Use of biotechnology to produce alcoholic and acetic fermentation: A review

Uso da biotecnologia para produção de fermentação alcoólica e acética: Uma revisão

Uso de la biotecnología para producir fermentaciones alcohólica y acética: Una revisión

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Adriana Rodrigues Machado
ORCID: https://orcid.org/0000-0002-2641-256X
Instituto Federal Goiano, Brazil
E-mail: adririzo85@gmail.com
Maria Inês Rodrigues Machado
ORCID: https://orcid.org/0000-0001-8016-6999
Universidade Federal do Cariri, Brazil
E-mail: inês.machado@edu.br
Letícia Fleury Viana
ORCID: https://orcid.org/0000-0002-2473-9446
Instituto Federal Goiano, Brazil
E-mail: leticia.viana@ifgoiano.edu.br

Abstract
Biotechnology enables numerous processes, such as fermentation, which uses desirable microorganisms to add value to commercial importance products. Alcoholic fermentation, a type of chemical reaction carried out by microorganisms (yeasts) in sugars, yields ethanol and carbon dioxide. Fermented acetic acid has been defined as the product obtained from the acetic fermentation of alcoholic liquid from fruit must, cereal, vegetable, honey, mixtures of vegetables, and hydroalcoholic mixtures. This review aimed to introduce alcoholic and acetic fermentation concepts and highlight the importance of several research types in the fermentation of different raw materials.
Keywords: Acetobacter; Ethanol; Yeast; Vinegar.

Resumo
A biotecnologia permite numerosos processos, como a fermentação, que utiliza microrganismos desejáveis para acrescentar valor a produtos de importância comercial. A fermentação alcoólica, um tipo de reação química realizada por microrganismos (leveduras) em açúcares, produz etanol e dióxido de carbono. O ácido acético fermentado foi definido como o produto obtido da fermentação acética do líquido alcoólico de mostos de frutas, cereais, vegetais, mel, misturas de vegetais e misturas hidroalcoólicas. Esta revisão teve como objetivo introduzir conceitos de fermentação alcoólica e acética e realçar a importância de vários tipos de investigação na fermentação de diferentes matérias-primas.
Palavras-chave: Acetobacter; Etanol; Levedura; Vinagre.

Resumen
La biotecnología permite numerosos procesos, como la fermentación, que utiliza microorganismos deseables para añadir valor a productos de importancia comercial. La fermentación alcohólica, un tipo de reacción química llevada a cabo por microorganismos (levaduras) en azúcares, produce etanol y dióxido de carbono. El ácido acético fermentado se ha definido como el producto obtenido de la fermentación acética del líquido alcohólico procedente de mostos de frutas, cereales, hortalizas, miel, mezclas de hortalizas y mezclas hidroalcohólicas. Esta revisión pretende introducir los conceptos de fermentación alcohólica y acética y destacar la importancia de varios tipos de investigación en la fermentación de diferentes materias primas.
Palabras clave: Acetobacter; Etanol; Levadura; Vinagre.

1. Introduction

Biotechnology has currently been one of the essential tools that benefit different sectors of society (Carvalho, 2015; Faleiro et al., 2011) since it uses desirable microorganisms to add value to commercial importance products. Alcoholic fermentation, a type of chemical reaction carried out by microorganisms (yeasts) on sugars, yields ethanol and carbonic gas. In contrast, acetic fermentation performs a chemical reaction that consists of partial oxidation of ethyl alcohol by bacteria with acetic acid production (Fagundes Neto, 2018; Ferreira & Montes, 1999). Virtually all fruit and sugary material can produce fermented beverages, provided that there are adequate moisture content and nutritive salts for the yeast (Fagundes et al., 2015;

Santos et al., 2005).

In the Brazilian legislation, a fermented fruit beverage is defined as a beverage with an alcoholic strength which ranges from 4% to 14% by volume (20 ° C). It must be obtained by the alcoholic fermentation of fresh, ripe, and healthy fruit must be of a species, its whole or concentrated juice or its pulp. The fermented beverage shall be called fermented beverage of the original fruit, such as fermented beverage of orange and fermented beverage of strawberry. Beverages may be carbonated when carbon dioxide is added to them (Brasil, 2009; Fagundes et al., 2015).

Fermented acetic alcohol is defined as the product obtained from acetic fermentation of the fermented alcoholic beverage of fruit, cereal or vegetable must, honey, mixtures of vegetables, and hydroalcoholic mixtures. It should have minimum volatile acidity of 4 g. 100 mL^{-1}, expressed as acetic acid, may have vegetable, aromatic plant extracts, juices, natural aromas, and condiments (Marques et al., 2010).

The Food and Agriculture Organization of the United Nations (FAO) establishes that vinegar is a liquid that is allowed for human consumption and shall be produced from agricultural raw materials containing starch and sugars using two consecutive fermentation processes. The first alcoholic fermentation shall be carried out by yeast, which transforms sugars into ethanol, followed by an acetic fermentation, carried out by aerobic bacteria of the genus Acetobacter, which convert ethanol into acetic acid, the main product of vinegar (Parrondo et al., 2003; Suman & Leonel, 2013).

In Brazil, the Ministry of Agriculture, Livestock, and Supply regulate vinegar's quality and identity. In the '90s, it controlled and allowed the commercialization of Agrin, a fancy brand of a blend composed of 90% fermented acetic alcohol and 10% fermented acetic pure red or white wine with minimum volatile sour acidity of 4g. 100 mL^{-1}, (Aquarone & Zancaro, 1990; Marques et al., 2010; Spinosa, 2002).

