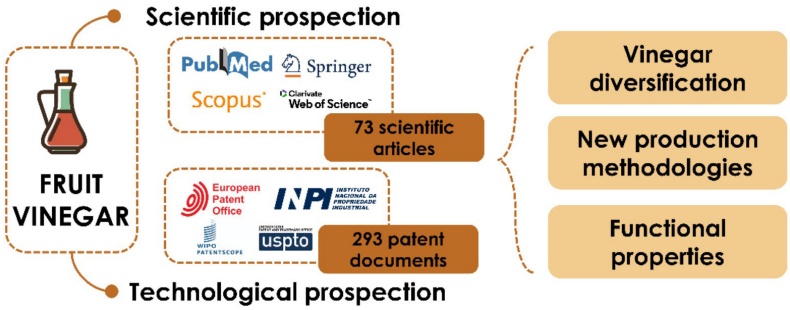
Graphical Abstract



Introduction

Food fermentation is one of the oldest biotechnologies of humanity and was initially used as a means of preservation. However, over time, new fermented foods have been developed with unique textures, flavors and features. Currently, it is estimated that there are more than 5,000 varieties of fermented food products (Diez-Ozaeta & Astiazaran, 2022). Fruits have, in particular, fermentation-prone characteristics due to their high sugar content and fermentative viability. This results in foods that are rich in different nutritional compounds, such as organic acids, phenolic compounds and melanoidins (Ousaaid et al., 2021). Therefore, acetic fermentation is a promising alternative that can be used to diversify fruit products.

Vinegar is a product that can be made from different raw materials, mainly cereals, honey and fruits, especially grapes and apples (Cavdaroglu & Ozen, 2022). Production of vinegar occurs by two distinct bioprocess, both of which result from the action of microorganisms, i.e., alcoholic fermentation by the action of yeast, followed by acetic fermentation by the action of acetic bacteria (Öztürk et al., 2022; Vikas Bhat et al., 2014). Furthermore, the categories of production processes may differ between conventional techniques and contemporary approaches. The traditional methods use surface culture, while the more modern methods use industrial fermenters with aeration and submerged culture (Jannah et al., 2020).

Although vinegars are commonly used as condiments, flavorings or food preservatives, recent investigations have shown important bioactive effects of fruit vinegars that can benefit human health (Bakir et al., 2016; Xia et al., 2020), mainly due to their content of organic acids, polyphenols, vitamins and minerals (Hu et al., 2022; Wang et al., 2022). The functional properties described for vinegars include antimicrobial and antioxidant activities, decrease in blood pressure, antidiabetic effect, and prevention of cardiovascular diseases (Ho et al., 2017; Song et al., 2016, 2020; Xia et al., 2020). The functional beverage market is considered a modern niche in which the food industry exerts great influence by disseminating simplified understandings on this subject (O'Hagan, 2023).

More and more scientific studies and technological innovations seek to produce differentiated vinegars from raw materials that are little exploited, aiming at attractive functional and sensory characteristics (Özdemir et al., 2022a). For this reason, exotic and native fruits from different regions of the world have been used in the preparation of vinegars, thus leading to the registration of patents and the publication of scientific articles that describe the main chemical and sensorial characteristics of the new products developed (Özen et al., 2020; Wang et al., 2022; Zhai et al., 2021). The development of new vinegars happens because consumers have become increasingly demanding in relation to food quality (Malheiros et al., 2022).

In the realm of advancing novel products and technologies within the food industry, scientific research stands as an imperative, paralleled by the fundamental necessity of patent filings. These filings serve to safeguard innovations, enabling enterprises to invest in the research and development of groundbreaking products. In this way, both the industry and the consumers benefit from safer, healthier and more innovative foods. Within this context, the goal of this study was to investigate the scientific studies published between 2007 and 2022 and the patents related to fruit vinegars filed between 1938 and 2022, aiming at identifying their potential application and meeting consumer demands. Thus, this study will contribute to the literature by providing a theoretical and empirical view on scientific and technological progress in the field of fruit vinegar.

Material and methods

Scientific prospection

The scientific prospection was carried out in December 2022, using a search in four databases, i.e., Pubmed, Scopus, Springer, and Web of Science. The advanced search consisted of combining keywords ("Vinegar AND Fruits AND Acetic AND Fermented") in titles, abstracts and keyword lists. After that, the types of documents retrieved were screened. Among those documents, the review articles, book chapters, articles published in conferences, and notes were not considered for analysis. The titles and abstracts of the documents retrieved were then read. Thus, only the articles regarding the production and the characterization of vinegars from fruits were selected. Those articles concerning other technologies that addressed the use of acetic fermentation with any objective other than obtaining vinegar were excluded. From the studies retrieved, the main data related to the scientific publication were selected (i.e., year of publication, area of knowledge, affiliation and country of the main author, keywords, raw materials and acetic bacteria used).

Technological prospection

The methodology used for technological prospection consisted of a search for patent documents using the following databases: European Patent Office (Espacenet®), INPI (Brazilian Institute of Industrial Property), Patent Scope, and the United States Patent and Trademark Office (USPTO). The search was carried out in December 2022, using the combination of keywords ("Vinegar AND Fruits AND Acetic AND Fermented") and the International Patent Classification (IPC) code C12J (vinegar; preparation or purification) in order to make the search more representative. Advanced searches were used on all the research platforms.

After the retrieval of the patent documents, all the summaries of the documents were read and, after that, the data were extracted according to strategic topics (annual evolution, geographic distribution, patent holders, and ICP codes). At this stage, two exclusion criteria were applied, i.e., duplicate documents and documents that did not address the preparation of fruit vinegar were excluded.

Subsequently, each patent document was read in full and technical information was collected (application areas, raw materials, microorganisms, and enzymes used), making it possible to establish a profile of the patent documents available.

