Biotechnology Research and Innovation, 2024, 8(1): e2024021. https://doi.org/10.4322/biori.00212023

Biotechnology Research & Innovation

www.biori.periodikos.com.br

REVIEW ARTICLES

Low-alcohol fruit wines: A bibliometric analysis, technological review, and market perspectives

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Highlights

- The number of articles and patents on low-alcohol fruit wines has grown in the last years.
- Prominent countries in the research field were identified.
- The evolution of this technology, over the years, were revealed.
- The main unconventional fruits used recently were explored.

Received: 9 November 2023. Accepted: 9 April 2024

KEYWORDS
Alcoholic fermentation; Innovation; Non-*Saccharomyces*; Technological prospection.

Abstract: Production of low-alcohol fruit wines can be a viable alternative for using different fruit species, besides offering healthier options to consumers. Thus, this work aimed to survey scientific articles and patent documents regarding the production of low-alcohol fruit wines. The search for articles was performed on the Scopus platform, whereas the patent search was performed on Espacenet®. Both searches were performed using the combination of the words "low-alcohol" AND "fruit" AND "wine", which showed 404 articles and 420 patents, respectively. However, only 52 and 101 documents were selected for formal analysis, respectively. The annual evolution of articles and patents shows an increase in interest in this research area, with 28 articles and 30 patents published since 2018. The bibliometric analysis showed that most articles are published in the Agriculture and Biological Sciences research area. China stood out as the leading affiliation country of the article's authors (n = 20) and with the most significant number of patents (n = 87). The use of non-*Saccharomyces* yeast strains appears as the primary emergent technology, as well as the utilization of nonconventional fruit for the fermentation, such as sea buckthorn, pomegranate, and blackberry. It was possible to note a more expressive growth in the production of low-alcohol wines in the past decades, which shows that this technology has become more promising for the exploitation and valorization of fruits, especially native and exotic ones.

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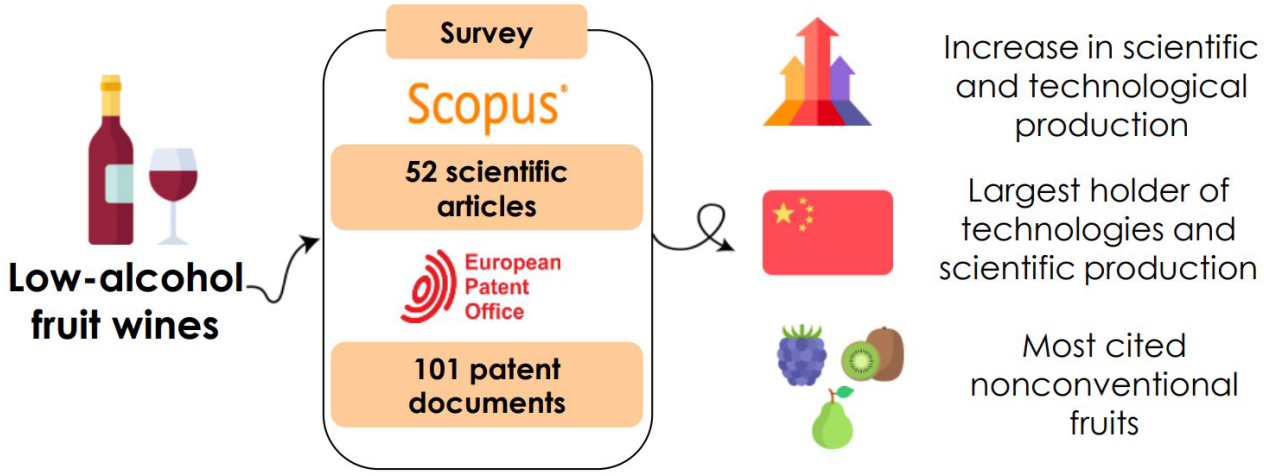
Graphical abstract



Introduction

Over the years, world fruit production has shown continual growth. According to the Food and Agriculture Organization of the United Nations (FAO), between 2000 and 2019, this production increased by 54% (Food and Agriculture Organization of the United Nations, 2021). China leads the world ranking of fruit-producing countries, with a production of more than 250 thousand tons in 2021, followed by India, with a production of more than 100 thousand tons, and Brazil with a production of almost 40 thousand tons (Shahbandeh, 2021). Given this scenario, it is possible to note that there is a large market for fruit processing and development of new products, where the use of fermentation processes can contribute to the diversification of products obtained from fruits, thereby promoting the preservation of their species and increasing their added value.

For the preparation of an alcoholic fermented product, it is possible to use many different fruit species, thus resulting in a wide variety of products with different chemical and sensory characteristics. From a technological point of view, the main condition for alcoholic fermentation to occur is related to the amount of sugar present in the fruit. This sugar generates ethanol during the fermentation process, which is caused by the metabolism of yeasts. However, the chemical composition of each fruit depends on its species and maturation stage, among other factors that also directly affect ethanol production (Boeira et al., 2020). The most commercially known fruit fermentation products are wine and cider, which are made from grapes and apples, respectively. Moreover, since the utilization of nonconventional fruits for the production of wines is still incipient, using these fruits as a source of raw materials may add value to them, especially because of their chemical composition and their potential benefits to human health (Lopes et al., 2019). Although the consumption of alcoholic beverages is common worldwide and is influenced by several socioeconomic and cultural factors, in recent years there has been an increase in consumer interest in beverages with low alcohol content and/or with no alcohol at all (zero alcohol) (Liguori et al., 2018). This is due to several factors, including concern about the harm that is caused to human health by high consumption of ethanol besides issues related to specific conditions, such as cardiovascular disease, obesity, religion, and pregnancy, among others (Fuchs & Fuchs, 2021).

The present work sought to investigate the scientific literature published in the low-alcohol fruit wines niche through a bibliometric analysis to comprehend the scenario of the proposed subject and guide the development of new products and technologies in the sector. Through bibliometrics it is possible to identify the research tendencies, the knowledge gaps, the state of the art, and the research areas besides the principal authors, countries, and institutions. Moreover, this study also realized a prospective analysis of the technological sector of the low-alcohol fruit wine industry production through information collected from patent documents.

Low-alcohol fruit wines

According to the International Wine and Spirit Research (2022), the production of low-alcohol and zero-alcohol beverages represents a 3.5% share of the entire beverage industry. The market niche for this type of beverage showed a growth rate of over 6% in consumption in 2021 in the top 10 global markets (Australia, Brazil, Canada, France, Germany, Japan, South Africa, Spain, United Kingdom, and United States), reaching a market value of approximately 10 billion USD, with Germany and Spain leading the production of these beverages.

In general, non-alcoholic fruit wines, also known as zero-alcohol fruit wines, are those that contain less than 0.5% alcohol in their composition. On the other hand, low-alcohol fruit wines are typically those whose alcoholic strength is between 1 and 7% (v/v) (Huang et al., 2022a). However, there is still no global consensus on the use of the terms “low-alcohol fermented beverage” or “low-alcohol fruit wine”. Both of these terms are subject to variations in the

regulations of different countries, some of which lack more detailed information.

Moreover, it is possible to note that investigations into low-alcohol fruit wine are focused on controlled fermentation processes and on fermentation interruption, as well as on beverage dealcoholization processes that use reverse osmosis, evaporative osmosis, or vacuum distillation technologies. Current studies have mainly investigated the use of different fermentative yeasts in search of lower ethanol conversion rates (Huang et al., 2022a). In addition, carrying out spontaneous fermentations by using the microorganisms naturally present in the must has been explored and proven to be effective in the production of low-alcohol beverages. A strategy that is also widely used to produce low-alcohol fruit wines is the use of fruit species that have low total soluble solids content, with which the fermentation is performed only with the sugars naturally present in the fruit and without chaptalization of the must. This method results in low alcoholic content, besides significantly reducing fermentation time in comparison with the traditional production methods (Yang et al., 2021).

Material and methods

For the bibliometric analysis, the data was collected in June 2023 in Scopus through the advanced search limiting the document type to research articles only and using keywords and Boolean operators' combination ("low-alcohol" AND "fruit" AND "wine") in all search fields. Four hundred and four research articles were found and their data were exported as a spreadsheet to Microsoft Office Excel version 2019. The documents were then filtered after their respective abstracts had been read. The presence of the term "low-alcohol" in the title, abstract, or keywords was established as the selection criterion, which resulted in 52 documents to be analyzed. The data of the selected articles were exported to the Bibliometrix (R language) (Aria & Cuccurullo, 2017) to realize the bibliometric analysis through the annual evolution of the publications, the research areas, the main keywords, and the most influential authors, journals, and countries.

The technological prospection was performed in June 2023, and the search for patent documents was conducted in the international database European Patent Office (Espacenet®), which covers patents filed in over 90 countries. A survey of the highest possible number of documents related to the topic of interest on Espacenet® was performed using the Advanced Search tool, where the same scientific search terms were typed in the "title", "abstract", and "claims" fields. The criteria used for selecting the patents were: the presence of the words "low-alcohol" in any one of the search fields and the mention of the alcoholic strength of the beverages. The 420 documents found on Espacenet® were exported as a spreadsheet to Microsoft Office Excel. After the summaries and descriptions (when available) of all the documents had been read, 312 of them were excluded from the study because they either were duplicates or did not meet the inclusion criteria, thus remaining 101 documents at the end of the investigation.