Thus, in Brazil, neither manufacture nor sale of artificial vinegar, i. e., vinegar produced from the dilution of acetic acid obtained from the synthesis of ethylene or dry distillation of wood, are allowed (Brasil, 1999; Leão et al., 2019; Machado et al., 2019). Adulteration of alcoholic vinegar or even of acetic acid to sell it as if it were wine vinegar, with the addition of substances, such as molasses, grape wine, wine vinegar, vinasse, or dyes, has been a common practice in some countries (including Brazil) since its identification is practically impossible by routine analyzes carried out by the bodies that are responsible for standardization of foods and beverages (Aquarone & Zancaro, 1990; Araújo, 2012) .

According to Alvarenga (2014) citing Fukaya et al. (1992) and Mecca et al.(1979), vinegar has been used worldwide as a condiment and food preservative. Also, it is considered an essential complement to human food due to its nutritional and bioregulatory activity. Tessaro et al. (2010) argue that traditional wine vinegar is highly valued in gastronomy. Their economic role has been increasing rapidly in ecological importance regions, such as southern Spain, besides being an essential condiment in the Mediterranean diet. Far from being the simple result of a change in wine, these vinegar have become unique, precious, and expensive products (Parrilla et al., 1997; Suman, 2012).

Vinegar has been historically recorded for more than ten thousand years. There is currently a variety of vinegar that has been widely used in different countries, such as cereal vinegar in China and Japan, wine vinegar in France, malt vinegar in England, and persimmon and pineapple vinegar in southeastern Asia (Xia et al., 2020; W. Xu et al., 2011).

Therefore, this study aimed at elaborating a review about alcoholic and acetic fermentation to highlight the importance of several investigations into the fermentation of different raw materials. Thus, this is a study with data collection performed from research tools such as Scopus, Scielo, Pubmed, Science direct, Google academic, through a bibliographic survey and based on the authors' experience when performing an integrative review. Thus, the integrative review is a method that provides the synthesis of knowledge and the incorporation of the applicability of the results of significant studies in practice.

2. Development

2.1 Historical period of alcoholic fermentation

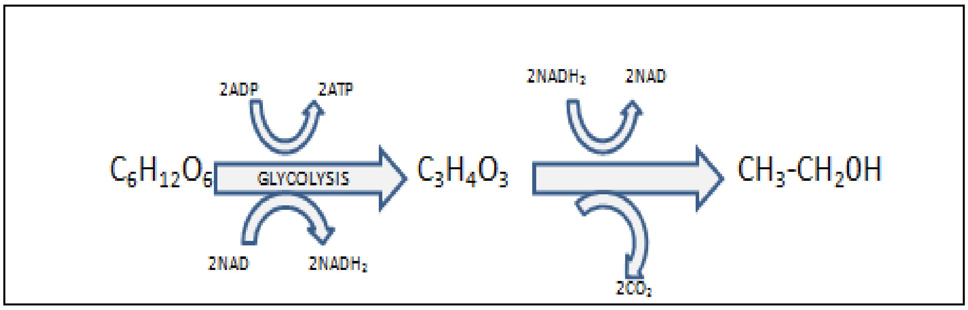
Fermentation originates from the Latin term *fervere*, which means bubbling or boiling. It resulted from the release of carbon dioxide during grape fermentation for wine production (Vasconcelos, 2012).

Gupta et al. (2016) cited Ward, (1991), who believed that wine has already been made since 10,000 BC. Therefore, alcoholic fermentation is an ancient process that has been carried out for many centuries. There are records of the development of alcoholic fermentation by the Egyptians and the Sumerians, who employed it to make wine and (Paul Ross et al., 2002; Ray & Joshi, 2014).

2.1.1 Biochemical concept: alcoholic fermentation

Fermentation comprises a set of enzymatically controlled reactions, whereby an organic molecule is degraded into simpler compounds and releases energy. The process begins with glucose activation, which receives, in successive reactions, two energetic phosphates supplied by two molecules of adenosine triphosphate (ATP) that become adenosine diphosphate (ADP). Thus, two ATP molecules are yielded for each glucose molecule (Corazza et al., 2001). Figure 1 shows the process of transformation of sugar into alcohol.

Figure 1 - Cycle of transformation of alcoholic fermentation.



Source: Adapted by the authors.

According to de Almeida Lima (2001)alcoholic fermentation is defined as the method of preserving food and beverages. It is the process in which anaerobic degradation of glucose occurs, with the transformation of sugars into ethanol and CO_2, catalyzed by enzymes and carried out mainly by yeasts, to obtain energy in ATP, which is used for performing their physiological activities growth, and reproduction. Ethanol is a byproduct of this process.

2.2 Historical period of acetic fermentation

Vinegar is a product that has been known for a long time. Its earliest references date back to 10,000 years when wine production was also referenced and vinegar formation. Its production was evidenced in the Babylonian culture about 5,000 years BC. The word vinegar derives from the French term *vinaigre*, whose meaning – "sour wine" – has been used in almost all Western languages, except in Italian (Aceto) and German (Essig) (Palma et al., 2001; Venquiaruto et al., 2016).

2.2.1 Biochemical concept: acetic fermentation

Acetic fermentation corresponds to the transformation of alcohol into acetic acid by certain bacteria, which confers its characteristic taste of vinegar (Rizzon, 2006).This process consists of partial aerobic oxidation of ethyl alcohol with acetic acid production (Figure 2). It can also develop during the deterioration of drinks with low alcohol content caused by acetobacter, yielding acetic acid and CO_2 (Mendes, 2019).

Figure 2 - Cycle of transformation of acetic fermentation.

Source: Adapted by the authors.

The ideal acetic acid bacterium is the one that resists a high concentration of alcohol and acetic acid, with the bit of nutritional requirement, high rate of transformation of alcohol into acetic acid, good processing yield without hyperoxidizing acetic acid, besides conferring good taste to the vinegar. These acetic bacteria need oxygen from the air to perform acetification. Therefore, they multiply more in the upper part of the wine, which is being transformed into vinegar and form a veil known as the "mother of vinegar." The thickness of this veil depends on the type of bacteria (Pereira, 2015).