Results and discussion

Data recovery

According to Table 1S (Supplementary Material), the combination of the keywords "vinegar", "fruits", "acetic", "fermented" and the code C12J were used because of the specificity of the combination used. However, on the INPI platform, the combination that was used did not retrieve any patent documents. In INPI's database, only the keyword "vinegar" was used. The same combination of keywords (without the ICP code C12J) was selected for the scientific prospecting.

The search performed in the four scientific databases by combining the keywords "Vinegar AND Fruits AND Acetic AND Fermented" showed 1,641 articles. However, after applying the exclusion criteria, only 73 scientific articles were selected. Moreover, 379 patent documents were retrieved. Among those documents, 46 duplicate documents and 40 documents which did not address the preparation and/or application of vinegars were excluded. In this way, 293 patent documents were selected to carry out the technological prospection and to make up the profile of the patents.

Scientific prospection

Annual evolution, subject areas and authors' affiliation

Figure 1a shows the annual evolution of scientific articles related to fruit vinegars. The first article that was retrieved in the search is dated 2007. Furthermore, it was noted that in the past three years there has been a gradual and significant increase in the number of articles, where 2022 is the year with the highest number of publications (n = 11). This increase in the number of scientific studies may be related to the ever-growing worldwide consumption of vinegars and foods that have health benefits, as well as to the demand for the development of new products. Moreover, there has also been a higher number of more recent studies that address the development of vinegars made from different raw materials (fruits) and their characterization (Boondaeng et al., 2022; Budak et al., 2022; Özdemir et al., 2022a; Rudra et al., 2022; Zou et al., 2022).

Through the analysis of the most cited keywords, it was possible to identify gaps and trends noted in scientific articles. Thus, the keywords found in the scientific articles are presented in the form of a word cloud (Figure 1b). It was noted that the most mentioned keyword was "phenolic" (n = 31), which shows that the characterization of the phenolic profile of vinegars was evident in the documents retrieved (Fernandes et al., 2019; Kim et al., 2020; Minnaar et al., 2021; Zou et al., 2017), followed by the words "vinegar" (n = 23), "antioxidant activity" (n = 14) and "fermentation" (n = 14). Moreover, it was possible to classify the scientific articles retrieved into subject areas (Table 1), where most studies were attributed to the areas of Agricultural and Biological Sciences (n = 57), and Biochemistry, Genetics and Molecular Biology (n = 34). Studies related to vinegars classified under the area of Agricultural and Biological Sciences focused on the production of new types of vinegars and their chemical, bioactive, and sensory characterization (Minnaar et al., 2021; Özdemir et al., 2022a, b; Siqueira et al., 2021; Zou et al., 2022).

Another parameter assessed was the affiliation (Table 1) (education and/or research institution and private company) of the first authors responsible for the publications. A total of 63 institutions were responsible for the scientific articles retrieved, the main ones being: Jeonbuk National University/Jeonju/South Korea (n = 3), Hefei University of Technology/Hefei/China (n = 3) and Federal University of Lavras/Minas Gerais/Brazil (n = 3). Besides, the 73 main authors were from 22 countries, with China having the highest number of researchers (n = 14), followed by Brazil (n = 7) and South Korea (n = 7).

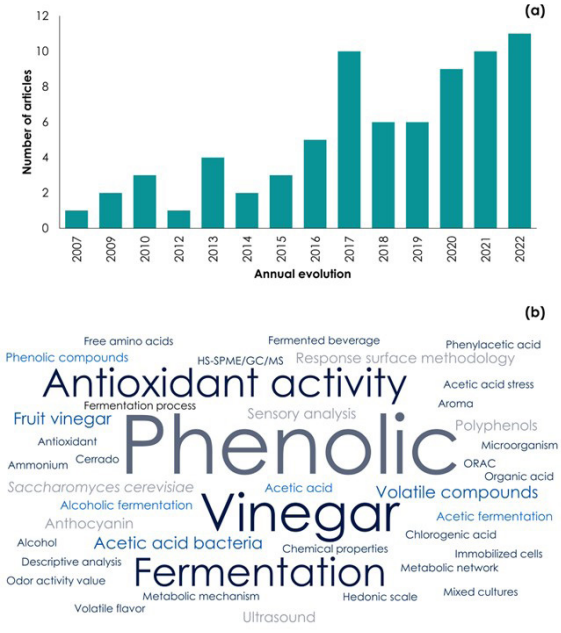


Figure 1. Annual evolution (a) and most cited keywords (b) of scientific articles published in Pubmed, Scopus, Springer, and Web of Science between 2007 and 2022.

Table 1. Main subject areas, affiliations and countries related to publications of scientific articles on fruit vinegars in Pubmed, Scopus, Springer, and Web of Science between 2007 and 2022.

Subejct areas	Number of articles	%
Agricultural and Biological Sciences	57	38.00
Biochemistry, Genetics and Molecular Biology	34	22.67
Nursing	12	8.00
Chemistry	11	7.33
Engineering	8	5.33
Immunology and Microbiology	7	4.67
Pharmacology, Toxicology and Pharmaceuticals	6	4.00
Chemical Engineering	6	4.00
Medicine	5	3.33
Environmental Science	4	2.67
Affiliations*	**Number of articles**	**%**
Jeonbuk National University	3	4.11
Hefei University of Technology	3	4.11
Universidade Federal de Lavras	3	4.11
Kyungpook National University	2	2.74
Rajabhat Maha Sarakham University	2	2.74
Suleyman Demirel University	2	2.74
Universidade Federal de Goiás	2	2.74
University of Cádiz	2	2.74
Agricultural Research Council	1	1.40
Andrzej Frycz Modrzewski Krakow University	1	1.40
Countries*	**Number of articles**	**%**
China	14	19.18
Brazil	7	9.59
South Korea	7	2.74
Turkey	5	6.85
Thailand	5	6.85
Spain	5	6.85
Italy	5	6.85
Korea	4	5.48
Poland	3	4.11
Japan	3	4.11

Footnote: *Affiliation and corresponding country of the first author of the scientific article.

