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Fruit vinegars through time: Production, diversity, and health benefits

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Abstract

Vinegar has been used for centuries as both a natural preservative and a condiment. It primarily consists of acetic acid, ranging from 4% to 18% per 100 ml, and is known for its distinct flavor and aroma. Table vinegar holds 4% acetic acid, whereas pickles with vinegar can have concentrations as high as 18%. Natural vinegar is considered a grander food additive compared to synthetic vinegar because it preserves nutrients from its fruit sources and is believed to provide medicinal benefits, such as relieving aches and aiding digestion. Vinegar also possesses various functional and therapeutic properties, including antibacterial, antihypertensive, antidiabetic, and antioxidant effects. This review paper emphasizes the significance of vinegar and its production from a variety of fruit sources.

Keywords acetic acid, acetic fermentation, acetobacter, pickle, vinegar

Introduction

Vinegar has been used for decades as a condiment and natural preservative. It contains acetic acid in the range of 4-18 per cent per 100 ml with a distinctive flavor and aroma. It is widely used to preserve food and add flavors to foods like pickles, sauces, salads, tomato products, and other processed foods. Its taste is described as mildly acidic with sour or tart [1].

Commercially, vinegar is of two types: natural or brewed, and synthetic vinegar. Natural vinegar is produced by a double fermentation process in which the sugars or starch in the substrate are initially converted to ethanol by alcoholic fermentation and further converted to acetic acid by acetic fermentation. Synthetic vinegar is produced without fermentation by diluting acetic acid to the preferred acidity content. Functional therapeutic properties of vinegar include antibacterial [2], anti-hypertensive [3], anti-diabetic antioxidants [4], and its role in the reduction of CVD and enhancement of vigour after exercise [5].

The term vinegar arises from the French words *Vin* (wine) and *Aigre* (sour), which means sour wine. Vinegar is an aqueous solution of acidic fluid produced by fermenting alcohol to acetic acid [6]. Codex Alimentarius defined vinegar as "a liquid, fit for human consumption, produced exclusively from a suitable product, containing starch or sugars, by the process of double fermentation, first alcoholic and then acetous". The byproduct utilization in vinegar production not only reduces the post-harvest losses but also helps the circular economy. This method addresses the development of sustainable, natural, and health-promoting food items, and reinforcing the nutritional, economic, and environmental value of fruit-based vinegar [7].

History of vinegar

Vinegar making is one of the ancient technologies in food preservation methods. The source of vinegar is emphatically coupled with the discovery of wine. The first record for vinegar production was found in 3000 B.C., where the Babylonians produced alcoholic beverages from fruits and sap of date palm, which were later transformed into vinegar when reacted with air. The phrase 'Wine matures as long as one does not open it', written in the Instruction of Ankhsheshonq, an ancient Egyptian papyrus, ensured that acidification was practiced in the Ptolemaic period (332-30 BC), and also some Egyptian urns were also found dating back to 3000 B.C. Vinegar on dilution served as an energy tonic [8].

The folktale about "four thieves' vinegar" was popular all around in European countries of the medieval period. Between 1347 and 1771, plague (Black Death) ravaged brutally in France, and approximately 50 million people died in line by rat flu. To bury the dead victims' bodies, the thieves from prison were sentenced to bury the dead victims; to survive in this condition, the thieves created vinegar marinated with garlic. Today, it is still possible to buy this vinegar called "four thieves' vinegar" [9].

Vinegar was usually used in military campaigns and wartime. Roman soldiers used vinegar diluted with water as a beverage and named this refreshing tonic "posca" during the Middle Ages. In the seventeenth century, Gerber studied the distillation method to increase the potency of vinegar. Berzelius in 1814 analysed the complete effects of acetic acid [10]. In 1823, Schutzenbach developed vinegar based on Dobereiner's theory of the conversion of acetic acid from alcohol [1].

Hermann Boerhaave (1668-1738) observed that wood shaving increased the oxidation (aerobic) process [11]. Christian Hendrik Persoon (1761-1836) observed a filmy surface on wine when set aside; he assumed it was a fungus and named it Mucor [9]. In 1823, Döbereiner published a chemical equation for the production of vinegar [9]. In 1864, Pasteur acknowledged five requisites for vinegar production as alcohol, oxygen, *Mycoderma aceti* (micro-organism), nutrients (sugar and proteins), and temperature 20 to 35°C [12].