Results and discussion

Annual evolution of articles and patents

The annual evolution of publications of scientific articles and patents related to low-alcohol fruit wines is shown in Figure 1. The main difference to be noted is the higher number of patents in relation to the number of scientific articles. Furthermore, while the first patent was published in 1973, the first article on these subject dates from 1998. This finding shows a hiatus of 25 years, during which only six patent documents were published.

It is possible to note that the first two articles on the subject are from the late 1990s (1998 and 1999), with a gradual increase in publications from 2010 onwards. Figure 1 shows a significant number of articles published in 2020 (n = 11), probably due to the growing concern of the population in recent years, which has led to the consumption of healthier beverages and thus stimulated research on this subject. On the other hand, in 2021 the number of publications was smaller. This result can be explained by the impacts of the COVID-19 pandemic on the field of scientific production worldwide. As for the patents, they also showed a significant increase from 2010 onwards, which may be related to the advancement of technologies used in the production of beverages, which has consequently drawn the attention of many sectors of society regarding the development and protection of technologies that involve low-alcohol fruit beverages. In addition, the warning released by the World Health Organization in 2010, through a resolution that addressed global strategies to reduce excessive alcohol consumption (World Health Organization, 2010), may have had great influence on this increase. Nevertheless, the difference in the number of patents compared to scientific publications may be related to the fact that alcoholic fermentation technology is already widespread in the beverage industry, which facilitates the invention of new products in this field. On the other hand, scientific research is mainly aimed at characterizing these products and evaluating their potential health benefits, which is a topic that has currently gained more and more attention.

Bibliometric analysis

Research areas, journals, affiliations, and authors

From the number of selected articles, it was observed that the research with low-alcohol fruit wines is an increasing

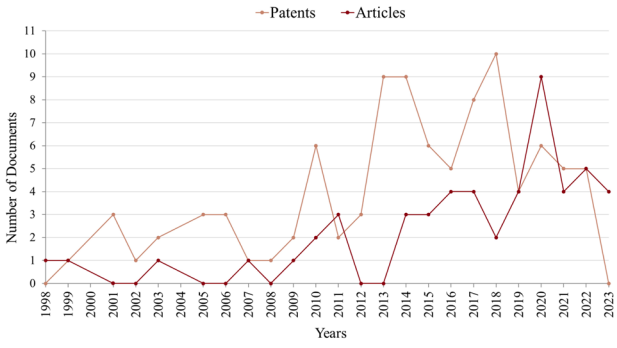


Figure 1. Annual evolution of scientific articles and patent documents for low-alcohol fruit wines.

area. Table 1 shows the ranking of the 10 main research areas, journals, affiliations, and articles authors in low-alcohol fruit wines.

From the 52 articles investigated, the vast majority were published on the subject of Agriculture and Biological Sciences (n = 45). The other related subjects were Biochemistry, Genetics and Molecular Biology, Immunology and Microbiology, and Chemistry. The journals that stood out in publishing articles in the low-alcohol fruit wines field were the International Journal of Food and Microbiology and the European Food Research and Technology, with six and five published articles, respectively. In ranking the ten top affiliations, two universities from Spain and one from Italy stood out. Those countries are among the principal wine makers, responsible for more than half of the global production (European Cider and Fruit Wine Association, 2022), encouraging those universities to seek innovations in the alcoholic fermentation field. Curtin, Escudero-López, Fernández-Pachón, and Varela were the most productive scientists in the area, all with four articles each.

Countries of origin of the publications

Figure 2 shows each country's scientific production, considering the affiliation country of all authors in each article. It is noticed that European countries (Spain, Italy, and Greece) stood out just as in the university's affiliation. Production and consumption of fruit fermented beverages is part of the culture of many European countries, especially of wine and cider (European Cider and Fruit Wine Association, 2022). This reflects the relevance of innovations in this field, which has currently gained more global visibility and importance. Furthermore, it is noteworthy that the results obtained for China showed 20 affiliations on this subject. China has stood out globally for its significant efforts in leveraging the fields of science and technology through high-impact reforms that reflect on the improvement of both scientific research and higher education and, consequently, of innovation, which plays an increasingly important role in China's economy (Freitas et al., 2022). Even though their numbers of publications are less expressive, countries in Oceania, such as Australia (n = 5) and New Zealand (n = 4), and in South America, such as Chile (n = 3) and Argentina (n = 3) have publications on the field of low-alcohol fruit wines. This shows a trend that is already present worldwide in this field of study in spite of it still being incipient.

Most used keywords in the research field

Table S1 (Supplementary material) shows the top 15 keywords used in the articles. The keywords analysis shows the evolution and changes that occurred over time in the research theme, which areas became obsolete, and which areas gained more attention once the variation in the research objectives may cause changes in the used keywords.

Figure 3 shows the thematic map regarding the 100 most frequent authors' keywords elaborated from the density and centrality of those words in the field of low-alcohol fruit wines. The superior left quadrant (niche themes) presents two clusters, both with high density, showing that those are topics well developed. The cluster with the words "low-alcohol", "nanofiltration", and "juice oxidation" displays a more prominent centrality, demonstrating a higher relation with the other themes. In the inferior left quadrant, the cluster with the word "sensory evaluation" is in the emerging themes that can be considered topics that have been approached more recently in the articles. The words "*Saccharomyces cerevisiae*", "glycerol", "unripe grape must", "fermentation", "alcohol", and "cider" are considered the motor themes since they showed high density and centrality, are topics well developed that interact with the other thematic areas. The basic themes quadrant, deemed

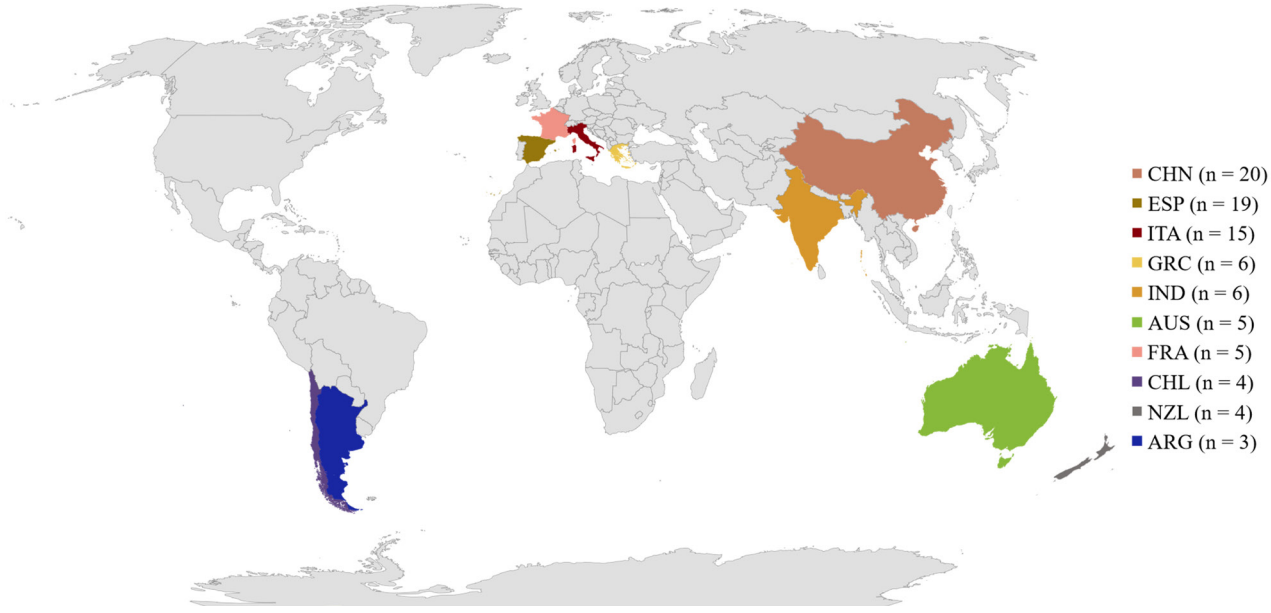


Figure 2. Scientific articles published on low-alcohol fruit wines by country. CHN = China; ESP = Spain; ITA = Italy; GRC = Greece; IND = India; AUS = Australia; FRA = France; CHL = Chile; NZL = New Zealand; ARG = Argentina.