Table 2. Scientific articles published recently (2020 to 2022) on fruit vinegar in the area of Agricultural and Biological Sciences.

Title	Raw material	Goal	Main results	Number of citations	Reference
Volatile aroma compounds and bioactive compounds of hawthorn vinegar produced from hawthorn fruit (*Crataegus tanacetifolia* (Lam.) Pers.	*Crataegus tanacetifolia* (Lam.) Pers.	Produce vinegar from *Crataegus tanacetifolia* (Lam.) Pers, in order to investigate the bioactive compounds and functional properties of this product.	Gallic acid (763.89 mg/L) was the main polyphenol quantified in *Crataegus tanacetifolia* (Lam.) Pers vinegar, followed by chlorogenic acid (534.83 mg/L). In addition, acetic acid (4162.69 µg/100mL) was the main volatile compound.	18	(Özdemir et al., 2022a)
The changes of physicochemical properties, antioxidants, organic, and key volatile compounds associated with the flavor of peach (*Prunus cerasus* L. Batsch) vinegar during the fermentation process	*Prunus cerasus* L. Batsch	Produce vinegar from *Prunus cerasus* L. Batsch, aiming to reveal its antioxidant capacity, organic compounds, volatile compounds. In addition to evaluating the alterations of these compounds during the fermentation process of this product.	Acetic acid (32,553.50 ppm) was the main organic acid present in *Prunus cerasus* L. Batsch vinegar. Among the predominant volatile compounds in the formation of aroma, ɣ-decalactone, phenylacetic acid, acetic acid, phenethyl-acetate and isovaleric acid stand out.	7	(Budak et al., 2022)

Table 2. Continued...

Title	Raw material	Goal	Main results	Number of citations	Reference
Anthocyanin-rich fruit vinegar from Grewia and Cantaloupe fruit blends	*Grewia asiatica* L. and *Curcumis melo*	Develop and characterize *Grewia asiatica* L. and *Curcumis melo* vinegar and model the kinetics of microbial growth and functional compounds during the fermentation process.	Vinegar made with 60% *Grewia asiatica* L. resulted in a high acetic acid content and greater retention of functional components.	1	(Rudra et al., 2022)
Phytochemical content, and antioxidant activity, and volatile compounds associated with the aromatic property, of the vinegar produced from rosehip fruit (*Rosa canina* L.)	*Rosa canina* L.	Investigate the physicochemical properties, phytochemical content, antioxidant activity and volatile compounds of vinegar from *Rosa canina* L.	Twenty-seven volatile compounds were identified in *Rosa canina* L. vinegar, where acetic acid (7,781.12 µg/100mL) was the major compound. Moreover, this vinegar showed a high content of phenolic compounds, especially catechin (5.66 mg/L).	18	(Özdemir et al., 2022c)
Comparison of the Chemical Properties of Pineapple Vinegar and Mixed Pineapple and Dragon Fruit Vinegar	*Ananas comosus* L. and *Hylocereus polyrhizus*	Develop vinegar from *Ananas comosus* L. and *Hylocereus polyrhizus* juice to create unique flavor combinations and increase their antioxidant activity.	The vinegar made with *Ananas comosus* L. juice and peeled *Hylocereus polyrhizus* showed an acetic acid content of up to 6.20%. Besides, the mixed vinegar made from *Ananas comosus* L and unpeeled *Hylocereus polyrhizus* juice showed a high antioxidant capacity (210.74 µg/g TE).	1	(Boondaeng et al., 2022)
Effect of alcoholic and acetous fermentations on the phenolic acids of Kei-apple (*Dovyalis caffra* L.) fruit	*Dovyalis caffra* L.	Investigate the effect of alcoholic and acetic fermentation on the composition of phenolic acids and on the physicochemical characteristics of *Dovyalis caffra* L. juice.	There were changes in the concentrations of phenolic acids and in the physicochemical characteristics of *Dovyalis caffra* L. juice subjected to alcoholic and acetic fermentation using different combinations of yeast and acetic bacteria.	3	(Minnaar et al., 2021)
An efficient method using ultrasound to accelerate aging in crabapple (*Malus asiatica*) vinegar produced from fresh fruit and its influencing mechanism investigation	*Malus asiatica*	Investigate the effect of ultrasound on the acceleration of aging of *Malus asiatica* vinegar.	The use of ultrasound in the aging of *Malus asiatica* cider vinegar proved to be a promising alternative for reduction of aging time.	10	(Zhai et al., 2021)
Elaboration of mangaba vinegar by semi-solid fermentation combined with enzymatic activity: chemical characterization and sensory evaluation	*Hancornia speciosa* Gomes	Produce vinegar from the pulp of *Hancornia speciosa* Gomes by semi-solid alcoholic fermentation with enzymatic action (pectinase), and to investigate the chemical composition and sensory evaluation of this product.	The study showed that fermentation of *Hancornia speciosa* Gomes pulp combined with enzymatic treatment resulted in high yields in alcohol content and acetic acid oxidation. In addition, it showed significant levels of total phenolic compounds (19.20 mg/100g) and total carotenoids (2.60 mg/100g).	0	(Siqueira et al., 2021)
Organic production of vinegar from mango and papaya	*Mangifera indica* and *Carica papaya*	Establish a protocol for processing *Mangifera indica* and *Carica papaya* from Côte d'Ivoire into fermented products such as wine and vinegar.	The vinegars that were prepared showed significant levels of organic acids, especially acetic acid (53.44 and 54.53g/L, for *Mangifera indica* and *Carica papaya* vinegars, respectively).	5	(Bouatenin et al., 2020)
Production and characteristics of high quality vinegar from *Cornus officinalis* produced by a two-stage fermentative process	*Cornus officinalis*	Produce high quality vinegar from fresh *Cornus officinalis* fruits, using a two-stage fermentation process, and evaluate the effect of this vinegar on the microbial environment of mice gut.	*Cornus officinalis* vinegar preserved morroniside (1,139.50 g/mL) and loganine (779.34 g/mL). In addition, mice treated with *Cornus officinalis* vinegar showed a significant reduction in the amounts of *Clostridia* and *Firmicutes* in their intestinal tracts.	2	(Chen et al., 2015)