Acetic bacteria usually differ from other aerobic bacteria because they do not wholly oxidize their energy sources in CO_2 and H_2O. Thus, they yield small amounts of other products such as aldehydes, ketones, esters, and organic acids. These bacteria oxidize ethyl alcohol found in the medium in two steps. In the first step, ethanol is oxidized to acetaldehyde, whereas in the second, acetaldehyde is oxidized to acetic acid. Since they are tolerant to acid, they are not harmed by the medium's acidity (Parazzi et al., 2008; Vaz, 2015).

2.3 Formation of compounds during alcoholic and acetic fermentation

During alcoholic and acetic fermentation, compounds that confer flavor and aroma to the vinegar are formed. The fragrance is one of the most important indicators of quality, and, for this reason, choosing raw material, and optimal conditions of acetification is fundamental to form these compounds (Callejón et al., 2008; Fernandes, 2016).

In the stage of alcoholic fermentation, higher alcohols, glycerol, aldehydes, esters, and acetates are components that are formed in less quantity than ethanol. However, these compounds are of great importance for the aroma of fermented alcoholic beverages, such as wine (Coutinho, 2019; Lurton et al., 1995; Marques & Pastore, 1999).

According to Callejón et al.(2009), more than 70 aromatic components, such as acids, alcohols, esters, carbonyl compounds, phenols, lactones, and acetals, have already been identified in wine vinegar. Therefore, aroma, which results from various chemical characteristics, has a wide range of polarity, solubility, and volatility.

Ethanol and methanol are the most abundant alcohols in wine vinegar. The content of ethanol in vinegar represents the residue of the wine-making process. According to the current legislation, the maximum limit of ethanol in commercial vinegar is 1% v/v (Brasil, 1999; Callejón et al., 2008). During the fermentation process, the aim is the highest yield of transformation of ethanol into acetic acid. However, vinegar should contain a little ethanol. Otherwise, in the absence of an alcoholic substrate, acetic bacteria may degrade acetic acid and, consequently, prevent acetic fermentation from taking place (Morales et al., 2001).

About the aroma of wine vinegar, esters are essential components of the fruity and floral scent, which results from the condensation reaction between the acid and alcohol. Volatile esters involved in the aroma are, mainly, ethyl acetate, methyl acetate, and isoamyl acetate (Charles et al., 2000; Souza, 2015).

According to Palacios et al.(2002); Souza (2015), the main aldehyde found in vinegar is acetaldehyde, an intermediate metabolite of acetic fermentation that does not accumulate in the phase of biological activity but decreases because of the oxidative metabolism of fermentation.

3. Production of Alcoholic Fermentation

Several authors have carried out studies of alcoholic fermentation of must from several sources, such as cassava and red fruits, with strains of S. cerevisiae. Curvelo-Santana et al., 2010, used hydrolysate of cassava starch to produce alcohol and obtained a possible result, i. e., yield increased 45%.

González et al. (2011) carried out the fermentation of red raspberries in the solid-state with S. cerevisiae IFI83 at concentrations of 5 x 10^5 cells/g pulp. Hidalgo et al. (2013), evaluated the effect of vaccination on strawberry fermentation with native yeast and acid-acetic bacteria strains. Saccharomyces cerevisiae was selected and tested as the starter cultures. Fermentation processes in which pieces were inoculated and processes in which fermentation was spontaneous were compared, that is, with native songs of the fruit. In the case of alcoholic fermentation, these authors inoculated 2 x 106 cells/mL juice.

Barbosa (2017) carried out a study of analysis and quantification of the alcoholic content of jabuticaba artisanal wine, where they identified physical-chemical properties of jabuticaba wine which reached 17.5% alcohol content, total acidity analysis of 187 meq/L, and volatile acidity of 0.6 meq / L.

Other authors carried out a study of the fermentative process of strawberry and bee honey, which is used for making a drink. The beverage had a dry flavor with a slight strawberry flavor, pH 3.18, 0.5% titratable acidity, and alcohol content of 10.1 ° GL in compliance with the Brazilian legislation's recommendations (Costa et al., 2017).

3.1 Physical, chemical, and microbiological factors which affect alcoholic fermentation

Yeast can be exposed to several stressors, such as temperature, acidity, and bacterial contamination, during fermentation (Basso, 2004; Dias, 2018).

Optimal growth temperature ranges between 20 and 30ºC. Growth cannot occur at temperatures above 35ºC, since it favors contaminants' development, increases acidity, and reduces yeast viability (Vasconcelos, 2012).

Other factors that must be controlled are aeration and agitation. They must be carried out at the beginning of fermentation for better yeast multiplication and avoided during fermentation since oxygen can enable acetic acid formation (Cabral, 2014; Henriques, 2014).

pH is essential in industrial fermentations due to its significant influence on the control of bacterial contamination, effect on yeast growth, and reduction in byproduct formation. In the process of cell recycling, the inoculum is treated in specific wells where the yeast is hydrated, and its pH is adjusted between 2.2 and 3.0 with the addition of sulfuric acid for approximately 3 hours before a new fermentative cycle starts. Sulfur addition favors bacterial loading while maintaining yeast viability (Vasconcelos, 2012).

Another chemical component that can affect alcoholic fermentation is sulfite, which is a component of molasses. Since 1990, Use of molasses in the formulation of the must for alcoholic fermentation has increased 1990. Consequently, the concentration of sulfite has also increased. Sulfite is commonly used in sugar clarification and can be found at high concentrations in sugarcane molasses, thus contributing to decreased alcohol yield and viability of yeast cells (Dorta et al., 2006).