Table 1. Ranking of the 10 top research areas, journals, affiliations, and authors in the field low-alcohol fruit wines

Ranking	Research area	Number
1st	Agricultural and Biological Sciences	45
2nd	Biochemistry, Genetics and Molecular Biology	12
3rd	Immunology and Microbiology	11
4th	Chemistry	10
5th	Engineering	8
6th	Chemical Engineering	6
7th	Environmental Science	3
8th	Health Professions	3
9th	Social Sciences	3
10th	Medicine	2
Ranking	**Journals**	**Number**
1st	International Journal of Food Microbiology	6
2nd	European Food Research and Technology	5
3rd	Fermentation	3
4th	Food Research International	3
5th	Foods	3
6th	LWT – Food Science and Technology	3
7th	Australian Journal of Grape and Wine Research	2
8th	Indian Journal of Natural Products and Resources	2
9th	Journal of Food Processing and Preservation	2
10th	Modern Food Science and Technology	2
Ranking	**Affiliations**	**Number**
1st	University Pablo de Olavide (Spain)	5
2nd	University de Valladolid (Spain)	4
3rd	University of Padova (Italy)	4
4th	Northwest A&F University (China)	3
5th	The Australian Wine Research Institute (Australia)	3
6th	Democritus University of Thrace (Greece)	2
7th	University of Horticulture and Forestry (India)	2
8th	Gansu Agricultural University (China)	2
9th	Guizhou University (China)	2
10th	Hochschule Geisenheim University (Germany)	2
Ranking	**Authors**	**Number**
1st	Curtin C.	4
2nd	Escudero-López B.	4
3rd	Fernández-Pachón M. S	4
4th	Varela C.	4
5th	Cerrillo I.	3
6th	Hernández A.	3
7th	Martín F.	3
8th	Palacio L.	3
9th	Prádanos P.	3
10th	Barnes M. F	2

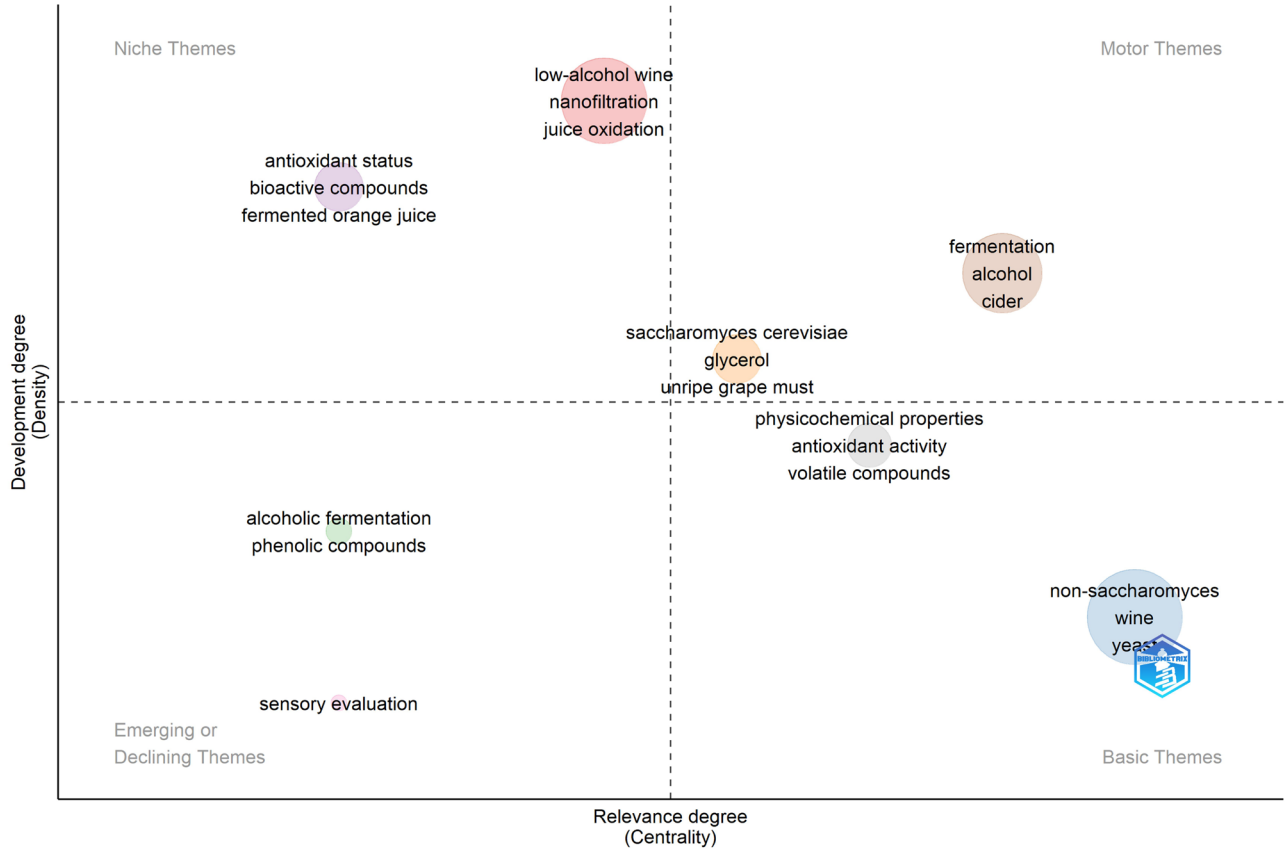


Figure 3. Thematic map of the 100 most frequent authors' keywords used in the articles of low-alcohol fruit wine.

essential to this research niche, includes the cluster with the words "non-*Saccharomyces*", "wine", and "yeast" that have high centrality and relevance for the theme, the cluster with the words "physicochemical properties", "antioxidant activity", and "volatile compounds" has high centrality and density, demonstrating that the characterization of those beverages is a relevant topic.

Most cited articles in the research field

The Table 2 shows the principal objective, fermentation conditions, alcohol content, and the main results of the ten most cited articles in the research area. As this is an emerging technology, it is noticed that all the works used grapes as the fruit for alcoholic fermentation, showing that the research in this area initiated aiming the reduction of the alcohol content of traditional wines. Whereas the higher alcohol content is a desirable characteristic for some types of wines, on the other hand, in some beverages, this negatively impacts their quality, besides not being attractive to the public searching for more healthful beverages. Furthermore, in some countries, the taxes related to alcoholic beverages are made according to their alcohol content (Varela et al., 2015). As those are the most cited articles, it is possible to conclude that those studies became a base for the elaboration of articles that began to explore other fruits than the grape, as shown in Table 3. Among the explored technologies to produce low-alcohol fruit wines or with reduced alcohol content, the utilization of non-*Saccharomyces* strains stood out as the main objective of six of the ten most cited articles. The non-*Saccharomyces* yeast strains are promising for the elaboration of low-alcohol wine because the biosynthesis of the metabolites of those yeasts uses other carbon fonts besides the sugar, directly affecting the complexity, flavor, and alcohol content of those beverages (Yang et al., 2021). Works that explored different strategies and techniques using the non-*Saccharomyces* yeasts reached a reduction of up to 2% in the alcohol content. Other techniques that can be applied in low-alcohol wine production are the utilization of enzymes, nanofiltration, use of unripe grapes, and pruning, or earliest harvest aiming a major control of the sugar produced by the grapes.

Most recently articles

The Table 3 shows the main information of the most recent articles (2021 to 2023) related to the production of low-alcohol fruit wines. The utilization of a wide variation of non-conventional fruits such as pomegranate, blackberry, mango, lemon, sea buckthorn, pineapple, strawberry, and recently pear and kiwi are noted. Those results demonstrate the possibility of inserting new beverages into the market, bringing innovation and diversity to consumers. Among the main objectives of these works, the most common ones address the quality of beverages, such as the evaluation of potential benefits to human health, or the optimization of production parameters aiming to improve nutritional and sensory composition, which may be linked to changes in the

Table 2. Main information about the elaboration of low-alcohol wines from the ten most cited articles

Fruit	Purpose	Fermentation conditions	Alcohol content (%)	Main results	Reference
Grape	Evaluation of 48 non-*Saccharomyces* yeast strains submitted to limited aeration and sequential inoculation with *Saccharomyces cerevisae* for the reduction of alcohol concentration in wine	T: 22 ºC Agitation at 200 rpm. Addition of *S. cerevisiae* strain after the reduction of sugar in 50%. Four different aeration treatments with 5 mL/min and 10 mL/min.	5.6 – 12.8	The utilization of *Torulaspora delbrueckii* e *Zygosaccharomyces bailii* strains, with low aeration in the beginning of the fermentation reduced the alcohol production up to 2%	(Contreras et al., 2015a)
Grape	Evaluation of the volatile flavor profile of Chardonnay and Shiraz wines produced with *Metschnikowia pulcherrima* and *Saccharomyces uvarum* in a sequential fermentation with *Saccharomyces cerevisiae*	Must maceration at 0 ºC for 24h. Must filtration (0.2 um). pH: 3.5. T: 22 ºC. Agitation at 120 rpm. Addition of *S. cerevisiae* strain after 50% of sugar was consumed.	11.45 – 14.10	For both wine types (Chardonnay and Shiraz), the *M. pulcherrima* strain showed the slowest fermentation kinetics; Fermentations with *M. pulcherrima* and *S. uvarum* produced 1.7 – 1.8% less ethanol than the fermentation with *S. cerevisiae*; The combination of non-conventional yeast strains did not produce high concentrations of volatile compounds that could negatively impact the flavor of wines.	(Varela et al., 2016)
Grape	Evaluation of sensory and volatile profile of Merlot wine with reduced alcohol content produced in pilot-scale using *Metschnikowia pulcherrima* and *Saccharomyces uvarum*	pH: 3.2. T: 22 ºC. Malolactic Fermentation with *Oenococcus oeni*	13.13 – 14.81	Wines elaborated with *M. pulcherrima* and *S. uvarum* produced 1.0% and 1.7% less ethanol than the *S. cerevisiae* strain; *M. pulcherrima* produced higher concentrations of volatile compounds; The fermentation with *M. pulcherrima*/ *S. cerevisiae* presented a sensory profile similar to the uninoculated wine, showing high scores for positive sensory descriptors	(Varela et al., 2017)

Table 2. Continued...

