

An Overview on the Biological Production of Vinegar

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ABSTRACT

Vinegar contains about 5% acetic acid in water, varying amounts of fixed fruit acids, colouring matter, salts and a few other fermentation products which impart characteristic flavour and aroma to the product. Vinegar traditionally has been used as a food preservative. Vinegar production methods could range from traditional methods employing wooden casks (Orleans Process) and surface culture (Generator Process) to submerged fermentation. Vinegar is the product made from the conversion of ethyl alcohol to acetic acid by a genus of bacteria *Acetobacter*. Many technical devices have been developed to improve the industrial production of vinegar. Generally, these improvements increase the speed of the transformation of ethanol into acetic acid in the presence of acetic acid bacteria. In this review a detailed description on vinegar production, methods of production, different substrates and microorganisms used for its production, and the chemistry of vinegar is presented.

Keywords: Vinegar, alcohol. *Saccharomyces*, *Acetobacter*, fermentation

The word Vinegar is derived from the French *Vin* (wine) and *Aigre* (sour). Vinegar is a sour and sharp liquid used as a condiment and food preservative (Cruess 1958). The available definition from the Codex Alimentarius (1987) states that vinegar is “a liquid, fit for human consumption, produced from a suitable raw material of agricultural origin, containing starch, sugars, or starch and sugars, by the process of double fermentation, first alcoholic

and then acetous". The raw materials used for vinegar production include rice, grapes, malt, apple, honey, potatoes, whey or any other sugary food (Bamforth 2005). In human history, vinegar appears at the beginning of agriculture with the discovery of alcoholic fermentation from fruits, cereals and vegetables. The genesis of vinegar can hardly be distinguished from the origin of wine. Although vinegar has always been considered among the lowest quality products of fermented foods, it has also been used as a food condiment, as a preservative agent and, in some countries as a healthy drink (Solieri and Giudici, 2009).

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Vinegar production

Vinegar is the product made from the conversion of ethyl alcohol to acetic acid by a genus of bacteria, *Acetobacter*. Therefore, vinegar can be produced from any alcoholic material from alcohol-water mixtures to various fruit wines (Pepler and Beaman 1967). Vinegar bacteria, also called acetic acid bacteria (AAB), are members of the genus *Acetobacter* and characterised by their ability to convert ethyl alcohol (C₂H₅OH) into acetic acid(CH₃COOH) by oxidation as shown below:

| Anaerobic | Aerobic |
|---|--|
| Glucose $\xrightarrow{\text{Yeast}}$ 2C ₂ H ₅ OH Ethanol | $\xrightarrow{\text{AAB}}$ 2CH ₃ COOH + 2H ₂ O Acetic acid (Vinegar) |

Vinegar is a solution of acetic acid produced by a two-step bioprocess. In the first step, fermentable sugars are transformed into ethanol by the action of yeast. In the second step, AAB oxidize the ethanol into acetic acid in an aerobic process. AAB are well known for their ability to spoil wines because they can produce large amounts of acetic acid from ethanol and other compounds present in wines (Joyeux *et al.*, 1984).

Substrates used in vinegar production

One of the critical steps in vinegar production is the preparation of the raw material (Solieri and Giudici 2009). This step is required to obtain

the fermentable sugar and juice solution to be acetified. The processing differs depending on the raw material used. In general, fruits require less preparation than seeds; however, seeds are more easily stored and preserved after harvest. Fruits are highly perishable, rich in water, and need to be processed very quickly. Therefore, basic safe food handling practices, storage, and processing are essential to prevent the growth of pathogenic microorganisms. These microorganisms could alter the quality of the final product or even produce dangerous toxins such as aflatoxin. Processing has expanded the market of both fruit and vegetable products (Singh and Verma 1995). The seasonal gluts are avoided by the utilization of fruits/vegetables in processing industries for the preparation of various value added products. In advanced countries, 70-75% of perishables are processed before reaching the consumer's table, whereas in India only 1-2% of the total produce is processed utilizing only 40% of the installed processing capacity.

Microorganisms involved in the vinegar production

After raw material preparation, the alcoholic fermentation and acetification processes play a key role in vinegar production. Depending on the environmental factors (temperature, pH, water activity) or the nutrients (carbon sources) and the microbial diversity present in the raw material, different biotransformations could take place. Microbial species involved in fermentations may range from yeast and lactic acid bacteria (LAB) to molds and AAB. The microorganisms involved in the elaboration of vinegars are mainly yeasts and AAB. The former being responsible for the alcoholic fermentation, and the latter needed for the acetification (Nanda *et al.* 2001; Haruta *et al.* 2006; Wu *et al.* 2010).