Bacterial contamination is undoubtedly one of the preponderant factors that can affect alcoholic fermentation since it is always found in industrial processes of ethanol production through fermentation (Nobre et al., 2007; Pereira et al., 2020).

In the industrial process of alcohol production, bacterial contamination due to the development of microorganisms in the alcoholic fermentation is a factor that limits the optimization of the process and may cause several problems, such as consumption of sugar and ethanol by contaminants, production of gums, inhibition and loss of viability of yeasts due to toxins and acids, such as lactic and acetic acid, excreted in the medium (Freitas & Romano, 2013, 2014; Gallo, 1990), loss of yeast cells in the bottom of vats or centrifuges, (Freitas & Romano, 2014; Oliva Neto, 1995) flocculation caused by the contact of flocculent bacteria and yeasts and other inconveniences that, together, generate a consequent decrease in the alcoholic yield of wine (Oliva Neto, 1995).

Contaminants in the fermentation lead to severe damage to the yeast and affect productivity and final yield directly. The highest losses caused by this contamination are the degradation of sucrose and the production of organic acids, which cause loss of sugar and yeast intoxication, according to Ceballos-Schiavone (2009).

The Saccharomyces cerevisiae yeast responsible for alcoholic fermentation competes for the substrate with bacteria that usually inhabit fermentation vats. A healthy fermentation process has bacterial levels close to 10^5 cells.mℓ^{-1}. Since contamination levels above 5,0x10^6 UFC.mℓ^{-1} are considered harmful, levels above 10^7 UFC.mℓ^{-1} cause significant losses. In contrast, levels above 10^8 UFC.mℓ^{-1} lead to a decrease in the fermentative yield, hindering centrifuges' operations and consequent increase in the consumption of acids and antibiotics (Andrietta et al., 2006).

Silva (2015) citing Gallo (1990) states that the first way to control and avoid bacterial contamination of fermentative processes in ethanol production begins in the field. Very contaminated raw material, along with problems in the broth treatment, take many contaminating microorganisms and the products of their metabolites to the fermentation process. Since contamination may occur from the field to the last stage of fermentation, conditions of each stage of ethanol production favor the selection and development of microorganisms.

4. Vinegar Production

Vinegar production occurs by two distinct biochemical actions which result from microorganisms in alcoholic fermentation by yeast activity, usually, Saccharomyces species, on raw sugary and amylaceous raw material, followed by acetic fermentation by the activity of aerobic bacteria of the genus Acetobacter (Bortolini et al., 2001; Tesfaye et al., 2002).

Processes of vinegar manufacture are carried out in both discontinuous and semi-continuous manners. In the first case, upon reaching the desired acidity characteristics, all vinegar is collected, and the process starts again. In the second case, upon reaching a particular acidity, part of the product is collected, and an equivalent quantity of raw material is added.

In the fermentation process, either oxygen or industrially pure air may be injected into fermented acetic acid. Fermented alcoholic beverage, nutrient salt, sugar, amino acid, and vitamin may also be injected, provided that it is allowed by the specific legislation, with the sole purpose of feeding acetic bacteria, at the minimum amount required to complement the substrate of acetic fermentation (Brasil, 2012).Therefore, there are three fermented acetic acid production processes: Slow, Fast, and Submerged processes.

4.1 Slow process

The slow process (French or d'Orléans) is the oldest method of vinegar manufacture. Three-quarters of a 200-liter oak barrel is filled with wine (Figure 3). A gelatinous film of Acetobacter, which is called the mother of vinegar (zooglea), forms on its surface in simultaneous contact with the air and the wine. A wooden trellis prevents it from sinking into the liquid. Acetification occurs on the surface, with natural aeration (Suman, 2012; Suman & Leonel, 2013).

Figure 3 - Barrel wooden.

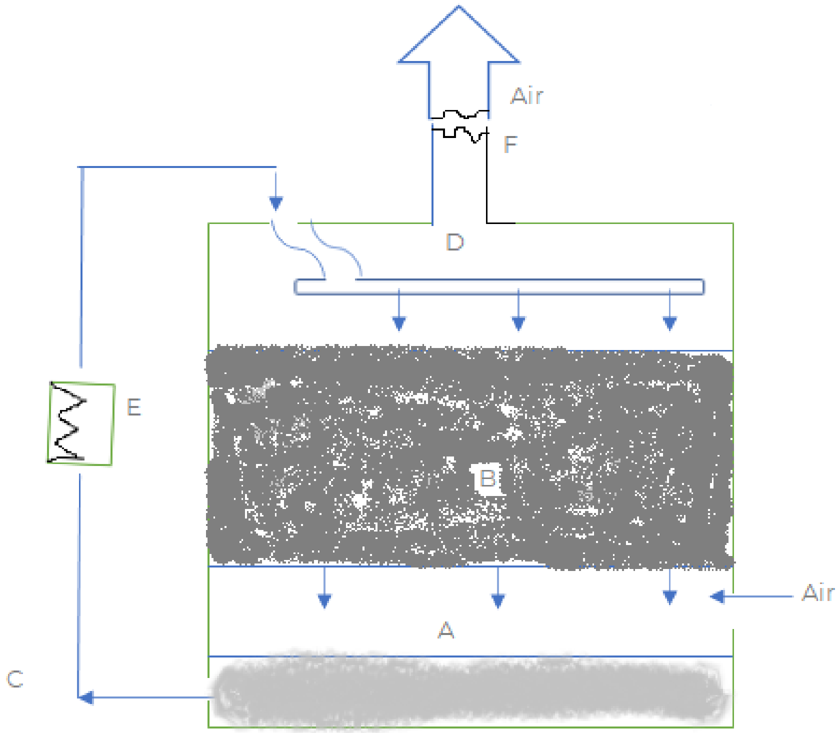
Source: Biorender (https://app.biorender.com).

