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A Concise Review of Methods for Producing Low-Alcohol Distilled Spirits

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Abstract: In recent years, there has been a growing consumer focus on health and wellness, leading to an increased demand for low-alcohol beverages that provide the sensory experience of traditional alcoholic drinks. Distilled spirits, typically produced through distillation and containing high alcohol by volume (ABV), can be adapted to meet this demand. Several methods exist to control or reduce the alcohol content in these beverages while preserving their organoleptic properties. Alcohol formation can be limited by interrupting fermentation, employing cold fermentation conditions, using low-fermenting yeast strains, and adjusting the composition of raw materials. Additionally, post-fermentation techniques to remove alcohol before distillation include vacuum, centrifugal, reverse osmosis, solvent extraction, pervaporation, osmotic distillation, nanofiltration, and dialysis. This review examines these techniques and their effectiveness in reducing the alcohol content of distilled spirits while maintaining desirable sensory characteristics.

Keywords: Distilled Spirits, Low Alcoholic beverages, Alcohol reduction techniques, Health promoting, Organoleptic properties.

Introduction:

Alcoholic beverages are the alcoholic drinks that are consumed most throughout the world. An alcoholic beverage can be produced by fermentation of grains, fruits, or other sugars into ethanol (Fentie et al., 2020). Throughout the world, numerous types of alcoholic beverages are consumed, with beer standing out as the most popular alcoholic drink and the third most consumed beverage after water and tea (Prabu et al., 2021). Since the invention of the first alcoholic beverage, the alcohol content in these drinks has been steadily increasing. However, excessive alcohol consumption can lead to severe health problems (Giri et al., 2023). Therefore, it is imperative to limit the alcohol content in beverages to a certain amount.In recent days, there has been a notable increase in the popularity of low-alcoholic beverages. Numerous studies have projected that the sales of these beverages are expected to rise by 30% by 2024 (Anderson et al., 2022). This trend reflects a broader societal shift towards health consciousness, with consumers increasingly opting for foods and drinks that are perceived as healthier and less harmful. In response to this growing demand, the beverage industry is keen to supply products that align with these health-conscious preferences (Krasnova et al., 2020). Manufacturers are focusing on creating low-alcohol options that not only meet safety standards but are also appealing and acceptable to consumers. This shift towards healthier alternatives is indicative of a larger movement within the industry to prioritize consumer health and well-being.

The consumption of alcohol presents a complex interplay of both positive and negative effects, contingent upon the amount ingested. Numerous studies have explored these effects, highlighting that the quantity consumed plays a critical role in determining the overall impact on health (Brutman et al., 2020). Moderate alcohol consumption has been associated with certain health benefits. For instance, research indicates that moderate intake of alcohol, particularly red wine, may reduce the risk of cardiovascular diseases. This is attributed to the presence of antioxidants, such as resveratrol, which can improve heart health by increasing high-density lipoprotein (HDL) cholesterol and protecting against artery damage (Wotherspoon et al., 2020). Additionally, moderate alcohol consumption has been linked to a lower risk of developing type 2 diabetes and may even offer cognitive benefits, potentially reducing the risk of dementia in older adults (Arora et al., 2023).

Conversely, excessive alcohol consumption poses significant health risks. Elevated levels of alcohol intake can lead to a range of serious health problems, including liver disease (such as cirrhosis), cardiovascular issues (like hypertension and cardiomyopathy), and an increased risk of various cancers (such as those of the liver, mouth, throat, esophagus, and breast) (Chikritzhs & Livingston. 2021). Chronic heavy drinking can also lead to neurological damage, and mental health disorders (including depression and anxiety), and can exacerbate social and behavioral issues, such as violence and accidents (MacKillop et al., 2022). Furthermore, alcohol dependency and addiction are significant concerns, often requiring professional intervention and support.

Classification of distilled spirits:

Distilled spirits are the alcoholic beverage containing an alcohol content above 30% abv. The type of distilled spirit depends on the type of raw material used in the process. The process involves fermentation and distillation of wash. The distills are aged before consumption.