Beijerinck was the first individual to name acetic acid bacteria as *Acetobacter aceti* in 1898 [13]. Hippocrates (Father of modern medicine) suggested vinegar as an antidote for the common cold and cough [14]. During the 20th century, the discovery of submerged fermentation shortened the production process to 1-2 days, facilitated large production of vinegar around the globe [15].

Classification of vinegar

Vinegar type diverges across regions, and its characterization was based on the resources used in its production. The main vinegars and their origin are discussed below [16].

Wine vinegar is produced from white, red, or rosé wine, popular in European countries. Vinegar aged in wood for a period of two years exhibited the best flavour and quality. The acid content is comparatively low when compared with other white or cider vinegars suitable for salad dressings [17]. ***Beer Vinegar*** is prepared from beer (widespread in the Netherlands, Austria, and Germany). The flavour is influenced by the raw material used for preparation and is malty in taste [18]. ***Balsamic vinegar*** has a rich aroma with a sweet-sour flavour. It is produced from grape must and aged in wood casks (acacia, mulberry, oak, and chestnut) for 12 to 25 years [19]. ***Cane vinegar*** is produced from sugarcane juice and contain sweet flavour used commonly in Philippine dishes [20]. ***Champagne vinegar*** is made from Chardonnay or Pinot Noir grapes. This super bright vinegar has a pleasant flavour without bubbles and is used in hot sauces for making vinaigrettes [17]. ***Cider vinegar*** is produced from apples and used in the United States [21]. ***Coconut vinegar*** is exclusively used in Thai dishes, with a unique flavour and aftertaste [17]. ***Malt vinegar*** is produced by fermenting barley and consumed in England. This vinegar has a hearty aroma and is eaten along with chips and fish [6]. ***Rice wine vinegar*** has a long history in Chinese cuisine of over 5,000 years. It is available in 3 forms, including red, white, and black. Red vinegar is used as a dipping sauce; white used for sweet dishes, and black used in fried dishes and salads [22]. ***Sherry vinegar*** has a nutty flavour and is aged in barrels made of wood in deep sunlight [23].

Vinegar from tropical and subtropical fruits

The alcoholic fermentation by strain IR-2 resulted in 30.6g/ liter of ethanol, and the acetic acid fermentation yielded 37.9 g/liter of acetic acid with a maximum productivity of 3.3 g/l/h, respectively. The two-step (Alcoholic and acetic) fermentation was performed for 50 days and proved to be competitive in production, yield, and low cost when compared to the immobilized cell system and free cell system [24].

The vinegar production from bee (*Apis mellifera*) honey [25]. The wort with pH 4.5, temperature 26 to 33 0 C, and 7.11% (w/v) total sugars yielded 8 per cent alcohol. The efficiency of the alcoholic fermentation was 81.34%. The bacteria inoculated to mead by the quick process yielded 9 per cent acetic acid in 72 hours. The acceptability index of 70 per cent indicated that honey vinegar was economically feasible and accepted by consumers.

Process conditions for mango vinegar production were optimized using response surface methodology [24]. The fruit pulp was treated with pectinase enzyme and centrifuged to obtain clear juice. The alcohol fermentation carried out by *Saccharomyces cerevisiae* strain (CFTRI 101) and acetic fermentation by *Acetobacter aceti* (MTCC No: 2945). The optimum conditions for the acetic acid fermentation process were temperature 30°C, pH 4.5, time 113 hours, ethanol content 8 per cent, and inoculum volume 10.5 per cent, respectively, for the highest yield of acetic acid (65.12g/l) by the RSM. Mango vinegar had an acidic strength with good physico-chemical properties when compared to the control (industrial vinegar). Finally, the mango vinegar produced was shelf-stable for 7 months with a distinct aroma and taste [26].