Fruit	Purpose	Fermentation conditions	Alcohol content (%)	Main results	Reference
Grape	Evaluation of the impact of different inoculation regimes on the performance of *Metschnikowia pulcherrima* during non-sterile sequential fermentation of Shiraz wine with reduced ethanol concentration	T: 22 °C. pH: 3.5.	12.32 – 14.10	The native microflora from non-sterilized musts can affect the *M. pulcherrima* performance; Sequential inoculation of *M. pulcherrima* with *S. cerevisiae*, and the inoculation of *M. pulcherrima* with *S. uvarum* reduced the alcohol content of the Shiraz wine up to 1.8% when compared to the wines produced only with *S. cerevisiae*	(Contreras et al., 2015b)
Grape	Use nanofiltration to reduce sugar concentration of white and red musts aiming to produce low-alcohol content wines	-	7.82 – 17.54	For both wines, the mix of control must with filtered must reduced 2° of the alcohol content and did not significantly affect the sensorial quality	(García-Martín et al., 2010)
Grape	Evaluation of the variability in the behavior and the ethanol production of 33 non-Saccharomyces yeast strains during fermentation	T: 25 °C. Nitrogen: 300 mg/L.	2.66 – 9.09	*Hanseniaspora uvarum*, *Zygosaccharomyces sapae*, *Zygosaccharomyces bisporus*, and *Zygosaccharomyces bailii* strains showed a significant reduction of the ethanol yield and in the fermentation efficiency in comparison with *S. cerevisiae*; *Candida zemplinina*, *Candida stellata*, *Saccharomycodes ludwigii* e *Dekkera bruxellensis* strains did not differ from *S. cerevisiae* in ethanol production and fermentation efficiency	(Gobbi et al., 2014)

Table 2. Continued...

Fruit	Purpose	Fermentation conditions	Alcohol content (%)	Main results	Reference
Grape	Elaboration of a vinification process to reduce, simultaneously, pH and alcohol content of wines produced with grape berries collected during cluster thinning	T: 18 °C. Clarification: charcoal (5 g/L) and bentonita (1 g/L). Sulfites: potassium metabisulfite (100 mg/L), before and after fermentation.	13.2 – 16.9	Wines mixed with low-alcohol wines (5%) showed a 0.9 to 3% reduction in the ethanol content compared with control wines; pH and titratable acidity were reduced; Wine colors with reduced alcohol content were optimized, and the phenolic composition was unaffected	(Kontoudakis et al., 2011)
Grape	Utilization of enzymatic treatments with glucose oxidase in grape must, converting glucose to gluconic acid, reducing the white wine alcohol content	-	-	After the optimization of parameters such as pH, enzyme dosage, oxygen, aeration, and temperature, a conversion of 87% of glucose to gluconic acid was reached	(Pickering et al., 1998)
Grape	To elaborate a reduced alcohol content wines without quality loss through determination and validation of optimum fermentation conditions with sequential inoculation using non-*Saccharomyces* yeast	T: 25 °C. pH: 3.8. 21 °Brix.	9.22 – 13.86	The time of permeance of the non-*Saccharomyces* yeast in the must before the addition of *S. cerevisiae* significantly affected the alcohol production; Inoculum size of non-Saccharomyces yeast did not affect the alcohol production; Wines produced in optimized conditions showed higher aromatic complexity, however, to color parameters the co-inoculation with *Candida membranaefaciens* presented negative results	(Maturano et al., 2019)
Grape	To compare the effect of two intensities of late trimming and defoliation on the sugar accumulation of Aglianico grape berries and its impact on wine alcohol content, composition, and sensory properties	T: 25 °C. Sulfites: sulfur dioxide (80 mg/kg).	11.8 – 14.1	Late trimming and defoliation can reduce total soluble solids content in grape must; Trimming treatments significantly reduced the ethanol concentration up to 1.1% without affecting pH, acidity, and color; Defoliation treatments positively influenced the wine global score in the sensory analysis	(Caccavello et al., 2017)

Table 3. Recently published scientific articles (2021 to 2023) on low-alcohol fruit wines in the research area of Agriculture and Biological Sciences

Article title	Purpose	Fruits	Alcohol content (%)	Reference
Enhancing antioxidant activity and fragrant profile of low-ethanol kiwi wine via sequential culture of indigenous *Zygosaccharomyces rouxii* and Saccharomyces cerevisiae	To perform the sequential fermentation of kiwi juice with *Zygosaccharomyces rouxii* in the initial fermentation phase and add *Saccharomyces cerevisiae* after two days, without adding sugar in the must.	Kiwi (*Actinidia deliciosa* cv. Yate)	3.83 – 6.87	(Li et al., 2023)
Chemical and chromatic effects of commercial wine yeast strains (*Saccharomyces* spp.) on 'dolgo' crabapple rosé cider	To investigate the effect of 15 *Saccharomyces* yeast strains used to produce white wine in the characteristics of rosé cider.	Apple	4.59 – 5.24	(Wang et al., 2023)
Effects of *Saccharomyces cerevisiae* and *Starmerella bacillaris* on the physicochemical and sensory characteristics of sparkling pear cider	Produce pear cider using mixed cultures of *Starmerella bacillaris* and *Saccharomyces cerevisiae* in simultaneous and sequential inoculation and its effect on the physicochemical and sensorial properties of the beverage	Pear (*Pyrus communis* L.)	5.70 – 6.0	(Guerrini et al., 2023)
Use of mixed cultures for the production of grape-plum low-alcohol fermented beverages	To develop a technology to produce grape and blackberry low-alcohol wine, using sequential fermentation with *Lachancea thermotoletans* adding *Saccharomyces cerevisiae* 72h later.	Red Globe grape and Black Kat plum	5.32 – 5.71	(Moreno et al., 2022)
Effect of acute intake of fermented orange juice on fasting and postprandial glucose metabolism, plasma lipids and antioxidant status in healthy human	Evaluate the potential beneficial health effects of fermented oranges compared to orange juice	Orange (*Citrus sinensis* L.)	0.90	(Escudero-López et al., 2022)
Effect of inoculation method on the quality and nutritional characteristics of low-alcohol kiwi wine	Investigate the effects of *Saccharomyces cerevisiae* and *Wickerhamomyces anomalus* inoculation methods on the nutritional characteristics and quality of low-alcohol kiwi wine	Kiwi (*Actinidia chinensis*)	5.30 – 5.50	(Huang et al., 2022a)

Table 3. Continued...

Article title	Purpose	Fruits	Alcohol content (%)	Reference
Enhancement of the aroma in low-alcohol apple-blended pear wine mixed fermented with *Saccharomyces cerevisiae* and non-*Saccharomyces* yeasts	Explore the effects of mixing pear and apple juice in different proportions, as well as the mixed culture of *Saccharomyces* with non-*Saccharomyces* on the volatile composition and sensory properties of pear wine	Pear (*Pyrus bretschneideri* Rehder) e maçã (*Malus domestica*)	6.47 – 6.53	(Yang et al., 2022)
Effect of fermentation strategy on the quality and aroma characteristics of yellow peach wines	Analyze the effects of different fermentation strategies on the physicochemical properties, phenolic monomer content, antioxidant activity, and volatile compounds in yellow peach wine	Peach (*Prunus persica* L. Batsch)	5.11 – 12.76	(Liang et al., 2022)
Study on the construction and aroma-producing characteristics of the recombinant Saccharomyces cerevisiae strain W303-EAT	To amplify the gene that express alcohol acetyltransferase to build a recombinant *Saccharomyces cerevisiae* strain and produce a low-alcohol blueberry wine	Blueberry	4.00 – 4.20	(Wang et al., 2022a)
Characterization of Roselle (*Hibiscus sabdariffa*) calyces wine using date palm (*Phoenix dactylifera*) fruit extracts as a substitute for granulated sugar	Characterize the rose wine produced from *Hibiscus sabdariffa* using *Phoenix dactylifera* extracts as a sugar substitute	Caruru-azedo calyx (*Hibiscus sabdariffa*) with date palm extract (*Phoenix dactylifera*)	2.15 – 10.24	(Sobowale et al., 2021)
Screening non-*saccharomyces* yeasts as low ethanol producing starter cultures	Evaluate the fermentative capacity of non-*Saccharomyces* yeasts under aerobic and anaerobic conditions as potential starter cultures for the production of low-alcohol beverages	Grape (*Vitis* vinifera cv. Chenin Blanc)	<5 – 11.9	(Mehlomakulu et al., 2021)
Chemical composition, sensory profile and antioxidant capacity of low-alcohol strawberry beverages fermented with *Saccharomyces cerevisiae* and *Torulaspora delbrueckii*	Investigate the chemical composition, sensory characteristics, and antioxidant activity of low-alcohol strawberry fermented beverage with *Saccharomyces cerevisiae* and *Torulaspora delbrueckii* without added sugar	Strawberry (*Fragaria* × *ananassa*)	1.3 – 2.7	(Yang et al., 2021)
Preparation of low-alcohol pineapple wine by different methods of terminating fermentation	Investigate the effects of different fermentation termination methods on the wine quality	Pinapple (*Ananas comosus*)	4.78 – 4.85	(Wang et al., 2021)

behavior of consumers who are increasingly looking for a healthier lifestyle. It is also noted that in the vast majority of the works, the alcoholic strength of the beverages remained below 6%, which shows the growing search for beverages that have low alcohol content when compared to traditional fermented products, which commonly show content between 11 and 14%.