Whiskey: Whiskey, often regarded as the world's oldest distilled beverage, traces its origins to Ireland in the mid-12th century. This distilled alcoholic drink is crafted from grains such as barley, corn, rye, and wheat, and typically contains an alcohol content of about 40 to 50% ABV (alcohol by volume) (Okolo et al., 2023). The production of whiskey involves the fermentation of a grain mash, followed by the distillation of the fermented wash. The resulting spirit is then aged in oak barrels, which contributes to its unique flavor profile. Several types of alcoholic beverages gain their distinct characteristics through different processing methods and the specific raw materials used (Gollihue et al., 2021).

Rum: Rum is an alcoholic beverage with an alcohol by volume (ABV) of 40%. It is a distilled spirit made from the fermented wash of sugarcane byproduct molasses (Mangwanda et al., 2021). Rum can be classified into two types based on their aging duration: dark rum and light rum. Dark rum is characterized by its rich flavor and deep color, resulting from prolonged aging. In contrast, light rum has a lighter color and milder flavor due to its shorter aging period (Anderson, 2020).

Vodka: Vodka is produced through the fermentation of saccharified cereals or potatoes followed by distillation (Mason et al., 2023). These fermentations can be conducted in either batch or continuous processes, with continuous processes generally offering better economic efficiency. Vodka typically has an alcohol content of 55 to 60% ABV. It is a colorless and odorless distilled spirit with one of the highest alcohol contents among distilled spirits. Vodka contains very few or no congeners, making it exceptionally pure (Chettri et al., 2022).

Gin: Gin is a distilled beverage derived from juniper berries. Distilled gin is produced by distilling alcohol in the presence of juniper berries. Similar to vodka, gin uses a grain-neutral spirit as the base for production (Gari et al., 2020). The juniper berries are distilled in a neutral spirit to impart flavor to the drink. Gin typically contains 35% to 55% alcohol by volume. Generally, gin is not aged in oak barrels, which results in a spirit that is colorless and odorless, much like vodka.

Brandy: Brandy is a spirit produced through the fermentation of fruit extract and the distillation of fruit wash, followed by aging in oak barrels. It typically contains 40% alcohol by volume (López, 2021). Over the years of aging, brandy develops its color and aromatic compounds. There are two main types of brandy: dark and light, distinguished by the duration of aging.

Tequila: Tequila is a distilled spirit primarily produced in the town of Tequila, located in Mexico (Hobbs, 2023). It is made from the blue agave plant. The process involves extracting the juice from the agave, fermenting it, and then distilling it twice. After distillation, tequila is aged in wooden barrels, similar to whiskey and brandy, which can enhance its flavor profile. The average alcohol content of tequila is approximately 40% alcohol by volume (ABV) (Tetreault et al., 2021).

Methods for production of low alcoholic spirits:

The health implications of high alcohol consumption have led to an increasing demand for low-alcohol beverages in the market. To meet this demand, it is essential to develop new varieties of these beverages that are acceptable to consumers (Silva, 2024). Various physical, biological, and chemical treatments can be employed to reduce the alcohol content in beverages. Broadly, these techniques can be categorized into two approaches: prevention or cessation of alcohol production, and the removal of alcohol after its production through different treatments.

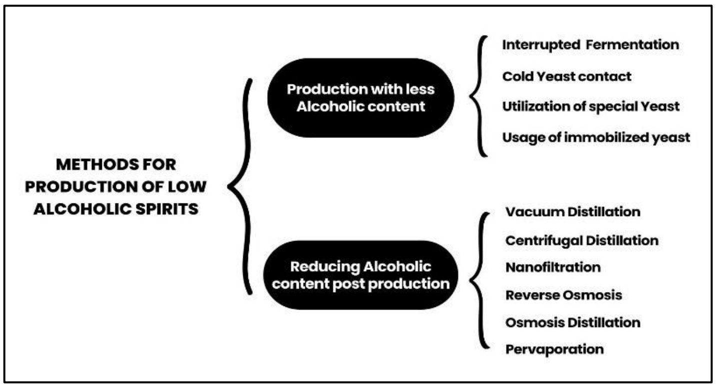

Figure 1: Schematic representation of Methods to produce Low alcoholic spirits.