4.2 Fast process

The primary process of industrial production of vinegar, known as Fast Process or German Process, was developed in Germany in the 19th and 20th centuries. It acknowledged the importance of a production system using a generator (Barbosa, 2017; Spinosa, 2002).

In the Fast process (Schuetzenbach or German), Figure 4, the generator or fermenter is a 100 to 100,000-liter container filled with sawdust or another material with a large contact surface, where acetic bacteria can set. Wine repeatedly circulates in the generator while air is injected in the opposite direction. Since heat does not spread so quickly as in the traditional method, a cooling method is required, establishing a temperature gradient that triggers air circulation. About the Slow process, productivity is higher, but the vinegar quality is lower (Malajovich, 2009; Pereira, 2015; Zancanaro, 2001).

Figure 4 - Fast Process or German Process. Cross section of an acetifier with porous support; A) grating; B) wood shavings; C) pump for moving the wine in the acetification process; D) wine disperser; E) water cooler; F) vapor condensation device.

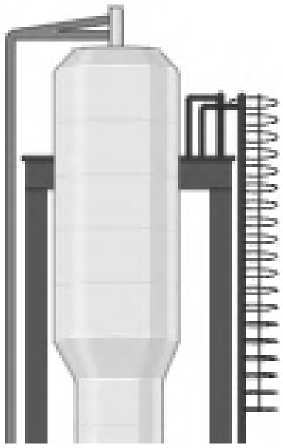


Source: Own authors.

4.3 Submerged process

The Submerged process of vinegar production stands out for its productivity, which is better than other processes and suits the industry most. Its most common equipment is the Frings Acetador (Figure 5). Acetic fermentation can be highly efficient and productive when steel or wood fermenters are equipped with aerators specially developed to provide air at all points of the fermenting must (Palma et al., 2001). In this process, acetic bacteria are submerged in the liquid to be fermented. They multiply and absorb energy from ethyl alcohol's oxidation reaction to acetic acid (Pereira, 2015; Spinosa, 2002).

Figure 5 - Submerged process (Frings Acetador).



Source: Biorender (https://app.biorender.com).

5. Microorganisms

5.1 Saccharomyces cerevisiae

The genus Saccharomyces is one of the most studied groups of microorganisms by the scientific community. This interest is due to the wide application of this microorganism to the biotechnology industry. This yeast has been reported as a food processing agent since 1800 (Andrietta et al., 2006).

Most wine production processes use cerevisiae strains to yield faster and more reliable fermentation, besides avoiding microbial contamination. As a result, these cultures are selected because they optimize the process and improve the raw material quality. The outcome is a product with high quality and good acceptability. Also, Saccharomyces cerevisiae are excellent producers of ethanol and CO_2 and more tolerant to fermentation products and its resilience to adverse conditions of osmolarity a nd pH changes during the fermentation process (Duarte et al., 2010; Parapouli et al., 2020).

Yeasts that belong to the genus Saccharomyces are among essential microorganisms used in fermented foods. They are applied to beer, wine, and bread production, products whose economic impact around the world means trillions of dollars (Hutkins, 2006; Souza, 2015).

In most fermentations, initial yeast cultures are used. Their selection is based on their physiological and biochemical properties (Campos et al., 2010). According to Görgens et al. (2015), Saccharomyces cerevisiae, a well-known yeast that has been widely used in the alcoholic beverage industry and bakeries, is usually the favorite one because it sustains production in the stationary state, can consume several sugar monomeric molecules, has high fermentability, ethanol yield, and ethanol tolerance, besides being "generally recognized as safe" (GRAS).

5.2 Acetobacter acetic

Acetobacter acetic is a bacterium that has been frequently used in the vinegar industry (Tesfaye et al., 2002) because it immediately initiates the fermentation process (Mas et al., 2014). The main species of Acetobacter used in vinegar production are rods and coconuts, forming chains and filaments. Regarding the temperature, the best yield is obtained between 25 ° C and 30 ° C, although they can stand minimum temperatures from 4 ° C to 5 ° C and maximum ones of 43 ° C. However, temperatures below 15 ° C and above 35 ° C make acetic fermentation very slow, as they reduce bacterial activity. As for alcohol, most species stand up to 11.0% v/v. Concerning acetic acid, acetic bacteria generally stand up to 10.0% v/v. The acetification process requires strict oxygen to occur. This is why bacteria multiply in the upper part of the liquid, which is being fermented (Hoffmann, 2006).

5.3 Vinegar characterization techniques

5.3.1 Vinegar composition

What characterizes the composition of vinegar is the raw material that originates it (Xavier et al., 2009). Besides, vinegar is formed by:

- Acetic acid: it is the main component of vinegar, regardless of which substrate originated it. Its concentration is expressed as acetic degrees (grams of acetic acid per 100 ml vinegar) (Xavier et al., 2009).

- Residual ethyl alcohol (ethanol): the industrial production of vinegar aims at obtaining the highest level of yield in the transformation of ethanol into acetic acid. However, the substrate should not be used up because acetic bacteria can degrade the previously yielded acetic acid when there is no ethyl alcohol (Xavier et al., 2009).

-Dry extract is composed of non-volatile substances, such as glycerin and pectic and nitrogenous substances, found in the product. Either very low or very high dry extract contents (6-7 g/L) in the product may imply fraud in the production process (Xavier et al., 2009).

-Ash: the ash content determines the minerals in the product and may also expose fraud in the production process if its minimum levels are 1.0 (g/L) (Xavier et al., 2009).

5.3.2 Factors that influence acetic fermentation

Both pH and acidity have a decisive influence on vinegar quality and sensory acceptability since such parameters are related to sensory perception. In vinegar with 5% acidity, pH ranges from 2.46 to 3.18. However, such characteristics depend on the raw material, such as fruits (grapes, apples, and oranges), and whether they originate from distillates (Marques et al., 2010). The Brazilian legislation recommends that vinegar from fruits must have titratable acidity of at least 4.00 g/100 ml (Brazil, 2012).