Moreover, these surveys meet the Sustainable Development Goals (SDGs) of the United Nations (UN), which in 2015 proposed to its member states a new sustainable development agenda for the following 15 years, the 2030 Agenda (United Nations, 2015). Some of these goals, in particular Goals 3 (Good health and Well-being), 9 (Industry, Innovation and Infrastructure) and 12 (Responsible Consumption and Production), may be part of the motivation for these scientists to investigate the beneficial properties and the opportunities for innovation in technology to obtain low-alcohol fruit wines, especially those produced with nonconventional fruits.

It is worth noting that the bioactive properties of low-alcohol beverages have been increasingly investigated in scientific studies. Huang et al. (2022a) produced different low-alcohol kiwi wine formulations with values averaging 5.4% (v/v) of alcoholic strength by using different yeast inoculation techniques, and the kiwi wine formulation prepared with the initial inoculation of *Wickerhamomyces anomalus* followed by *Saccharomyces cerevisiae* showed the highest vitamin C content and the highest sensory acceptance. Yang et al. (2021) evaluated the potential of beverages with alcoholic strengths between 1.3 and 2.7% (v/v) produced from different strawberry cultivars, and the beverage with the lowest alcohol strength showed the highest levels of anthocyanins, total phenolic content, and antioxidant capacity.

Technological prospection

Mapping of patents filed by country/organization

Figure 4 shows the number of patents filed by country. China stands out as the main holder of technology for producing low-alcohol fruit wines, holding 87 patents, followed by Japan with 3 patents, while South Korea, France, and Spain hold two patents each. Moreover, the United States, Taiwan, Romania, and the Czech Republic have filed one patent each. China ranks 12th out of 132 economies in the 2021 global innovation index (World Intellectual Property Organization , 2021), and in 2020 the country ranked second in the world for science and technology hotspots (World Intellectual Property Organization, 2020b). In addition, in 2019 China became the main source of international patent applications filed with the World Intellectual Property Organization (WIPO) (World Intellectual Property Organization , 2020b). Japan, on the other hand, ranks 13th among the 132 economies found in the Global Innovation Index (GII) (World Intellectual Property Organization, 2020a).

The data presented in the present study show that developed countries with adequate investments have a higher number of scientific publications and patent applications, thereby contributing to their economic growth. It is also worth noting that China leads the world ranking of fruit-producing countries, with a production of more than 240,000 tons in 2020 (Shahbandeh, 2021), which considerably increases the alternatives available on the market and that can be exploited.

International patent classification codes and filing status

According to the WIPO, the classification codes are intended to establish an effective search tool for the retrieval of patent

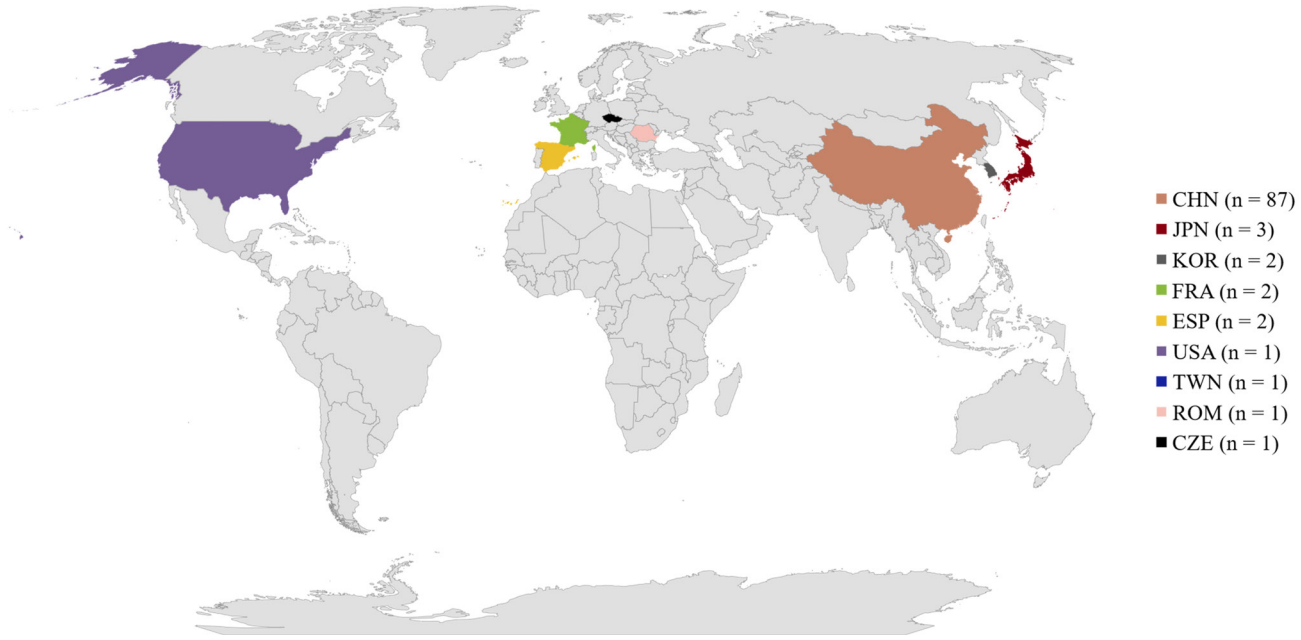


Figure 4. Number of patents on low-alcohol fruit wine filed by country. CHN = China; JPN = Japan; KOR = South Korea; FRA = France; ESP = Spain; USA = United States of America; TWN = Taiwan; ROM = Romania; CZE = Chez Republic.

documents by intellectual property offices and other users. Since a patent document may have more than one code, the 101 documents retrieved from Espacenet® had 75 different codes of the International Patent Classification (IPC). The codes that showed the highest frequency of appearance were those of the group C12G3, with emphasis on subgroup C12G3/02, which is related to the preparation of other fermented alcoholic beverages, and subgroups C12G3/024 and C12G3/04, which are related to the preparation of alcoholic beverages from fruits other than the genus *Vitis* and to the preparation of other alcoholic beverages by mixing different types thereof, respectively. Moreover, subgroup C12R1/865 also showed a significant frequency of appearances and is related to processes that use *S. cerevisiae* as the fermenting microorganism. It is possible to note that the codes present in the documents are directly related to the subject of the patent mapping proposed in this study, which includes not only methods of reducing the alcohol content, but also preparation of beverages with different yeasts and ingredients that are beneficial to human health. Regarding the status of these documents, it was noted that in the Espacenet® database, 39.6% of the documents (n = 40) are listed as "granted" and 60.4% show their status as "filed" (n = 59). When a patent is granted, it means that it has met the patentability requirements and that it is innovative and has industrial applicability; and when the patent has not yet been granted, it means that it is undergoing analysis and that it will continue to be taken into consideration as long as it is not abandoned or withdrawn (Deconinck et al., 2018). Besides, the applicant must keep up to date with the payments of the necessary fees so that the documents remain active in the systems of the responsible offices in each country.

Inventors and applicants

Among the 101 patent documents, 345 inventors were found, 26 of which hold more than one patent each. The main inventors in the field of low-alcohol fruit wines were Jiang Weiling and Liu Minghan, who are inventors and applicants for four patents, while Yu Ran and Zhang Jun also stand out for being listed as inventors in three patent documents. As for the applicants, it was possible to note that 40% of the patent applications were filed by the beverage industry, while educational and research institutions were responsible for 38% of the applications, and 22% of the applications were filed by independent individuals and/or inventors. Two patent applications were filed by more than one institution, through partnerships between educational institutions and producers. Among the producers, the Sino-French Joint-Venture Dynasty Winery stood out for holding five patents. The company's most recent patent was published in 2022 (Bin et al., 2022) and described an elaboration method of a grape low-alcohol wine using non-Saccharomyces yeast with 5 – 6% alcohol content. Of the 32 educational and research institutions that filed patent applications, five hold two patent documents each, namely, Shanghai Institute of Technology, Beibu Gulf University, Northwest A&F University, Shaanxi Normal University, and Tianjin Agricultural University.