Ghosh et al., [15], produced vinegar from palm juice. Response surface methodology was used for optimizing the media components like carbon and nitrogen (DAHP and urea) using 2^3central composite design. They used *Saccharomyces cerevisiae* (NCIM 3045) for ethanol production and *Acetobacter aceti* (NCIM 2251) for acetic acid production. Palm vinegar contained vitamin B1, B3, ascorbic acid, folic acid, and minerals like calcium, magnesium, manganese, and iron in higher quantities than palm juice.

Yikmis [27] produced vinegar from apples. The commercial wine yeast of 0.3 per cent was used for alcohol fermentation for 40 days. After the wine, the sharp vinegar at 5% was inoculated. Sonication treatment was performed in vinegar in dark conditions (26KHZ frequency) at a temperature of 20°C using a 200W ultrasonic processor. Total phenol, total flavonoid, total antioxidant, and colour values were significantly high in ultrasound treated russet apple vinegar. The optimized condition for ultrasound was 7.4 µs and 62.2amplitude.

Chauhan [28] produced wild apricot vinegar with pectin esterase pretreatment. The optimisation of acetic acid fermentation was done using response surface methodology. The optimized condition for acetic fermentation was 7 per cent inoculum, 1per cent DHAP as nitrogen source, and 30°C temperature, in a submerged condition. The wild apricot vinegar was rich in polyphenol and flavonoid and can be stored for a period of 9 months.

Saha and Banerjee [29] developed vinegar from bananas due to its feasibility and low cost. The pectinase enzyme (0.0003%) was treated with banana pulp to obtain clear juice. Active dry yeast 10 per cent and *Acetobacter aceti* (MTCC 2623) were used for fermentation. The banana vinegar was pale yellow in colour. They observed that acetic concentration increased with an increase in inoculum concentration. Maximum acetic acid of 4.67 per cent was observed in 15percent.

A. aceti concentration for 72 hrs. at 37°C. The optimization of banana vinegar demonstrated that the maximum value of optical density was 1.459 for 72 hrs., alcohol content 6.29 percent, and acetic inoculum 15 percent.

Alawad et al., [30] reported production and evaluation of vinegar from tamarind pulp. The methodology was carried out in 3 stages: fermentation, distillation, and vinegar production. Tamarind juice was treated with *Saccharomyces cervisiae* at Ph 6.5 and a temperature of 30°C for fermentation, the fermented slurry was distilled at 70-80°C using distillation unit. An acetic acid bacterium at 10 percent was inoculated in the ethanol substrate at 37°C for vinegar production. The acetic acid of tamarind vinegar was found to be 16-17 per cent with a pH of 2.0

Kocher et al., [31] reported the cane vinegar production by immobilization techniques. The 8 % alcohol yield was used for vinegar production with adsorbed bagasse, including wood shavings and corn cobs. On fermentation, the maximum acetic acid content was observed in corn cobs (6.7 g/100ml) after 28 days of fermentation.

Chen et al., [32] produced vinegar from watermelon juice; 4 percent *S. cerevisiae* was inoculated in the wort (v/v), which yielded 9.45% alcohol (V/V). The acetic acid fermentation performed by the quick process resulted in vinegar containing 5% acetic acid (W/V). The vinegar was pale yellow in colour with no haze or sediment. Phenyl ethyl alcohol, phenyl ethyl acetate, and Ethyl acetate were the major volatile compounds in watermelon vinegar.

Tomato vinegar was developed in a two-stage (alcohol and acetic) fermentation. The alcoholic fermentation yields 4.6 to 5.8 per cent ethanol. The maximum acetic acid content (5.6%) was obtained on the 8th day of the acetic fermentation process. Tomato vinegar contained lycopene 3.19 mg/100ml and carotenoid content 6.45 mg /100ml, respectively [33].

Cejudo-Bastante et al., [34] studied the differentiation in orange vinegar production by surface and submerged methods. In surface fermentation, orange vinegar had a high concentration of polyphenol, while submerged vinegar contained higher content of volatile compounds. The sensory acceptability was high in vinegar produced from the submerged condition.