Yeasts

Yeasts are the most important microorganisms during alcoholic fermentation because they influence fermentation speed, wine flavour and other wine qualities (Pretorius *et al.* 2006). Yeasts are defined as 'unicellular ascomycetous or basidiomycetous fungi, whose vegetative growth result predominantly from budding or fission'. Yeasts do not form their sexual states within or upon a fruiting body (Kurtzman and Fell 1998).

In 2009, Rainieri and Zambonelli optimized alcoholic fermentation as a process where the sugar as a substrate was converted into ethanol in presence of a yeast belonging to the Class Saccharomycetes; Phylum Ascomycota and was responsible for fermentation (Rainieri and Zambonelli

2009). Further the studies revealed that yeasts had high tolerance to acidity that facilitated their survival and growth in fruit juices that have pH values below the tolerance level for several other microorganisms. The substrate used for yeast metabolism was mainly monosaccharides like glucose, fructose and mannose that were metabolised into two molecules of pyruvate in the glycolysis, also called Embden-Meyerhof-Parnas pathway (EMP pathway). The pyruvate was further reduced to ethanol (C₂H₅OH) and carbon dioxide by the enzymes pyruvate decarboxylate and alcohol dehydrogenase. The overall chemical reaction is presented as:



Results indicated that theoretically, the yield of ethanol was about 65% (v/w) of the initial glucose content, but the actual conversion efficiency was reduced to about 60% due to loss of glucose for production of minor compounds and growth.

Fleet *et al.*, (2003) explored that the *Saccharomyces* genus was most commonly used in beverage industry due to their higher capacity to ferment sugars which allowed them to colonize sugar-rich media over other yeasts, which were not tolerant to alcohol. They reported that the imposition of *Saccharomyces cerevisiae* along the AF was associated with the increasing presence of ethanol, the anaerobic conditions, the use of sulfites during harvesting and the high concentration of sugar in the must.

Joshi *et al.*, (2002) studied that for cider production, the strains commonly used belonged to the species *Saccharomyces cerevisiae* or *Saccharomyces bayanus* and the choice of yeast strain as starting culture could have a high impact on the flavour profile of fermented beverages. The studies revealed that during fermentation of apple juice, the rate and content of ethanol, sugars, tannins, esters, methanol and volatile acids were some of the quality characteristics that could be affected by the specific yeast strain.

Kocher *et al.*, (2006) studied the conversion of sugarcane juice to ethanol by *Saccharomyces cerevisiae*. This ethanol was used for vinegar production using adsorbed (bagasse, corn cobs and wood shavings) and entrapped (calcium alginate) cells of *Acetobacter acetii* NRRL 746. All the three adsorbed carrier materials were statistically similar for acetic acid production and produced acidity from 5.9 to 6.7% after 28 days of submerged fermentation.

Acetic Acid Bacteria (AAB)

The ninth edition of Bergey's Manual of Systematic Bacteriology classified the acetic acid bacteria (AAB) in the family *Acetobacteriaceae* and *Gluconobacter*. AAB are Gram-negative or Gram-variable bacteria, with ellipsoidal to rod-shaped morphologies, being motile due to the presence of flagella, which could be either peritrichous or polar. Their size varies between 0.4-1 μm wide and 0.8-4.5 μm long. They are observed as individual cells, in pairs or in chains. They show a strict aerobic metabolism with oxygen as the terminal electron acceptor, and are catalase positive and oxidase negative (Gonzalez *et al.*, 2004).

Gullo and Giudici (2008) reported that the AAB were present in the environment and in the raw material, but they cannot grow during alcoholic fermentation because of the anaerobic conditions. When the alcoholic liquid was exposed to oxygen, the AAB started their growth on the surface. Du Toit and Pretorius (2002) reported that most AAB growth was observed between pH 5.4 - 6.3, but they also could grow at pH values lower than 4. They also reported that AAB could also be isolated at pH values of 2.0-2.3 in media containing acetate, if they were aerated. The optimal temperature for their growth was 25-30°C, but their growth was also observed between 38-40°C and weakly at temperatures as low as 10°C.

Yamada and Yukphan (2008) studied that AAB were usually found in substrates containing sugar and/or ethanol. These substrates include fruits, flowers, food and fermented beverages, such as fruit juices, wine, cider, beer, cocoa and vinegar.