The dried extract reduced in fruit kinds of vinegar is verified to evaluate whether they originate from the established raw material's wine. This statement emphasizes that red wine vinegar must use red grapes wine as its raw material. Thus, the Brazilian legislation determines that fruit vinegar must contain at least 6 g/L (Brazil, 2012).

5.4 Vinegar -aid in human digestion

Vinegar is a condiment widely used due to its beneficial properties on the human organism and its importance in food. Daily intake of a liquid containing 15 mL vinegar (750 mg acetic acid) may improve lifestyle-related diseases, such as hypertension, hyperlipidemia, and obesity. Acetic acid and other vinegar components may be responsible for its therapeutic effect (Samad et al., 2016).

Several studies have highlighted the biological properties of vinegar and the health benefits it can provide. Vinegar in food makes it more digestive, especially leafy vegetables, since they are softened and have their digestion improved by the gastric juice. In the human organism, it increases the activity of gastric ferments and, at the same time, leads to a stimulating effect on the pancreatic gland. It is considered better than other acidic foods because it contains acetic acid, which is the most dissociable organic acid and favorable to digestion (Bortolini et al., 2001; Hoffmann, 2006). The use of vinegar also promotes blood pressure control, stimulates appetite (Kondo et al., 2001; Q. Xu et al., 2007), promotes the absorption of calcium (Hadfield et al., 1989; Q. Xu et al., 2007), prevents arteriosclerosis, cardiovascular diseases, inflammatory processes and various types of carcinomas (Tapiero et al., 2002), promotes the replacement of hepatic and muscular glycogen and contributes to a reduction in levels of cholesterol and triglycerides (Fushimi et al., 2001).

According to Budak & Guzel-Seydim (2010)phenolic compounds in wine and vinegar positively affect health because they have antioxidant effects. These authors studied Ulugbey Karasi grape vinegar production by two processes, i. e., by the Slow or Surface process and by the Industrial one. They evaluated whether the production process could influence the antioxidant activity and phenolic compounds. They observed that the content of phenolic compounds in vinegar yielded by industries was higher than the one found by the Slow process (2690 mg. L^{-1} and 2461 mg. L^{-1} GAE, respectively). Concerning antioxidant compounds, these authors verified that the vinegar produced by the Industrial method (13.50 mmol. L^{-1}) had a slightly higher value than the one recorded by the Slow method (10.37 mmol. L^{-1}).

5.5 Fermentation production

Several studies of the production of fermented beverages have various sources, such as fruits, cereal, and honey.

Silva et al. (2007) produced cashew wine of demi-sec grade in a stirred batch reactor. They found a concentration of acetic acid in cashew vinegar above 4%, as required by the Brazilian legislation (Vieira, 2020).

Miranda et al. (2014) evaluated kefir's effect regarding its viability for ethanol production by alcoholic fermentation and got satisfactory results of kefir fermentation in ethanol production. Alvarenga et al. (2015) analyzed discarded pulp in pineapple processing as a possible substrate for alcoholic fermentation. They concluded that small producers and extensive industrial processes could use pineapple peel to obtain distillates, vinegar, and ethanol.

Ubeda et al. (2011) produced vinegar from surplus production of strawberries grown in Spain (the second-largest producer of strawberries) by double fermentation (alcoholic and acetic one) to study the evolution of antioxidant activity, total phenols, and monomeric anthocyanins in the vinegar production process (in glass containers and oak and cherry tree barrels). The authors found that these parameters increased when sulfur dioxide and pectolytic enzymes were added to the substrates and when wooden barrels, mainly made of cherry tree wood, were used. According to the authors, the acidification phase led to a high loss of antioxidant compounds in general.

In this study, volatile compounds responsible for the aroma could be characterized by GC-FID and identified by GC / MS and Chromatography-olfactometry gas (GC-O). Bertelli et al. (2015) studied the chemical composition and functional characterization of Modena balsamic vinegar (BVM) and of traditional balsamic vinegar from Modena (TBVM) by different methods of testing phenolic content and antioxidant activity.

Spinosa et al. (2015) studied the use of alcoholic fermented rice (Oryza sativa L.) for the production of vinegar, in which a process of submerged fermentation oxidized the alcoholic solution with ethanol at 6.28% (w/v) to produce vinegar. The fermentation process of acetic acid occurred at 30 ± 0.3 ° C in a FRINGS® Acetador (Germany) for vinegar production. Rice vinegar had total acidity of 6.85% (w / v), 0.17% alcohol (w / v).

Zoche et al.(2015) studied Brazilian grape vinegar production by spontaneous fermentation in different fermentation conditions. Leonel et al. (2015) evaluated the effects of acid fermentation parameters on the production of ginger vinegar; they reached high-quality vinegar with high yield.

Xiong et al. (2016) stated that Chinese vinegar is mainly made from grain crops in a long manufacturing period. They highlighted four types of traditional vinegar in China, i. e., aromatic vinegar, ripe vinegar, rice vinegar, and white vinegar. In this study, this vinegar's antioxidant properties and hepatoprotective mechanisms on hydrogen peroxide-induced oxidative stress (H_2O_2) were investigated (Xia et al., 2017).

Xiangxi vinegar is one of the traditional fermented vinegars from the Hunan Province. It is produced from herbs, rice, and spring water by spontaneous techniques of liquid-state fermentation. In their study, the authors investigated the antioxidant property of this vinegar. They analyzed its antioxidant compounds, its property to eliminate in vitro and in vivo free radicals, and its positive effects on antioxidant enzyme activity and apoptosis in Caenorhabditis elegans (Huang et al., 2017).