Dried hibiscus flower (Roselle) was used for vinegar production. The must was prepared by diluting dried powder (200g) with water (l) and by adjusting TSS to 23.70 and Brix at a pH of 5.0. Starter culture of yeast (10ml) was added to the must and subjected to primary fermentation for 7 days. The maximum ethanol concentration was obtained (63.47 g/litre) at 72 hours. The acetic fermentation yield 65.2g/L acetic acid. The antioxidant activity of vinegar was higher than that of the extracts, indicating that during fermentation, bioactive compounds and antioxidant activity increased [35].

Extracts of pomegranate were used to produce vinegar [36]. The optimized temperature and pH for yeast fermentation were 25°C and 3.5 pH. Acetification was carried out by the submerged method at 30°C with continuous stirring (450rpm) and air supply (60L/k). The developed vinegar was rich in antioxidants and polyphenol content, which was like red wine vinegar.

Blueberry vinegar was optimized by 2 step fermentation. The alcohol fermentation was carried out by yeast KCCM 34709 (10% v/v) at 30°C for 3days and *Acetobacter sp*. KCCM 40085 10% for 3days. The acetic acid content of Blueberry vinegar was 42.31 mg/ml with 5.3 per cent total acidity [37].

Gokirmakli et al., [38] studied the antioxidant property of strawberry vinegar; the two-step fermentation process was used for its production. The physico-chemical composition of strawberry vinegar was pH 3.57, total acidity 4.59g/100ml. The antioxidant activity -TEAC and Oxygen Radical Absorbance Capacity (ORAC) was found to be 6.2mM and 1.67mMol/ml. The antioxidant capacity of vinegar was lower when compared with juice. The aromatic compound in strawberry vinegar was ethyl-2-methyl.

Factors affecting acetic fermentation

Fermentation efficiency totally depends on the metabolic activity, growth, and survival of microorganisms. The quality of vinegar is optimized by considering numerous factors. These factors may be categorized into primary factors (temperature, pH, substrate, and oxygen supply) and secondary factors (starter culture, loading proportion, fermenter design, and working volume).

The most significant factor in the production of wine and vinegar is the raw materials (substrates), which regulate the progression of acetic acid bacteria. Substrate produced from *Candida stellata* or *Kloeckera apiculata* provided good quality vinegar with an optimum yield, compared to the ones produced from *Saccharomyces cerevisiae*. The wine substrates with negative effects like high residual sugar, high sulphur dioxide, and high alcohol concentration (> 12 % v/v) resulted in poor quality vinegar. The nutrients, such as minerals and vitamins, could be added to the substrate before the initiation of acetic fermentation [44].

Acidification is truly an aerobic process, where 430L of oxygen is used to oxidize 1 liter of ethanol at a temperature of 30°C. The disruption of oxidation, along with varied temperature stops the acetification process. The industrially submerged fermentation method is widely used because of its rapid aeration system. It can break air bubbles and maintain aerobic conditions to prevent the Acetobacter cell death [45]. The desirable temperature for the growth of acetic acid bacteria was 25 to 30°C. High temperatures would destroy the acetic acid bacteria and enzymes. AAB persists at the pH of 5.4-6.3, but they also survive at pH less than 4 [13].

At present, submerged culture fermenters are widely used for industrial vinegar production. It is designed in such a way to provide the required temperature, aeration, and agitation for the growth and multiplication of microbes. The working volume or quantity is supposed to be one – third of the total capacity of the fermenter to oxygenate the system. They used air as an oxygen source to maintain a viable acetic acid bacteria population. The fermentation efficiency was determined by the biomass remaining in the fermenter at the end of the production cycle [46].

The most significant factor in vinegar production is the volatile compounds. Their flavor is based on the material source, processing methods, and ageing. Almost 14 volatile compounds have been quantified in wine vinegar, including acetic acid, malic acid, lactic acid, tartaric acid, and citric acid [47].

Potential Health Benefits from Vinegar

Anti-microbial property

An antimicrobial is a natural or synthetic agent that kills or inhibits the growth of the spoilage-causing microorganisms [48]. Sengun and Karapinar [49] documented that vinegar with 4.03 percent acetic acid was effective against *Salmonella typhimurium* in carrots. The result showed that vinegar and lemon juice in the ratio 1:1 (v/v) at 60 minutes of time interval ensured the maximum reduction of *S. typhimurium* populations. A substantial microbial reduction of approximately 3 log units was achieved when lettuce was treated with acetic acid (5%) at a temperature of 25°C for 5 minutes. Apple vinegar hindered the progression of harmful bacteria like *Staphylococcus epidermidis*, *Pseudomonas aeruginosa*, *Proteus Mirabilis* and *Klebsiella pneumoniae* [50].