Raw materials

The creation of fruit-based vinegars stands as a merging scientific and marketing phenomenon. Fruits, boasting abundant sugar content and a propensity for fermentation, establish themselves as prime elemental sources in the crafting of acetic fermentation commodities (Cantadori et al., 2022). Moreover, acetic fermentation of fruits can contribute to the formation of bioactive compounds, thus increasing the functional properties of vinegar (Budak et al., 2022).

In the scientific articles retrieved, a diversity of 62 types of fruit was noted. The main fruit mentioned in the studies was apples (*Malus domestica*) (n = 8). This is related to the fact that apples are traditionally one of the main raw materials used in the production of vinegar that are made from commercial fruits (Xia et al., 2020). Apples stand out in the food industry since their juice can be used in different technological processes, particularly in the production of cider and vinegar (Costa et al., 2022). Moreover, it is estimated that the global apple cider vinegar market will generate 1.1 billion dollars in 2027 (Global Industry Analysts, 2022).

However, other fruits also stood out, such as persimmons (*Diospyros kaki*) (n = 6), grapes (*Vitis* spp.) (n = 6), pineapples (*Ananas comosus* (L.) Merr.) (n = 5), cherries (*Prunus* spp.) (n = 4) and mangoes (*Mangifera indica*) (n = 4), thus showing the potential of using different fruits, with different characteristics, for the preparation of vinegar. Furthermore, the studies retrieved used unconventional fruits, such as rosehip (n = 3), cashew from the Brazilian Cerrado (*Anacardium othonianum* Rizzini) (n = 1), jabuticaba (*Myrciaria jaboticaba* Berg.) (n = 1), cornelia cherry (*Cornus mas* L.) (n = 1), mangaba (*Hancornia speciosa* Gomes) (n = 1) and rambutan (*Nephelium lappaceum*) (n = 1). These results show that there is a great demand for the development of products made with regional raw materials from different parts of the world, especially native and/or exotic fruits, which, despite still being little exploited commercially, have promoted the advance in scientific knowledge about their potential for application in different products, including fermented products, such as vinegar.

Acetic acid bacteria

Acetic fermentation consists of the oxidation of ethanol into acetic acid caused by acetic acid bacteria (AAB), especially bacteria of the genera *Acetobacter* and *Gluconobacter* (Gullo et al., 2014). The main genus of AAB used in the scientific articles was the *Acetobacter* (n = 37), especially of the species *Acetobacter aceti* (n = 13) and *Acetobacter pasteurianus* (n = 13). Besides, many studies used commercial vinegars as their starter cultures, which predominantly have *Acetobacter* strains (Bouatenin et al., 2020; Budak et al., 2022; Özdemir et al., 2022a, b; Siqueira et al., 2021). Other genera, such as *Gluconobacter* (n = 5) and *Komagataeibacter* (n = 2), were mentioned less frequently. One example is the study carried out by Ma et al. (2021), where the authors reported the feasibility of using pear pomace in the production of vinegar and in the obtainment of bacterial cellulose, and through which those authors selected the strains *Komagataeibacter rhaeticus* M12 and *Komagataeibacter intermedius*.

Recent research studies on the characterization of fruit vinegars (2020 – 2022)

Aiming to evaluate the focus of the most recent studies in the field of Agricultural and Biological Sciences retrieved in the search, an investigation was carried out in the articles that were published between 2020 and 2022 (Table 2). Among those articles, the most recent ones addressed the preparation of *Crataegus tanacetifolia* (Lam.) Pers. vinegar and evaluated its bioactive and volatile characteristics. The study revealed that sea buckthorn vinegar is a source of organic acids, in particular acetic acid (39.65 g/L), and of polyphenols such as gallic acid (763.89 mg/L) (Özdemir et al., 2022a). On the other hand, in the vinegar made with fruits of *Dovyalis caffra* L., the predominant polyphenol was chlorogenic acid, which showed mean values between 1,910.98 and 1,958.75 mg/L (Minnaar et al., 2021). In addition, Özdemir et al. (2022a) reported that the major polyphenol found in vinegar made from fruits of *Rosa canina* L. was catechin (5.66 mg/L). Given this scenario, it is possible to note that raw material plays a key role in the phenolic composition of vinegars.

The composition of organic acids present in vinegar plays a key role in understanding its chemical and sensory characteristics. Because of the fermentative characteristics of vinegar, acetic acid is the predominant organic acid (Bouatenin et al., 2020; Budak et al., 2022; Özdemir et al., 2022a). However, other organic acids have been reported, such as citric acid in hawthorn vinegar (8.31 g/L) (Özdemir et al., 2022a) and lactic acid in peach vinegar (2,167.90 ppm) (Budak et al., 2022) and in mango vinegar (89.80 g/L) (Bouatenin et al., 2020). This fact has also been reported by other authors, since these acids may originate not only from the fermentation process of vinegar, but also from the spontaneous fermentations and metabolism of lactic acid bacteria and yeasts of the raw materials used (Nie et al., 2013, 2017).