5.6 Publications about alcoholic and acetic fermentation

Articles published in recent years on alcoholic and acetic fermentation are shown in Table 1.

Table 1 - Recent publications on alcoholic and acetic fermentation.

Article	Objective	Type of fermentation	References
Myrtle (Eugenia gracillima Kiaersk.) as a fermented alcoholic beverage alternative to wine: Preliminary study	This preliminary study aimed to develop myrtle-based fermented alcoholic beverages and evaluate the effects of different concentrations of total soluble solids (TSS), in which B1 (15 °Bx) and B2 (20 °Bx)	Alcoholic fermentation	Feitosa et al. (2023)
Ultrasound Treatment Influence on Antioxidant Properties of Blueberry Vinegar	The aim of this research was to investigate the antioxidant properties of experimental vinegar variants obtained by an innovative manufacturing recipe using an alcoholic substrate containing blueberry juice for a rapid initiation of acetic fermentation.	Acetic fermentation	Padureanu et al. (2023)
Vinegar production via spontaneous fermentation of different prickly pear fruit matrices: changes in chemical composition and biological activities	This study focused on the valorization of prickly pear (PP) fruit (Opuntia ficus-indica) into vinegar by spontaneous surface fermentation on different starting matrices (with/without the addition of sucrose and with/without PP peel in the raw material).	Acetic fermentation	Hammouda et al. (2023)
Production of Herbal Vinegar Using Isolated Microorganisms from Traditional Herbal Vinegar Fermentation	Schizosaccharomyces pombe YM-19 and Acetobacter pasteurianus EM2-03 were isolated and identified from the traditional herbal vinegar fermentation process using cultural and molecular techniques.	Acetic fermentation	Thongluedee et al. (2023)
Bioconversion of Agricultural and Food Wastes to Vinegar	The production and biotransformation of agricultural and fruit wastes into vinegar and the genetic manipulations done on microorganisms to utilize a wide range of substrates and achieve maximum product titer.	Acetic fermentation	Saha et al. (2023)
The bioconversion of pineapple waste extract into vinegar with using various sugar concentrations and its antioxidant activity	The aim of this study was to determine the effect of adding sugar with various concentrations in producing acetic acid and its antioxidant activity in producing vinegar from pineapple waste.	Acetic fermentation	Jannah et al. (2023)
Production of Vinegar Mango Using Acetobacter tropicalis CRSBAN-BVA1 and CRSBAN-BVK2 Isolated from Burkina Faso	Production and quality of vinegar from mango juice was evaluated using a two steps production procedure	Acetic fermentation	Ouattara et al. (2023)
Pyruvic acid stress caused color attenuation by interfering with anthocyanins metabolism during alcoholic fermentation	In this study, PA has induced in the simulative wine fermentation system contained a single and typical anthocyanin, cyanidin-3-O-glucoside (C3G). The color change was determined, the anthocyanins corresponding derivatives and degradation products were identified and quantified, and the non-targeted metabolomic analysis was conducted for the anthocyanins related metabolites profile under PA stress. This study will be beneficial to a better understanding of the effect of PA on anthocyanins profile and during alcoholic fermentation.	Alcoholic fermentation	Li et al. (2022)
Physicochemical characterization, bioactive compounds, in vitro antioxidant activity, sensory profile and consumer acceptability of fermented alcoholic beverage obtained from Caatinga passion fruit (Passiflora cincinnata Mast.)	The aim of this research was to evaluate the quality of fermented alcoholic beverage from passion fruit produced using passion fruit species obtained from the Brazilian Caatinga biome (Passiflora cincinnata Mast.).	Alcoholic fermentation	Santos et al. (2021)