Patent profile

The Table 4 presents the main information on the patent applications filed in the last two years (2021 to 2023). Among the 10 patent documents published in that period, four are related to the use of grapes and two are related to the use of apples as raw material for the preparation of fermented beverages, and a similar behavior was noted in the documents investigated in the scientific prospection of the present study. This is an expected result since grape wine is one of the most consumed beverages in the world and its consumers are increasingly aware of the harm that daily consumption of alcohol can cause to human health, thus leading the wine industry to look for alternatives that promote the reduction of the beverage's alcoholic strength (Lemos Junior et al., 2019). Besides, despite the cider industry being smaller than the wine industry, this result shows its rapid growth rate since apples are already traditionally known for their use in the production of cider. The cider industry is currently one of the fastest growing markets in East European countries (European Cider and Fruit Wine Association, 2022). According to the European Association of Cider and Fruit Wines (European Cider and Fruit Wine Association, 2020), cider is an alcoholic beverage obtained exclusively from complete or partial fermentation of fresh or concentrated apple juice. The alcohol content in cider may range between 1.2 and 8.5% and there already exist low-alcohol ciders on the market, whose alcoholic strength range from 0.5 to 1.2% (Guiné et al., 2021). For the vast majority of recently patented beverages, the alcohol strengths noted also remained below 6%, which shows that the fields of scientific research and technology have shown similar objectives regarding the production of low-alcohol fruit wines. However, due to the lack of specific legislation, there are still divergences in both sectors regarding the parameters that define the maximum and minimum limits of alcoholic strength in a beverage for it to be considered low-alcohol. Moreover, the 2020 Compendium of International Methods of Wine and Must Analysis of the International Organization of Vine and Wine considers low-alcohol beverages only those with an alcohol content ≤ 1.5%. Even so, that same document contains an annex with the validation parameters related to the measurement of the alcohol content of these beverages, which mentions samples containing up to 6.5% alcohol (Organization of Vine and Wine, 2020).

The definitions available and easily found on this topic are directly related to beverages considered zero-alcohol or non-alcoholic. According to the United States law, non-alcoholic beverages are those that contain less than 0.5% (v/v) of alcohol in their composition (United States, 1988). In Brazil, the *Divisão de Inspeção de Produtos de Origem Vegetal* (Division for Inspection of Products of Vegetal Origin) (DIPOV) states that dealcoholized grape wines must undergo an adequate physical process to lower their alcohol content to less than 0.5% (v/v) (Brasil, 2020).

Among the technologies used to produce the beverages patented in those documents, the interruption of fermentation when the product reaches the desired alcoholic strength and vacuum distillation are the ones that most stand out. Moreover, techniques such as dilution, membrane filtration, short-term fermentations, or low-temperature fermentations were also used, as well as non-*Saccharomyces* yeasts and yeasts with low tolerance or low ethanol production.

Perspectives for the low-alcohol beverage market

Harmful consumption of alcohol is the cause of about 5.3% of annual deaths worldwide, which represents an average of

Table 4. Patent documents published on Espacenet® between 2021 and 2022 on low-alcohol fruit wines

Patent title	Technology	Fruits	Alcohol content (%)	Reference
Preparation method of fruit wine	Fermentation temperature between 18 and 22 °C, with agitation every 8 -12 h, in a sealed tank during 14 to 16 days, separating the precipitated must every 2 to 4 days	Apple	6.5 – 6.8	(Li et al., 2022)
Brewing method of fermentation type low-alcohol wine	Utilization of non-*Saccharomyces* yeast in a low-temperature fermentation for 3-5 days, then adding the *Saccharomyces* yeast and continuing the fermentation at 15-25 °C until the desirable alcohol content is reached	Grape	5 – 6	(Zhang et al., 2022)
Preparation method of *Morinda citrifolia* enzyme fruit wine and *Morinda citrifolia* enzyme fruit wine	Mixture of the lactic acid fermentation product from the fruit with grape wine dealcoholized by reverse osmosis	*Morinda citrifolia* and grape	0.5 – 7	(Wang et al., 2022b)
Brewing method of frozen fermented low-alcohol grape wine	Fermentation temperature between -6 and 0 °C	Grape	1	(Huang et al., 2022b)
Siraitia grosvenorii wine and preparation method thereof	Concentration of nutrients in the fruit juice using resin and nanofiltration, fermentation time from 7 to 15 days	*Siraitia grosvenorii*	2 – 5	(Liu et al., 2022)
Fruit-flavor low-alcohol refreshing apple wine and preparation method thereof	Use of low ethanol tolerance yeast	Fuji apple	4 – 5	(Sun et al., 2021)
Yeast strain with low ethanol yield and high aroma and use thereof	Yeast strain with low ethanol production and its application in a beverage	Kiwi	2.90%	(Zhou et al., 2021)
Method for manufacturing of non alcohol wine and low-alcohol wine prepared thereby	Reduction of the alcohol content of the beverage by vacuum distillation without deteriorating either the color or the flavor of the fermented product	Grape, raspberry, blueberry, aronia, pomegranate or apple	0 – 10	(Kim et al., 2021)
Production method of high-resveratrol low-alcohol fermented *Vitis davidii* oral liquid	Distillation of the fermentation beverage to remove its alcohol and methanol, mixture of the distillate with resveratrol and mogroside	Grape (*Vitis davidii*)	<1	(Hu et al., 2021)
Fragrance-enhancing *Hanseniaspora opuntiae* and application thereof in low-alcohol sweet navel orange wine	Addition of sulfur dioxide to terminate fermentation when the stipulated alcohol content is reached	Orange	7 – 8	(Liu et al., 2021)

3 million people. The negative impact that alcohol consumption can cause on human health is associated with risk of development of mental and behavioral disorders, as well as diseases such as liver cirrhosis, cancer, and cardiovascular diseases, besides the risk of injuries resulting from violence and traffic accidents (World Health Organization, 2022b). For these and other reasons, the development of low-alcohol fermented beverages is important, since consumers are increasingly concerned about their health. This is made evident by data that show a decrease in alcohol consumption worldwide between 2010 and 2019 (World Health Organization, 2022a). Moreover, the low taxes and tariffs' correlation with the low alcohol content in fruit wines draws the attention of the commercial sector (Yang et al., 2021). From a public health point of view, this is the best option for governments to control and reduce harmful consumption of alcohol, as this measure applied in high-income countries that have a high number of alcohol consumers can encourage the consumption of low-alcohol beverages instead of those with high alcoholic strength (World Health Organization, 2020).

It is noteworthy that one of the few low-alcohol fermented beverage niches that already have a well-established market is that of beer, whereas fermented beverages made from fruits are still on the rise worldwide since this type of beverage is not so easily found on the market. Another aspect of this market is the possibility of exploiting native and exotic fruits, often underutilized in the beverage industry. Moreover, the utilization of these fruits in the production of fruit wines can be a viable alternative to circumvent the problems of post-harvest losses, thus helping to preserve their species as well as enabling the creation of a source of income for small producers.

However, during the research, no specific regulations were found worldwide regarding the identity and quality parameters of low-alcohol fruit wines, which is a challenging and interesting topic since this makes it difficult to standardize and market this type of beverage within legal parameters.

Conclusion

Given the above, it is concluded that in the scientific and technological fields there has been an increase in interest in technologies regarding the production of low-alcohol fruit wines in the past ten years, mainly due to these beverages' healthfulness appeal. The fact that countries from different continents show interest in this technology emphasizes the importance of encouraging research, innovation and technology in this field since the amount of patent applications and scientific production is related to the country's economic development.

Among the main raw materials found in the articles and in the patents, there are fruits that are already traditionally used to produce alcoholic fermented products. However, it was possible to observe a growing interest among inventors and scientists in taking advantage of nonconventional fruits aiming to bring innovation to the low-alcohol beverage market.

Conflicts of interest

The authors confirm that they have no conflicts of interest with respect to the work described in this manuscript.

Funding: This work was supported by the Coordenação de Aperfeiçoamento de Pessoal de Nivel Superior (CAPES, Brazil) (Finance Code 001); Fundação de Amparo à Pesquisa e Inovação do Estado de Santa Catarina (FAPESC, Brazil) (2021TR000353); Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, Brazil) (n.140616/2021-7). Renata D. M. C. Amboni was granted a fellowship (PQ1D) from CNPq.

References

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, *11*(4), 959-975. http://doi.org/10.1016/j.joi.2017.08.007.

Bin, Z., Ran, Y., Ying, L., Xiaolong, L., Fengjun, Y., & Tian, H. (2022). *Brewing method of fermentation type low-alcohol wine* (Patent CN115786051A). Espacenet. https://worldwide.espacenet.com/patent/search/family/085427288/publication/CN115786051A?q=CN115786051A

Boeira, L. S., Bastos Freitas, P. H., Uchôa, N. R., Bezerra, J. A., Cád, S. V., Duvoisin Junior, S., Albuquerque, P. M., Mar, J. M., Ramos, A. S., Machado, M. B., & Maciel, L. R. (2020). Chemical and sensorial characterization of a novel alcoholic beverage produced with native acai (*Euterpe precatoria*) from different regions of the Amazonas state. *Lebensmittel-Wissenschaft + Technologie*, *117*, 108632. http://doi.org/10.1016/j.lwt.2019.108632.