The characteristic aroma of vinegar is attributed to the presence of acetic acid; however, other compounds are formed during the acetic fermentation process, which results in the sensory characteristics of vinegars. In view of this, studies have investigated the volatile composition of vinegars made from various raw materials to assess their impact on the chemical and sensory properties of the products. Özdemir et al. (2022c) observed that vinegar made from fruits of *Rosa canina* L. had a high concentration of acids, ketones, terpenes, alcohols, esters, phenols, aldehydes and lactones, with emphasis on acetic acid (7,781.12 µg/100mL), acetoin (1446.14 µg/100mL), pentanoic acid (1296.50 µg/100mL), propionic acid (665.20 µg/100mL) and octanoic acid (603.89 µg/100mL). Budak et al. (2022) reported that peach vinegar showed high concentrations of acids (68%), alcohols (10%) and esters (8%). However, regarding hawthorn vinegar, 37 volatile compounds were mentioned. Those volatile compounds were mainly formed by acids (75.19%), ketones (9.14%) and alcohols (7.78%) (Özdemir et al., 2022a).

Among the most recent studies from those retrieved, the use of different technologies to improve the characteristics of vinegars was noted, as in the study carried out by Zhai et al. (2021), who used ultrasound as a technique to reduce the time of maturation of apple cider vinegar, resulting in products with satisfactory sensory quality. Another example was the study conducted by Siqueira et al. (2021), in which the

enzymatic treatment of the pulp of mangaba, a fruit native to the Northeast Region of Brazil, was carried out for the preparation of vinegar, and the final product showed high antioxidant capacity and good sensory acceptance.

Technological prospection

Annual evolution, geographic distribution, and patent holders

Figure 2a shows the annual evolution of patent filings related to vinegar production technology. Despite being an old technology, the earliest documents retrieved were of patents that had been published in 1938 and another in 1940. Those two documents addressed generic methodologies for the production of fruit vinegars (Hans, 1938, 1940), and were both filed by the same inventor.

It is possible to note that there is a time gap in the number of documents filed, and that the more recent patent documents that were retrieved in this study are from 1986 onwards. The patent document that was published in 1986 addressed the preparation of vinegars made from flowers, leaves, roots, fruits or vegetable seeds (JPS61254180A) (Tomohiko, 1986).

Although it is possible to note that there is a wide variation in the number of patent documents published, from the year 2010 onwards there has been an increase in the number of publications. The highest number of publications was noted in 2018 (n = 44). This fact coincides with studies that report that in the past 20 years there has been an increase in vinegar consumption, especially due to its potential health benefits (Shishehbor et al., 2017).

Observations indicate a decline in the number of patent filings from 2019 to the present. Nonetheless, this decline does not necessarily reflect a lack of inventiveness in this domain, given that there exists an average period of 18 months between patent document submission and publication (Severo et al., 2021). Moreover, patent activities from the year 2020 may have been affected due to the COVID-19 pandemic.

The countries that hold patent documents are those in which the technology was invented. Through the geographical distribution of the patent-holding countries, it is possible to see the dissemination and development of technologies worldwide. Thus, the countries holding patent documents related to vinegar are shown in Figure 2b. China tops the ranking of the main patent-holding countries, with a total of 231 patent documents related to vinegar. Such number of patent documents may be due to the high daily consumption of vinegar in the country, which is of over three million liters (Ho et al., 2017). A prospective study carried out by Santos et al. (2021) on fermented fruit wines also noted that China was the country with the highest number of patent documents, accounting for 93.7% of the patent documents found among all the countries investigated in that study.

The issuance of a patent signifies that the corresponding document meets the criteria for patentability (novelty, non-obviousness, possible industrial application, and usefulness) (Aydogmus, 2022; Deconinck et al., 2018). At the time of conducting this current study, China had been granted 37 patents, followed by the Republic of Korea with a total of 17 patents granted. These data can be justified by the 2020 Global Innovation Index, in which China occupied the sixth position (WIPO, 2020b). On the other hand, the Republic of Korea, was in the 10th position among the 131 economies evaluated (WIPO, 2020c).

Although Brazil places third in the ranking of countries holding patent documents related to vinegar (n = 7), it is possible to note that Brazilians tend to invest in the protection of their technologies only in Brazil since no Brazilian technologies were found in the search carried out in the Espacenet®, Patent Scope and USPTO databases. According to the Global Innovation Index, in 2020 Brazil ranked 64th overall among the 131 economies featured in the GII 2020, with better performance in innovation inputs (59th position) than in innovation outputs (64th position) (WIPO, 2020a). However, among the seven Brazilian patent documents published, only one patent was granted. This patent document is related to the production of fermented jamelon products, particularly jamelon vinegar (Pereira, 1999).

The holders responsible for the published patent documents related to fruit vinegar are distributed in different sectors of society, such as private companies, individuals, and educational and research institutions. A patent document can have more than one holder, and thus 355 patent holders were found in the patent documents retrieved. Private companies hold the largest number of patent documents (40.30%), followed by individuals (38.80%) and educational and research institutions (20.90%) (Figure 2c). This scenario was also noted by Otero et al. (2022), who reported that most patent documents were owned by private companies, followed by individuals and public institutions.