Evaluation of quality the pumpkin, wild plum, pear, cabbage traditional homemade vinegars using the spectroscopy and rheology methods	In this study, the quality evaluation of homemade pumpkin, pear, wild plum and cabbage vinegar produced by traditional methods was carried out using the ultraviolet (UV) spectroscopy, rheology technique and Fourier transform infrared (FTIR) spectroscopy method.	Acetic Fermentation	Öztürk (2021)
Taste-active indicators and their correlation with antioxidant ability during the Monascus rice vinegar solid-state fermentation process	The present study evaluated the changes of taste profiles, taste active indicators, and antioxidant activity in Monascus rice vinegar during the solid-state fermentation process, as well as their potential relationships.	Acetic Fermentation	Gao et al. (2021)
The use of wood vinegar as a non-synthetic herbicide for control of broadleaf weeds	The objectives of this research were to 1) identify the composition and property of wood vinegar resulting from the pyrolysis of elm (Ulmus spp.) tree pruning waste and 2) evaluate the efficacy of wood vinegar for control of several broadleaf weed species.	Acetic fermentation	Liu et al. (2021)
Fine tuning of medium chain fatty acids levels increases fruity ester production during alcoholic fermentation.	Pichia fermentans Z9Y-3 and its intracellular enzymes were inoculated along with S. cerevisiae in synthetic grape must modulate fruity ester production. The levels of ester-related enzymes, ester precursors, and fruity esters were monitored every 24 h during fermentation.	Alcoholic fermentation	Kong et al. (2021)
Traditional homemade Tunisian vinegars: Phytochemical profile, biological, physicochemical and microbiological properties	The aim of this study was to investigate the diversity of Tunisian fruit vinegars, such as grape vinegars (GV), fig (FV), prickly pear (PPV) and dates (DV), in terms of their physicochemical, microbiological and biological properties, as well as their phytochemical profiles.	Acetic fermentation	Ben Hammouda et al. (2021)
Dynamic changes in physico-chemical attributes and volatile compounds during fermentation of Zhenjiang vinegars made with glutinous and non-glutinous japonica rice	This study analyzed and compared the physico-chemical properties changes and volatile composition throughout the whole process at different stages of two kinds of vinegars, which were fermented under the traditional production process of Zhenjiang aromatic vinegar with glutinous rice (ZAV) and non-glutinous japonica rice (RV).	Acetic fermentation	Gong et al. (2021)
ATR-MIR spectroscopy as a process analytical technology in wine alcoholic fermentation – A tutorial	The goal of this article is to guide the reader through the critical points to be faced when monitoring a fermentation following a Process Analytical Technology (PAT) approach. To achieve this purpose Attenuated Total Reflectance – Mid-Infrared (ATR-MIR) spectroscopy coupled to chemometric techniques are proposed.	Alcoholic fermentation	Schorn-García et al. (2021)
Vinegar from Anacardium othonianum Rizzini using submerged fermentation	This work aims to investigate the production of A. othonianum Rizzini vinegar using submerged fermentation.	Acetic fermentation	da Rocha Neves et al. (2021)
Antioxidant capacity, phytochemical compounds, and volatile compounds related to aromatic property of vinegar produced from black rosehip (Rosa pimpinellifolia L.) juice.	This study aimed to produce vinegar with enormous functional properties from the black rosehip fruits, which is disadvantaged due to its low water content, and high functional activities, and to convert from this fruit into a high value-added product.	Acetic fermentation	Pashazadeh et al. (2021)
Barley malt wort and grape must blending to produce a new kind of fermented beverage: A physicochemical composition and sensory survey of commercial products	The aim of this work was the physicochemical, volatile, and sensory profile characterization of 22 commercial samples.	Alcoholic fermentation	De Francesco et al. (2021)
Wood vinegar resulting from the pyrolysis of apple tree branches for annual bluegrass control	Wood vinegar, resulting from the pyrolysis of wood-waste materials, exhibits herbicidal activity against various broadleaf and grass weeds. The objectives of this research were to investigate the composition, property, and efficacy of wood vinegar resulting from the pyrolysis of pruned apple (Malus × domestica Borkh.) tree branches for control of annual bluegrass (Poa annua L.).	Acetic fermentation	Liu, Wang, et al. (2021)
Acetic Acid Fermentation of Soybean Molasses and Characterization of the Produced Vinegar	This study aims to evaluate the parameters required for the acetic acid fermentation of soybean molasses and characterise the resultant vinegar. To study the most suitable parameters for the acetic acid fermentation, vinegar was produced from the alcohol fermentation of soybean molasses through eight fermentation cycles: five for adaptation and three for production.	Acetic Fermentation	Miranda et al. (2020)
Effects of pectinase treatment on the physicochemical and oenological properties of red dragon fruit wine fermented with Torulaspora delbrueckii	In this study, we evaluated the effects of pectinase pre-treatment on red dragon fruit wine fermented with Torulaspora delbrueckii	Alcoholic fermentation	Jiang et al. (2020)
Sour cherry (Prunus cerasus L.) vinegars produced from fresh fruit or juice concentrate:	In this study, it was aimed to determine the bioactive compounds and volatile aroma compounds of the sour cherry vinegar, and to investigate the usability of concentrated juice instead of the fresh fruit juice in vinegar production	Acetic Fermentation	Özen et al. (2020)

Bioactive compounds, volatile aroma compounds and antioxidant capacities			
Factors influencing the production of the antioxidant hydroxytyrosol during alcoholic fermentation: Yeast strain, initial tyrosine concentration and initial must	This work explored the factors that could increase the content as the strain of yeast, the initial tyrosine concentrations as precursor and the effect of synthetic and sterilized natural grape musts.	Alcoholic fermentation	Rebollo-Romero et al. (2020)
Cashew wine and volatile compounds produced during fermentation by non-Saccharomyces and Saccharomyces yeast	In this study, the ability to ferment cashew apple juice of non-Saccharomyces strains previously isolated from tropical fruits and Saccharomyces were evaluated, as well as their production of desirable volatile compounds	Alcoholic fermentation	Rêgo et al. (2020)
Bio-functional alcoholic beverage preparation using prickly pear juice and its pulp in combination with sugar and blossom honey	A bio-functional alcoholic beverage using prickly pear juice and its pulp, in combination with sugar and blossom honey was studied.	Alcoholic fermentation	Karabagias et al. (2020)
Evaluation of cagaita (Eugenia dysenterica) fruits for acetic fermented production.	This work aimed to characterize fruits and elaborate alcoholic and acetic fermentation of cagaita (Eugenia dysenterica DC.).	Alcoholic and acetic fermentation	Santana (2019)
Traditional Fermented Alcoholic Beverages of Rwanda (Ikigage, Urwagwa, and Kanyanga): Production and Preservation	The purpose of this chapter is to document the production processes of these traditional Rwandan alcoholic beverages and to highlight, where appropriate, the technological advances made, as well as to suggest what could be done for improving the production process and preserving the traditional alcoholic beverages of Rwanda for the future generation.	Alcoholic fermentation	Lyumugabe & Bajyana Songa (2019)
The development of an alternative fermentation model system for vinegar production	This study was conducted to develop and optimise an alternative fermentation model system using mushrooms (Pleurotus pulmonarius and Volvariella volvacea) and yeast (Saccharomyces cerevisiae) as the starter cultures, while standard glucose solution was used as the substrate for fermentation	Acetic fermentation	Mat Isham et al. (2019)

Source: Own authors.

6. Final Considerations

This study concluded that fermented acetic acid (vinegar) is an essential ingredient in Brazilian cuisine, as well as in many parts of the world since it can benefit consumers' health.

Both alcoholic and acetic fermented liquids from several sources have drawn attention due to their functional advantages.

Further research should be carried out to verify the availability of acetic fermentation with existing fruits worldwide to verify beneficial properties that may be transferred to vinegar.

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