I. Production with less alcoholic content:

A. **Interrupted Fermentation**: Interrupted fermentation is a technique applicable in the production of all distilled spirits, as it involves the fermentation of wort, which is primarily carried out by yeast. The most used yeast in fermentation is *Saccharomyces cerevisiae*. In interrupted fermentation, partially fermenting yeast is utilized, and the yeast can be removed during the fermentation process. This results in partial fermentation and produces a product with low alcohol content (De Fusco et al., 2019). Due to the removal of yeast, the resulting product is characterized by a reduced concentration of aromatic compounds.

B. **Cold yeast contact**: Cold yeast contact method fermentation is conducted at low temperatures, significantly below the typical ambient temperature range for yeast fermentation, which is between 30°C to 25°C (Pilarski &Gerogiorgis, 2020). When the temperature is reduced, the fermentation rate correspondingly decreases. A notable characteristic of this method is the ability of yeast to reduce carbonyl compounds from the wort, facilitating the production of desirable aromatic compounds. However, it is important to note that these yeasts can also convert amino acids into aldehydes, which may lead to the formation of off-flavors in the final product (Piornos et al., 2023).

C. **Utilization of special yeast**: To produce low-alcohol beverages, specialized yeast strains such as *Saccharomyces rouxii*, known for its low fermentation capability, are used to reduce alcohol content in fermented wort (Kato &Takahashi, 2023). Additionally, mutant strains like *Saccharomyces ludwigii* are employed, with genetic modifications to eliminate alcohol dehydrogenase and overexpress glycerol-3-phosphate dehydrogenase, leading to increased glycerol and reduced ethanol production. Cultures of *Lactobacillus spp.* or *Saccharomyces spp.* can also be utilized for this purpose (Dileep et al., 2024).

D. **Usage of immobilized yeast**: In the method of immobilizing yeast, the yeast cells are fixed onto the surface of carrier materials such as DEAE-cellulose, calcium alginate, calcium pectate, or sintered glass (Nedović et al., 2015). This immobilization reduces yeast activity due to the limited availability of fermentable sugars, consequently decreasing the fermentation rate. Despite this reduction, the method is advantageous for developing the final product's characteristic taste, flavor, and aroma.

II. Reducingthe alcoholic content:

A. **Vacuum distillation**: In the vacuum distillation process, the fermented wash is initially preheated using a plate heat exchanger. This step facilitates the simultaneous removal of volatile compounds from the liquid, which are collected in a separate chamber for later reintroduction. During the rectification phase, the liquid is maintained at 42 to 45 degrees Celsius (Jiang et al., 2017). It encounters hot vapor, which causes the alcohol to evaporate due to its relatively low boiling point. Following the evaporation, the dealcoholized wash is cooled down. To preserve the original aromatic characteristics of the wash, the previously collected volatile compounds are reintroduced into the cooled liquid. This method ensures the retention of desired aromatic qualities while effectively separating the alcohol from the wash (Horácio et al., 2020).

B. **Centrifugal distillation**: Centrifugal distillation involves passing fermented wash through a thin film onto heated surfaces of centrifugal disks. Under the influence of centripetal force, the mash is evenly distributed and heated on these thin disks, facilitating rapid evaporation of alcohol. The evaporated alcohol is subsequently removed from the system, while the reduced-alcohol mash exits under pressure and collects on output disks (Kozłowski et al., 2021). This distillation process is meticulously controlled at a temperature of 35 degrees Celsius, ensuring optimal separation efficiency. Each step of the process is completed within approximately 10 seconds, making it a highly efficient method for alcohol recovery and concentration in industrial applications (Mahrous &Farag, 2022).This technique not only enhances the efficiency of alcohol separation but also maintains precise control over temperature and processing time, critical factors in industrial distillation processes (Gantumur et al., 2022).

C. **Nanofiltration**: Nanofiltration employs polymeric and ceramic membranes to separate alcohol from fermented liquids based on particle size. When the solution is pressurized, particles larger than 2 nanometers are retained by the membrane (Yadav et al., 2022). This process effectively reduces alcohol content and filters out volatile compounds larger than the membrane's pore size (Castro-Muñoz, 2020). Nanofiltration is widely utilized in brandy production to maintain product quality.