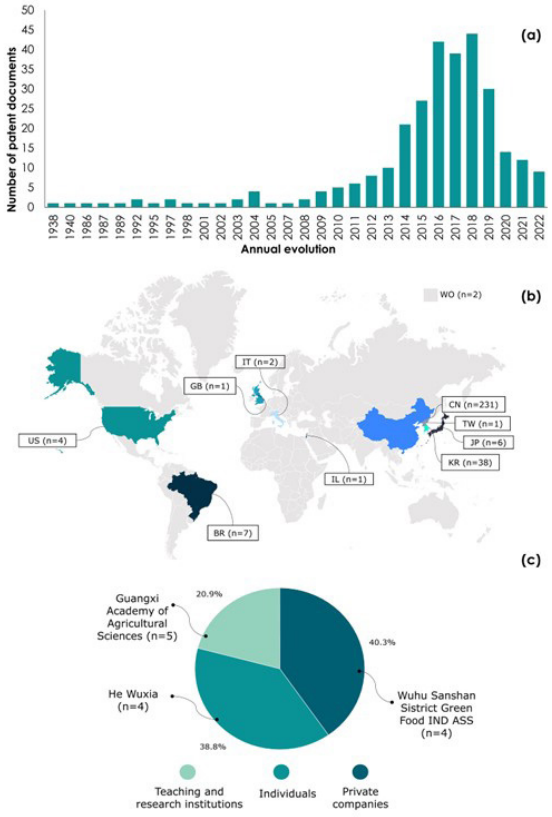


Figure 2. Annual evolution (a), patent-holding countries (b), and holders (c) of patent documents related to fruit vinegars published in the databases Espacenet®, INPI, Patent Scope and USPTO between 1938 and 2022. Footnote: CN: China; KR: Republic of Korea; JP: Japan; IL: Israel; IT: Italy; BR: Brazil; WO: World Intellectual Property Organization; US: United States of America; UK: United Kingdom.

In this present study, it was noted that the company Wuhu Sanshan Sistrict Green Food IND ASS (China) was the main holder of patent documents in its category (n = 4). The Wuhu Sanshan District Green Food IND ASS has an industrial focus on the production of food, beverages and pharmaceuticals, with a technological focus on the production of food, coffee, wine, cocoa, vinegar, pharmaceuticals, therapeutic compounds, among others. Currently, the company has a total of 266 patent documents filed in China (GoodIP IQ, 2023).

Regarding the educational and research institutions, the Guangxi Academy of Agricultural Sciences stands out (n = 5). The Guangxi Academy of Agricultural Sciences is a Chinese research center focused on studies related to horticulture, vegetables, cash crops, biotechnology, plant protection, and viticulture, among other fields of research (GFAR, 2023) and is also responsible for the publication of four scientific articles related to vinegar production (Chen et al., 2015, 2020; Li et al., 2020a, b)

International patent classification

During patenting activities, the International Patent Classification (IPC) system is used to categorize documents in different technological fields according to their technological function (Otero et al., 2022). Two hundred and two IPC codes were found in the patent documents retrieved in the search in the databases Espacenet®, INPI, Patent Scope and USPTO. Among those codes, the most relevant ones are related to sections: A (Human needs) (n = 149) and C (Chemistry; metallurgy) (n = 53). Figure 3 shows the main IPC codes. It is noteworthy that patent documents may have more than one IPC code. In view of this, the frequency of IPC codes (n = 1,063) is higher than the total number of patent documents (n = 293).

The analysis of the patent documents showed that code C12J1/04 (Vinegar; its preparation or purification; made from alcohol) was the most frequent code found (n = 188), followed by code C12J1/00 (Vinegar; its preparation or purification) (n = 97).