Gullo *et al.*, (2006) reported clear growth differences between AAB species isolated from fruits, flowers and fermented foods, and they had displayed differing abilities to grow using different culture media depending on the available nutrients. Results showed that there was a poor recovery on synthetic culture media due to the lack of a suitable synthetic media, as not all synthetic media equally support the growth of AAB and could even be selective among strains. However, considerable progress in AAB isolation had been made with the development of various culture media.

Garcia-Garcia *et al.*, (2009) conducted studies on the acetous fermentation of ethanol into acetic acid by acetic acid bacteria belonging to the family *Acetobacteriaceae* and the genera *Acetobacter* and *Gluconobacter*. The total chemical reaction that took place was as follows:



The studies revealed that there were two steps in the oxidation of ethanol to acetic acid, driven by the enzymes alcohol dehydrogenase (ADH) and aldehyde dehydrogenase (ALDH). The first step was oxidation to acetaldehyde by ADH, which was further oxidised to acetic acid by ALDH. The reaction was exothermic, thus increased the temperature in the medium. The acetic acid could be further oxidised to carbon dioxide in the tricarboxylic cycle, that was an unwanted process in vinegar production but it could occur when the ethanol concentration was limited and leads to the process, called over-oxidation, caused by bacteria belonging to *Acetobacter*, because two of the key enzymes required for oxidation were non-functional in species of *Gluconobacter*.

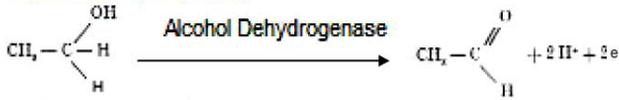
Raspor and Goranovic (2008) reported that ethanol content affects AAB both in beginning and at the end of fermentation. High initial ethanol concentration decreased bacterial vitality due to the antimicrobial effect of ethanol. And if instead, initial concentration was too low, (0.1-0.2%), the risk for over-oxidation increased. When acetic acid concentration increased during fermentation, the pH decreased and reduced the bacterial activity, and set a limit for the concentration of acetic acid.

Maal *et al.*, (2010) reported production of Apricot Vinegar using an isolated *Acetobacter* strain from Iranian apricot. They reported that the isolation and identification of an *Acetobacter* strain from Iranian apricot had a very good tolerance against high ethanol concentrations as well as high acetic acid productivity in an acceptable incubation period of time industrially. Furthermore this strain could be used in vinegar industry to convert apricot spoilage to a beneficiary product.

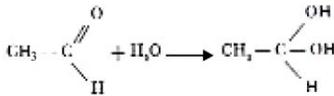
Chemical Reaction and Formulation

The production of acetic acid (vinegar) is presented in figure 1. Initially, alcohol is hydrogenated to form acetaldehyde and two hydrogen ions and two electrons are released. In the second step, two hydrogen ions bind with oxygen to form water that hydrates acetaldehyde to form aldehyde. During third step, aldehyde dehydrogenase converts acetaldehyde to acetic acid and releases 2 hydrogen ions and 2 electrons.

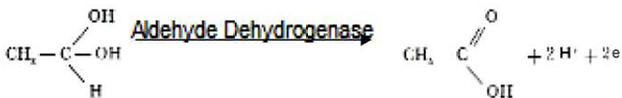
1. Formation of Acetaldehyde



2. Hydration of Acetaldehyde



3. Formation of Acetic Acid



4. Electron Transfer

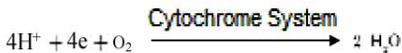


Figure 1. Conversion of alcohol to acetic acid reaction (Source: Kehrar 1921)

Production methods of vinegar

Vinegar production methods could range from traditional methods employing wooden casks (Orleans Process) and surface culture (Generator Process) to submerged fermentation (Morales *et al.*, 2001). Vinegar is an important ingredient in many food products. The need for large amounts of the vinegar demands industrial fermentation systems that are capable of producing volumes that could reliably be controlled (De Ory *et al.*, 1999). Many technical devices have been developed to improve the industrial production of vinegar. Generally, these improvements increase the speed of the transformation of ethanol into acetic acid in the presence of AAB (Tesfaye *et al.*, 2002).