D. **Reverse Osmosis**: Reverse osmosis, while less frequently employed in dealcoholizing processes, has proven highly effective despite its significant equipment costs. This technique involves the filtration of alcohol and water through a semipermeable membrane, against the osmotic pressure of the solution. This process allows for the removal of alcohol and volatile compounds from fermented liquids, resulting in a product of high quality with reduced alcoholic content (Ratnaningsih et al., 2021).

E. **Osmatic distillation**: Osmotic distillation is a process that offers significant advantages over reverse osmosis, particularly in energy efficiency and preservation of aromatic compounds. Operating under low pressure and temperature conditions, this method ensures minimal loss of volatile aromatics, which are crucial for product quality. Unlike reverse osmosis, osmotic distillation mitigates membrane damage due to its gentle operation (Cassano et al., 2020). This technique employs a selective membrane for separation, where alcohol selectively adheres to the membrane surface when passed through a standard solution. The resulting low-alcohol liquid is collected at the opposite end of the membrane, demonstrating its potential for efficient alcohol removal in various applications (Piornos et al., 2023).

F. **Pervaporation**: Pervaporation is a membrane separation technique similar to nanofiltration, utilized for alcohol separation. It operates based on the difference in chemical potential between substances, facilitating the movement of alcohol molecules across a membrane from regions of high concentration to low concentration. This technique effectively removes alcohol while maintaining the quality and characteristics of the product (Do Thi et al., 2020). By applying a feed above the membrane and a vacuum below it, the permeate, containing reduced alcohol content, is selectively absorbed and collected. Pervaporation also aids in the removal of concentrated volatile compounds from the fermented mash, offering a cost-effective and straightforward method for dealcoholization processes (Prestes Alves et al., 2020).

The future outlook for Low alcoholic distilled spirits:

Low-alcoholic distilled spirits and low-alcoholic beverages are gaining increasing attention and traction in the beverage industry, driven by evolving consumer preferences and regulatory changes (Rošul et al., 2019). These products, typically containing lower alcohol content than traditional counterparts, appeal to health-conscious consumers seeking lighter alternatives without compromising on flavor or experience. The future prospects for these categories appear promising, fueled by growing consumer awareness of wellness trends and a desire for more diverse drinking options (Anderson et al., 2021). Market forecasts indicate a steady rise in demand, supported by innovations in production techniques and ingredients that maintain taste profiles while reducing alcohol content (Wang et al., 2023). Moreover, as sustainability becomes a focal point for many brands, low-alcoholic beverages often align with eco-friendly practices, further enhancing their appeal. Regulatory shifts towards more lenient alcohol regulations in some regions also contribute to market expansion, allowing for greater product diversity and accessibility (Lyons &Kersey, 2020). Overall, the future looks bright for low-alcoholic distilled spirits and beverages, driven by consumer preferences for healthier, more varied drinking choices and industry efforts to meet these evolving demands.

Conclusion:

The rising awareness of the health risks associated with alcohol consumption has driven the demand for low-alcoholic distilled spirits. This review has explored the importance of such beverages, highlighting their potential to offer consumers healthier alternatives without sacrificing the sensory experiences associated with traditional spirits. The classification of distilled spirits sets the foundation for understanding the variety of products available in the market. The methods for producing low alcoholic distilled spirits, including interrupted fermentation, cold yeast contact, utilization of special yeast, and immobilized yeast, provide a comprehensive approach to reducing alcohol content during production. Additionally, advanced techniques such as vacuum, centrifugal, osmotic distillations, nanofiltration, reverse osmosis, and pervaporation offer effective means to lower alcohol levels post-production.

These innovative methods collectively contribute to the development of low-alcoholic distilled spirits, aligning with current health trends and consumer preferences. The future outlook for these products appears promising, as ongoing research and technological advancements continue to enhance their quality and acceptance. The success of low-alcoholic distilled spirits will depend on the industry's ability to balance reduced alcohol content with the preservation of flavor, aroma, and overall drinking experience. The production of low-alcoholic distilled spirits represents a significant stride toward healthier drinking options. As the industry evolves, these beverages are poised to become a staple in the market, catering to a growing segment of health-conscious consumers. The continued exploration and refinement of production methods will ensure the success and widespread adoption of low-alcoholic distilled spirits.

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