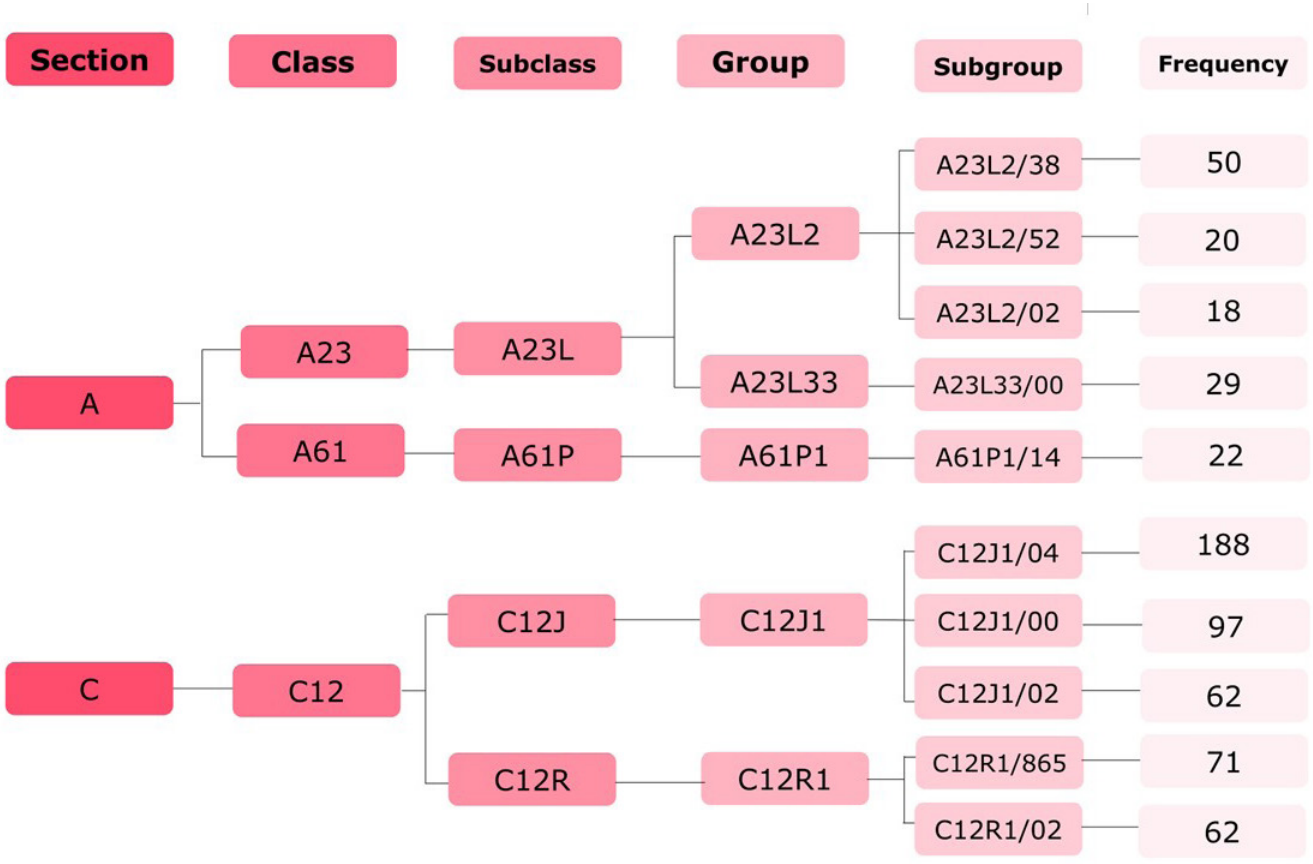


Figure 3. The main IPC codes noted in the patent documents on fruit vinegar retrieved from the databases Espacenet®, INPI, Patent Scope, and USPTO between 1938 and 2022. Footnote: A: human needs; C: Chemistry; metallurgy; A23: Food or food products; their improvement, not included in other classes; A61: medical or veterinary science; hygiene; C12: Biochemistry; beer; alcohol; wine; vinegar; microbiology; enzymology; genetic or mutational engineering; A23L: Food, food products or non-alcoholic beverages; their preparation or treatment; conservation of food or of food products in general; A61P: Specific therapeutic activity of chemical compounds or of medicinal preparations; C12J: Vinegar; its preparation or purification; C12R: Referring to microorganisms; A23L2: Non-alcoholic beverages; dry compositions or concentrates thereof; their preparations; A23L33: changes in the nutritional qualities of foods; dietetic products; their preparation or treatment; A61P1: Pharmaceuticals for the treatment of disorders of the alimentary tract or digestive system; C12J1: Vinegar; its preparation or purification; C12R1: microorganisms; A23L2/38: Other non-alcoholic beverages; A23L2/52: Addition of ingredients; A23L2/02: Containing fruit or vegetable juices; A23L33/00: changes in the nutritional qualities of foods; dietetic products; their preparation or treatment; A61P1/14: Digestion aids; C12J1/04: made from alcohol; C12J1/00: vinegar; its preparation or purification; C12J1/02: made from wine; C12R1/865: Saccharomyces cerevisiae; C12R1/02: Acetobacter.

Some codes are related to the process of making vinegar, such as code C12J1/02 (from wine) (n = 62), since vinegar is obtained through the acetic fermentation of fruit wines. Moreover, there are two ICP codes related to the microorganisms used in vinegar production. The first one is code C12R1/865 (n = 71), which refers to the yeast *Saccharomyces cerevisiae*. This type of microorganisms is used in the alcoholic fermentation stage of the vinegar production process. However, the other ICP code that was frequently found is C12R1/02 (n = 62) (*Acetobacter*), which refers to the *Acetobacter* bacteria used in the acetic fermentation step of the process (Ho et al., 2017).

Profile of patents related to the production of fruit vinegars

Patent documents referring to vinegar production technologies were related to three major areas: foods (n = 272); biotechnology (n = 12) and; pharmaceuticals (n=9). The area of foods is the most expressive one, and the improvement in the protection of these technologies is in line with the scientific advancement in this field. According to Ho et al. (2017), vinegar has been consumed for over 10,000 years, and its utilization for therapeutic benefits has been reported on multiple occasions. In view of this, the pharmaceutical industry has shown interest in protecting these technologies in relation to the beneficial health properties derived from this food. Furthermore, in vivo studies have recently been carried out to evaluate the effectiveness of physiological activities related to vinegar consumption (Chou et al., 2015; Mitrou et al., 2015; Xia et al., 2019, 2021). Documents related to the area of biotechnology addressed the application of different strains of acetic acid bacteria in order to improve the sensory and fermentative characteristics of vinegar.

During the screening of the documents, it was noted that the production methods involve one or more raw materials. In all, 12 categories of raw materials were noted (fruits; cereals and/or grains; plants and/or medicinal plants; flowers; vegetables; fungi; herbs; roots and/or tubers and/or bulbs; legumes; spices; leaves; and vegetables). Thus, a total of 235 raw materials were mentioned.

Among the most cited fruits, the sea buckthorn (n = 34) was the one that was most frequently mentioned. Sea buckthorn (*Hippophae rhamnoides* L.) fruits have been domesticated all over the world; however, their production is widely distributed in the higher altitude regions of Asia and northwest Europe. Besides, these berries are rich in bioactive substances of nutritional importance, such as phenolic acids, ascorbic acid, and carotenoids (Ciesarová et al., 2020).

Traditionally, the most produced and consumed vinegars are fruit vinegars, with grapes and apples being the fruits that are mostly used in the preparation of commercial vinegars (Özen et al., 2020; Xia et al., 2020). It was noted that apples (n = 28) and grapes (n = 28) were representative in the patent documents found. Even so, fruits that are not conventionally found in the formulations of commercial vinegars were also found in the patent documents, showing that there is a demand for technologies related to the production of vinegars from different fruits. According to Chanivet et al. (2020), the food industry seeks to offer products with improved sensory characteristics to satisfy the interest of consumers. Therefore, the industry has tried to make vinegar from the juice, pulp, and other edible parts of the fruit that are underutilized.