Antioxidant property

Antioxidants are the molecules that protect the human system from harmful effects by donating electrons to the free radicals and neutralizing the free ones [51]. Budak and Guzel-Seydim [52] measured the scavenging property of grape vinegar by using 2 methods - traditional surface and the industrial submerge method. The scavenging activity was measured by ORAC (Oxygen Radical Absorbance Capacity) and TEAC (Trolox Equivalent Antioxidant Capacity). The results showed that traditional vinegar had higher ORAC (10.50 μmol/mL TE) and TEAC (13.50 mmol/L) than industrial ORAC (8.84 μmol/mL TE) and TEAC (10.37mmol/L). Sakanaka and Ishihara [44] reported that persimmon vinegar exhibited a higher antioxidant property (84.2 % by DPPH) than commercial vinegar. When treated with fatty tuna fish, vinegar efficiently inhibited lipid oxidation. Therefore, Persimmon vinegar could be used in fish processing industries to avert the off-flavor in fish.

Anti-diabetic effect

Leeman et al., [53] documented that the combination of cold storage and vinegar considerably reduced the Glycemic index (GI) of boiled potatoes by 43 per cent and insulinemic indices (II) by 31 per cent. Cold-storing boiled potato significantly increased the RS (resistant starch) content from 3.3 to 5.2 per cent (starch basis). Acetic acid in vinegar hinders carbohydrate absorption and decreases glycemic [4].

Anti-tumour property

Kurosu is vinegar from unpolished rice that contains significant phenolic compounds, which reduced the cancer cell proliferation. In a study, Nishidai et al., [54] analyzed the anti-cancerous property of ethyl acetate extract of kurosu in the in vitro study of mice. They observed a 36 per cent tumour reduction at 15 weeks after supplementation with vinegar. They suggested that the anti-tumour property may be due to the decomposition of free radicals and the generation of leukocytes. The vinegar prepared from sugarcane juice was named kibizu. Mimura et al., [55] concluded that, the apoptosis was induced by Kibizu vinegar and resulted in suppressing the growth of leukaemia cells.

Anti-obesity effect

Vinegar consumption reduced the glycemic effect by providing a satiety feel to the consumers [56]. Ok et al. [57], documented the anti-obesity property of pomegranate vinegar (PV). It is the most popular vinegar for obesity treatment through the control of AMPK (Activated protein kinase), which leads to lipolysis in adipose tissue and a boost in fatty acid oxidation in the liver. Lee et al., [33] acknowledged the therapeutic property of tomato vinegar against 3T3-L1 obese rats. These rats are nurtured with fatty foods (45 %) along with tomato vinegar (7 mL/kg/day) for 5 weeks. Tomato vinegar positively reduced the visceral fats (perirenal, abdominal, and epididymal adipose tissues) and adipocyte size compared to the control fed with a normal diet.

Prevention of cardiovascular diseases

Apple cider vinegar was prepared by surface and submerged fermentation methods. Albino rats fed with cholesterol 2.5 per cent and 1ml of diluted apple cider vinegar by oral gavage for 7 weeks and observed the increased HDL level in surface methods. This vinegar has high phenolic compounds, chlorogenic acid, TEAC, and ORAC, thereby inhibiting LDL oxidation and reducing the CVD [58].

Conclusion

Vinegar is known as both a functional food and a sustainable product, with a varied substrate for production. The beneficial components that assist toward the vinegar's health properties would be acetic acid and other bioactive substances. Beyond its nutritional and industrial benefits, research evidence supports vinegar's medicinal capacity in treating obesity, diabetes, and atherosclerosis, aligning with traditional practices and new biological findings. However, clinical research remains confined, with insufficient data on safe dosage, long-term stability, and mechanisms of action, thus illustrating the requirement for greater comprehensive trials.

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