Brasil. Ministério da Agricultura e Pecuária Secretaria de Defesa Agropecuária, Departamento de Inspeção de Produtos de Origem Vegetal Coordenação-Geral de Vinhos e Bebidas - DIPOV. (2020). *Consolidação das Normas de Bebidas, Fermentado Acético, Vinho e Derivados da Uva e do Vinho*. https://www.gov.br/agricultura/pt-br/assuntos/inspecao/produtos-vegetal/legislacao-de-produtos-origem-vegetal/biblioteca-de-normas-vinhos-e-bebidas/AnexoNormaInternaDIPOV2Edicao.pdf

Caccavello, G., Giaccone, M., Scognamiglio, P., Forlani, M., & Basile, B. (2017). Influence of intensity of post-veraison defoliation or shoot trimming on vine physiology, yield components, berry and wine composition in Aglianico grapevines. *Australian Journal of Grape and Wine Research*, *23*(2), 226-239. http://doi.org/10.1111/ajgw.12263.

Contreras, A., Hidalgo, C., Schmidt, S., Henschke, P. A., Curtin, C., & Varela, C. (2015a). The application of non-Saccharomyces yeast in fermentations with limited aeration as a strategy for the production of wine with reduced alcohol content. *International Journal of Food Microbiology*, *205*, 7-15. http://doi.org/10.1016/j.ijfoodmicro.2015.03.027. PMid:25866906.

Contreras, A., Curtin, C., & Varela, C. (2015b). Yeast population dynamics reveal a potential 'collaboration' between *Metschnikowia pulcherrima* and *Saccharomyces uvarum* for the production of reduced alcohol wines during Shiraz fermentation. *Applied Microbiology and Biotechnology*, *99*(4), 1885-1895. http://doi.org/10.1007/s00253-014-6193-6. PMid:25388943.

Deconinck, N., Muylaert, K., Ivens, W., & Vandamme, D. (2018). Innovative harvesting processes for microalgae biomass production: A perspective from patent literature. *Algal Research*, 31, 469-477. http://doi.org/10.1016/j.algal.2018.01.016.

Escudero-López, B., Cerrillo, I., Ortega, Á., Martín, F., & Fernández-Pachón, M.-S. (2022). Effect of acute intake of fermented orange juice on fasting and postprandial glucose metabolism, plasma lipids and antioxidant status in healthy human. *Foods*, 11(9), 1256. http://doi.org/10.3390/foods11091256. PMid:35563979.

European Cider and Fruit Wine Association – AICV. (2020), *European Cider Trends 2020*. www.aicv.org

European Cider and Fruit Wine Association – AICV. (2022), *European Cider Trends 2022*. www.aicv.org

Food and Agriculture Organization of the United Nations – FAO. (2021). World Food and Agriculture – Statistical Yearbook 2021. In Food and Agriculture Organization of the United Nations – FAO. *World Food and Agriculture – Statistical Yearbook 2021*. FAO. http://doi.org/10.4060/cb4477en.

Freitas, T. J., Assunção, L. S., de Lima Silva, V., Oliveira, T. S., Conceição, I. S. R., Machado, B. A. S., Nunes, I. L., Otero, D. M., & Ribeiro, C. D. F. (2022). Prospective study on microencapsulation of oils and its application in foodstuffs. *Recent Patents on Nanotechnology*, *16*(3), 219-234. http://doi.org/10.2174/1872210515666210422123001. PMid:33888053.

Fuchs, F. D., & Fuchs, S. C. (2021). The effect of alcohol on blood pressure and hypertension. *Current Hypertension Reports*, *23*(10), 42. http://doi.org/10.1007/s11906-021-01160-7. PMid:34762198.

García-Martín, N., Perez-Magariño, S., Magariño, M., Ortega-Heras, M., González-Huerta, C., Mihnea, M., Luisa González-Sanjosé, M., Palacio, L., Prádanos, P., & Hernández, A. (2010). Sugar reduction in musts with nanofiltration membranes to obtain low alcohol-content wines. *Separation and Purification Technology*, *76*(2), 158-170. http://doi.org/10.1016/j.seppur.2010.10.002.

Gobbi, M., De Vero, L., Solieri, L., Comitini, F., Oro, L., Giudici, P., & Ciani, M. (2014). Fermentative aptitude of nonsaccharomyces wine yeast for reduction in the ethanol content in wine. *European Food Research and Technology*, *239*(1), 41-48. http://doi.org/10.1007/s00217-014-2187-y.

Guerrini, S., Galli, V., Barbato, D., Facchini, G., Mangani, S., Pierguidi, L., & Granchi, L. (2023). Effects of *Saccharomyces cerevisiae* and *Starmerella bacillaris* on the physicochemical and sensory characteristics of sparkling pear cider (Perry). *European Food Research and Technology*, *249*, 341-352. https://doi.org/10.1007/s00217-022-04119-3.

Guiné, R. P. F., Barroca, M. J., Coldea, T. E., Bartkiene, E., & Anjos, O. (2021). Apple fermented products: An overview of technology, properties and health effects. *Processes*, *9*(2), 1-25. http://doi.org/10.3390/pr9020223.

Hu, Y., Yang, Z., Huang, Y., Shen, L., & Li, M. (2021). *Production method of high-resveratrol low-alcohol fermented vitis davidii oral liquid* (Patent CN112812913A). Espacenet. https://worldwide.espacenet.com/patent/search/family/075864445/publication/CN112812913A?q=CN112812913A

Huang, J., Wang, Y., Ren, Y., Wang, X., Li, H., Liu, Z., Yue, T., & Gao, Z. (2022a). Effect of inoculation method on the quality and nutritional characteristics of low-alcohol kiwi wine. *Lebensmittel-Wissenschaft + Technologie*, *1561*, 113049. http://doi.org/10.1016/j.lwt.2021.113049.

Huang, Z., Tang, A., Li, M., & Zhang, X. (2022b). *Brewing method of frozen fermented low-alcohol grape wine* (Patent CN114958510A). Espacenet. https://worldwide.espacenet.com/patent/search/family/082969652/publication/CN114958510A?q=CN114958510A

International Wine and Spirit Research - IWSR. (2022). *No- and Low-Alcohol in Key Global Markets Reaches Almost US$10 Billion in Value*. https://www.theiwsr.com/no-and-low-alcohol-in-key-global-markets-reaches-almost-us10-billion-in-value/

Kim, S. S., Kim, T. W., Park, H., Choi, H. D., & Ye, N. K. (2021). *Method for manufacturing of non alcohol wine and low alcohol wine prepared thereby* (Patent KR20220152673A). Espacenet. https://worldwide.espacenet.com/patent/search/family/084233216/publication/KR20220152673A?q=KR20220152673A

Kontoudakis, N., Esteruelas, M., Fort, F., Canals, J. M., & Zamora, F. (2011). Use of unripe grapes harvested during cluster thinning as a method for reducing alcohol content and pH of wine. *Australian Journal of Grape and Wine Research*, *17*(2), 230-238. http://doi.org/10.1111/j.1755-0238.2011.00142.x.

Lemos Junior, W. J. F., Nadai, C., Crepalde, L. T., de Oliveira, V. S., de Matos, A. D., Giacomini, A., & Corich, V. (2019). Potential use of *Starmerella bacillaris* as fermentation starter for the production of low-alcohol beverages obtained from unripe grapes. *International Journal of Food Microbiology*, *303*, 1-8. http://doi.org/10.1016/j.ijfoodmicro.2019.05.006. PMid:31102962.

Li, J., Li, Y., Yang, B., & Sun, Y. (2022). *Preparation method of fruit wine* (Patent *CN115584303A*). Espacenet. https://worldwide.espacenet.com/patent/search/family/084779469/publication/CN115584303A?q=CN115584303A

Li, S., Chen, X., Gao, Z., Zhang, Z., Bi, P., & Guo, J. (2023). Enhancing antioxidant activity and fragrant profile of low-ethanol kiwi wine via sequential culture of indigenous *Zygosaccharomyces rouxii* and *Saccharomyces cerevisiae*. *Food Bioscience*, *51*, 102210. http://doi.org/10.1016/j.fbio.2022.102210.

Liang, H., Gao, D., Wang, C., Gao, H., Guo, Y., Zhao, Z., & Shi, H. (2022). Effect of fermentation strategy on the quality and aroma characteristics of yellow peach wines. *Fermentation (Basel, Switzerland)*, *8*(11), 604. http://doi.org/10.3390/fermentation8110604.

Liguori, L., Russo, P., Albanese, D., & Di Matteo, M. (2018). Production of low-alcohol beverages: current status and perspectives. In A. M. Grumezescu & A. M. Holban (Eds.), *Food processing for increased quality and consumption* (pp 347-382). Academic Press. http://doi.org/10.1016/B978-0-12-811447-6.00012-6.