Contrary to what was noted in the scientific studies, most inventions reported in the patent documents used enzymatic treatment in the pre-fermentation stage because, during the vinegar production process, enzymes can be used in the alcoholic fermentation of the fruits and also contribute to the extraction of different chemical compounds from the fruits (Guo et al., 2018; Jiang et al., 2020). Besides, the use of enzymatic treatment results in a better clarification of the musts (Martín et al., 2020). Thus, Figure 4a shows the main enzymes noted in the patent documents. The use of enzymes was reported 188 times in the documents retrieved, especially pectinase (n = 94) and cellulase (n = 41), and the use of these enzymes, either combined or isolated, is a recurring practice in the preparation of vinegars (Roda et al., 2014; Takahashi et al., 2011). According to Shrestha et al. (2021), pectinase represents 25% of the world enzyme market, since and its use in the preparation of alcoholic fermented products, such as wine, has been reported for over 200 years. Pectinase is an enzyme responsible for hydrolyzing pectic substances, thereby breaking down the pectin complex into D-galacturonic acids (Ahmed et al., 2021), and its production can have different origins. However, the production of pectinase of microbial origin shows the best productivity rates (John et al., 2020). Thus, pectinase is considered an important biocatalyst for the biotechnology industry, as it is widely used for clarifying beverages, extracting antioxidants, and supporting fermentations (Zhang et al., 2021).

During the screening of the documents, it was noted that most of them did not specify the AAB strain that was used. Therefore, “acetic acid bacteria” or “acetic fermentation stage” were mentioned in many patent documents. In addition, it was noted that in 19 patent documents they used unpasteurized vinegar that contained mother of vinegar to promote acetic fermentation. A mother of vinegar is nothing more than a film composed of AAB and cellulose, which is formed during the vinegar preparation process, and this film is later used as a starter culture in the acetic fermentation stage in the production of traditional vinegars (Yetiman & Kesmen, 2015). According to Qin et al. (2022), microbial strains of *Acetobacter* are often used in vinegar formulations because of the efficient conversion of ethanol into acetic acid and their high resistance to the medium. In addition to bacteria of the genus *Acetobacter* (n = 61), strains of the genus *Gluconobacter* (n = 7) were also mentioned, and the most cited species are specified in Figure 4b.

Challenges and prospects in the global fruit vinegar market

The vinegar production sector is a well-established market in the food industry because, besides being used as a seasoning, it is widely used in the preservation of fruits and vegetables, and also in the preparation of mayonnaise, ketchup and salad dressings (Perumpuli & Dilrukshi, 2022). Among economically significant vinegars, notable varieties include: apple cider vinegar (Ameur & Heleili, 2022), balsamic vinegar (Liu et al., 2022), sherry vinegar (Jiménez-Sánchez et al., 2020), rice vinegar (Taweekasemsombut et al., 2021) and vinegar from fruits in general (Perumpuli & Dilrukshi, 2022).

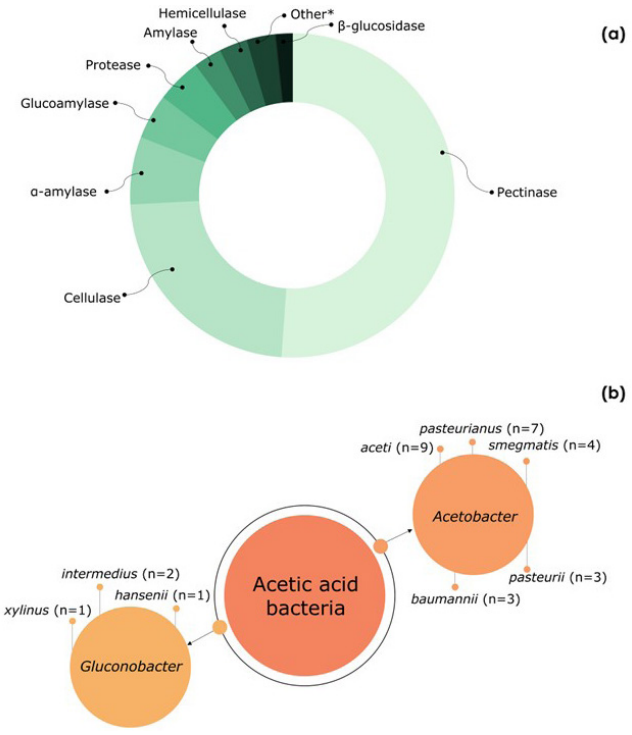


Figure 4. Main enzymes (a), and acetic acid bacteria (b) noted in vinegar patent documents retrieved from the databases Espacenet®, INPI, Patent Scope, and USPTO between 1938 and 2022. Footnote: *Other: amyloglucosidase; lipase; papain.

However, it is noted that there is a demand for the diversification of vinegars made from unconventional raw materials, particularly native and exotic fruits, often underutilized despite their important nutritional and sensory characteristics. However, it is necessary to carry out studies to assess the viability and the technological limitations of these raw materials. Therefore, research studies in this field are of great value, since studies regarding unconventional raw materials promote the development of processed products, thus increasing the chain of commercialization of vinegar, besides contributing to the preservation and enhancement of these species.

Conclusions

Through the mapping of scientific studies, it was possible to note that research studies have sought a diversification of acetic fermentation products. Despite the increase in studies related to fruit vinegar, there is still a large knowledge gap for studies regarding new production methodologies, as well as the use of different raw materials and fermentation processes to obtain products with greater added value and chemical and sensory quality. Moreover, it is necessary to scientifically prove the functional properties attributed to vinegar.

Furthermore, in the past decade, there has been an evident increase in the number of filings of patent documents and in the publication of scientific studies related to the preparation of vinegars. It was possible to note that China is the country that mostly stands out in relation to the development and protection of technologies related to fruit vinegars, since independent inventors venture on the diversification of raw materials for the development of new products.

Through the search carried out in the patent databases, it was possible to note that most of the documents addressed the methodology, development and production of fruit vinegars. Although grapes and apples are fruits that are traditionally used in the process of making acetic fermentation products, exotic/native fruits have increasingly gained visibility.

Conflict of interests

The author declares that there is no conflict of interest.

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Supplementary Material

Supplementary material accompanies this paper.
Table 1S - Combination of keywords used on different platforms for scientific and technological prospection.
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