Liu, G., Zeng, R., & Liu, Y. (2022). *Siraitia grosvenorii wine and preparation method thereof* (Patent CN114410411A). Espacenet. https://worldwide.espacenet.com/patent/search/family/081271993/publication/CN114410411A?q=CN114410411A

Liu, W., Zhang, J., Shan, Y., Fu, F., Zhang, Q., Su, D., Li, Z., & Mao, Y. (2021). *Fragrance-enhancing Hanseniaspora opuntiae and application thereof in low-alcohol sweet navel orange wine* (Patent CN113308388A). Espacenet. https://worldwide.espacenet.com/patent/search/family/077376389/publication/CN113308388A?q=CN113308388A

Lopes, A. C. A., Eda, S. H., Andrade, R. P., Amorim, J. C., & Duarte, W. F. (2019). New alcoholic fermented beverages-potentials and challenges. In A. M. Grumezescu & A. M. Holban (Eds.), *Fermented Beverages* (Vol. 5, pp. 577-603). Elsevier. http://doi.org/10.1016/B978-0-12-815271-3.00014-2.

Maturano, Y. P., Mestre, M. V., Kuchen, B., Toro, M. E., Mercado, L. A., Vazquez, F., & Combina, M. (2019). Optimization of fermentation-relevant factors: A strategy to reduce ethanol in red wine by sequential culture of native yeasts. *International Journal of Food Microbiology*, *289*, 40-48. http://doi.org/10.1016/j.ijfoodmicro.2018.08.016. PMid:30196180.

Mehlomakulu, N. N., Hoff, J. W., Erten, H., Beukes, L., & Jolly, N. P. (2021). Screening non-*saccharomyces* yeasts as low ethanol producing starter cultures. *South African Journal of Enology and Viticulture*, *42*(1), 56-66. http://doi.org/10.21548/42-1-4335.

Moreno, D., Redondo, P., Lozano, E., Valdés, M. E., & Pérez-Nevado, F. (2022). Use of mixed cultures for the production of grape–plum low-alcohol fermented beverages. *Fermentation (Basel, Switzerland)*, *9*(1), 29. http://doi.org/10.3390/fermentation9010029.

Organization of Vine and Wine – OIV. (2020). *Compendium of International Methods of Wine and Must Analysis* (Vol. 1). OIV.

Pickering, G. J., Heatherbell, D. A., & Barnes, M. F. (1998). Optimising glucose conversion in the production of reduced alcohol wine using glucose oxidase. *Food Research International*, 31(10), 685-692. http://doi.org/10.1016/S0963-9969(99)00046-0.

Shahbandeh, M. (2021). *Major producers of fresh fruit worldwide 2021*. Retrieved from: https://www.statista.com/aboutus/our-research-commitment/1239/m-shahbandeh. Accessed 3 July 2023

Sobowale, S. S., Omosebi, O. M., & Animashaun, O. H. (2021). Characterization of Roselle (*Hibiscus sabdariffa*) calyces wine using date palm (*Phoenix dactylifera*) fruit extracts as a substitute for granulated sugar. *Journal of Food Processing and Preservation*, 45(11), e15935. http://doi.org/10.1111/jfpp.15935.

Sun, Y., Guan, X., Lin, X., Zhang, X., Ding, Y., Tang, X., Zhao, X., & Wang, X. (2021). *Fruit-flavor low-alcohol refreshing apple wine and preparation method thereof* (Patent CN113755289A). Espacenet. https://worldwide.espacenet.com/patent/search/family/078798695/publication/CN113755289A?q=CN113755289A.

United Nations – UN. (2015). *Transforming our world: The 2030 agenda for sustainable development*. UN.

United States - US. (1988).*27 USC* (Chap. 8: Subchapter II: Alcoholic beverage labeling). US. https://www.govinfo.gov/content/pkg/USCODE-2014-title27/pdf/USCODE-2014-title27-chap8-subchapII.pdf.

Varela, C., Barker, A., Tran, T., Borneman, A., & Curtin, C. (2017). Sensory profile and volatile aroma composition of reduced alcohol Merlot wines fermented with *Metschnikowia pulcherrima* and *Saccharomyces uvarum*. *International Journal of Food Microbiology*, *252*, 1-9. http://doi.org/10.1016/j.ijfoodmicro.2017.04.002. PMid:28436828.

Varela, C., Dry, P. R., Kutyna, D. R., Francis, I. L., Henschke, P. A., Curtin, C. D., & Chambers, P. J. (2015). Strategies for reducing alcohol concentration in wine. *Australian Journal of Grape and Wine Research*, *21*, 670-679. http://doi.org/10.1111/ajgw.12187.

Varela, C., Sengler, F., Solomon, M., & Curtin, C. (2016). Volatile flavour profile of reduced alcohol wines fermented with the non-conventional yeast species *Metschnikowia pulcherrima* and *Saccharomyces uvarum*. *Food Chemistry*, *209*, 57-64. http://doi.org/10.1016/j.foodchem.2016.04.024. PMid:27173534.

Wang, T., Li, X., Chen, C., & Chen, X. (2022b). *Preparation method of Morinda citrifolia enzyme fruit wine and Morinda citrifolia enzyme fruit wine* (Patent CN114395460A) Espacenet. https://worldwide.espacenet.com/patent/search/family/081234079/publication/CN114395460A?q=CN114395460A

Wang, X., Shen, K., Tang, S., Li, P., Zhou, H., Luo, X., Qiu, S., & Ban, S. (2022a). Study on the construction and aroma-producing characteristics of the recombinant *Saccharomyces cerevisiae* strain W303-EAT. *European Food Research and Technology*, 248(2), 447-456. http://doi.org/10.1007/s00217-021-03890-z.

Wang, Y., Zeng, X. A., & Cai, J. L. (2021). Preparation of low-alcohol pineapple wine by different methods of terminating fermentation. *Xiandai Shipin Keji*, *37*(3), 70-76. http://doi.org/10.13982/j.mfst.1673-9078.2021.3.0297.

Wang, Z., Svyantek, A., & Hatterman-Valenti, H. (2023). Chemical and Chromatic Effects of Commercial Wine Yeast Strains (*Saccharomyces* spp.) on "Dolgo" Crabapple Rosé Cider. *Current Research in Environmental & Applied Mycology*, *13*(1), 79-91. http://doi.org/10.5943/cream/13/1/6.

World Health Organization – WHO. (2010). *Global strategy to reduce the harmful use of alcohol*. https://www.who.int/publications-detail-redirect/9789241599931

World Health Organization – WHO. (2020). *Alcohol pricing in the WHO European Region: Update report on the evidence and recommended policy actions*. https://www.who.int/publications-detail-redirect/10665-336159

World Health Organization – WHO. (2022a). *World health statistics 2022: monitoring health for the SDGs, sustainable development goals*. https://www.who.int/publications/i/item/9789240051157

World Health Organization – WHO. (2022b). *Alcohol*. https://www.who.int/news-room/fact-sheets/detail/alcohol

World Intellectual Property Organization – WIPO. (2020a). *The Global Innovation Index 2020 (GII): Japan*. https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2020/jp.pdf

World Intellectual Property Organization – WIPO. (2020b). *China Becomes Top Filer of International Patents in 2019 Amid Robust Growth for WIPO's IP Services, Treaties and Finances*. https://www.wipo.int/pressroom/en/articles/2020/article_0005.html

World Intellectual Property Organization – WIPO. (2021). *Global Innovation Index 2021: Tracking Innovation through the COVID-19 Crisis*. https://www.wipo.int/wipo_magazine/en/2021/03/article_0002.html

Yang, W., Liu, S., Marsol-Vall, A., Tähti, R., Laaksonen, O., Karhu, S., Yang, B., & Ma, X. (2021). Chemical composition, sensory profile and antioxidant capacity of low-alcohol strawberry beverages fermented with *Saccharomyces cerevisiae* and *Torulaspora delbrueckii*. *Lebensmittel-Wissenschaft + Technologie*, *149*, 111910. http://doi.org/10.1016/j.lwt.2021.111910.

Yang, X., Zhao, F., Yang, L., Li, J., & Zhu, X. (2022). Enhancement of the aroma in low-alcohol apple-blended pear wine mixed fermented with *Saccharomyces cerevisiae* and non-*Saccharomyces* yeasts. *Lebensmittel-Wissenschaft + Technologie*, *155*, 112994. http://doi.org/10.1016/j.lwt.2021.112994.

Zhang, B., Yu, R., Liu, Y., Lyu, X., Yang, F., & He, T. (2022). *Brewing method of fermentation type low-alcohol wine* (Patent CN115786051A). Espacenet. https://worldwide.espacenet.com/patent/search/family/085427288/publication/CN115786051A?q=CN115786051A

Zhou, Y., Zhou, S., Zhou, Q., & Chen, L. (2021). *Yeast strain with low ethanol yield and high aroma and use thereof* (Patent CN113773977A). Espacenet. https://worldwide.espacenet.com/patent/search/family/078873218/publication/CN113773977A?q=CN113773977A

Supplementary Material

Supplementary material accompanies this paper.

Table S1. The most used keywords in the field of low-alcohol fruit wines research.

This material is available as part of the online article from https://doi.org/10.4322/biori.00212023