The Orleans Process

The slow method of acetifying wine which had been used in France since 1670 is known as the French or Orleans process. The Orleans process was the only method to make pure wine vinegar and was reported to be the best

process to produce fine quality table vinegar. In this process, wood barrels were used and filled with alcohol fermenting liquid to approximately $\frac{3}{4}$ full, which was provided with holes at the end of the barrel just a few inches above the liquid surface. These holes were left open and covered with a fine screen (Cruess 1958).

Peppler and Beaman (1967) standardised the method of adding 20-25% of fresh vinegar into the barrel in order to acidify the liquid to the point of optimum growth for the vinegar bacteria. They reported that the bacteria settled into the liquid from the air and formed a gelatinous slime layer on the top of the liquid. The liquid was then fermented for about 1 to 3 months at 70°F to 85°F.

Maazaand Murooka (2009) reported that the Orleans process relies on the natural acetic acid bacteria present in the raw material, or makes the use of a seed culture from a previous production batch. It was found that the bacteria, was belonging to the species *Acetobacterxylium*, and showed growth on the liquid-air interface of the medium. Due to the oxygen requirement, the species were able to produce cellulose, a thick mat of a gelatinous substance containing bacterial cells and cellulose was developed over time on the top of the liquid. And the oxygen was moving into the mat used for the oxidation of ethanol into acetic acid. As a result of this, the concentration gradient within the barrel was produced with a continuous diffusion of finished vinegar down-wards and a diffusion of ethanol towards the mat. The acetification process took a long time compared to more recent methods, with a production rate of about 1% acetic acid per week.

Raspor and Goranovic (2008) reported that the vinegar produced by the Orleans process was of high quality due to the slow production process that promotes the development of flavour and aroma. It was found that this way of processing provides a constant availability of finished vinegar. But the drawback of this process was the long time required, resulting in high costs per volume produced even though the investment in equipment and the running costs were low.

The Generator process

Early in the nineteenth century, a vinegar-making system called the trickle method (now called generator fermentation or quick process) was developed by German chemist Schutzenbach in 1832. In this process, the bacteria were grown and formed a thick slime coating around a non-

compacting material like beech wood shavings, charcoal or coke (Peppler and Beaman 1967).

The fermentation was most commonly performed in tanks made of wood or steel, with a volume of 50000–60000 litres. The surface area where bacteria were exposed to oxygen was increased by a packing material in the tank, on which the bacteria were immobilised. The mostly used packing was made of beech wood shavings, over which the liquid was sprayed and then allowed to drip through to the bottom of the reactor and the air was blown in from the lower part to maintain high oxygen availability. The partly finished vinegar that was accumulating at the bottom of the tank was re-circulated to the top again until the desired concentration of acetic acid was obtained. The process was performed at 27–30°C and a cooling coil in the tank was used to prevent overheating (Raspor and Goranovic 2008).

There were some disadvantages associated with the generator process like high risk of clogging due to the cellulose-producing bacterial growth in the generator, accumulation of dead bacteria and infection with vinegar eels. Another disadvantage observed was a relatively high loss of ethanol by evaporation that made it difficult to produce vinegar with high acetic acid concentration (Tefsaye *et al.*, 2002).

Submerged Fermentation

The most common production method was submerged culture which improved the general fermentation conditions like aeration, stirring, heating, etc. As generator culture was slow and expensive, submerged culture fermentors have been used widely at industrial scales. In this process, the mash is stirred and aerated frequently and the fermentors are fitted with a heat exchanger for the maintenance of the optimum temperature during the fermentation process (De Ory *et al.*, 1999).

The most commonly method used for commercial vinegar production is submerged-culture fermentor where bacteria are suspended in medium, in contrast to traditional and generator process. The first bioreactor of submerged type was Fring's acetator in early 1950's, and it was followed by other patented methods as Cavitator, bubble column fermentor and Effigas turbine vinegator (Tefsaye *et al.*, 2002).

The fermentor was normally made by stainless steel with several different volumes, but most commonly in the range of 10000–40000 litres. Basic

principle was that the bacteria were free of substrate and air was forced into the medium by a stirrer at bottom of tank. The fermentor was equipped with a mechanical agitation which generated fine bubbling in system. At the top of a fermentor there was an air outflow, thermometer, cooling coils and a system to control and remove the build-up of foam. Studies revealed that system was very sensitive, and since bacteria were dispersed in medium, even a short interruption of air inflow and stirring could result in cell death (Mazza and Murooka 2009).

Submerged process could be used for production of vinegar in either a discontinuous, semi-continuous or continuous system. In discontinuous system, vinegar was produced in batches where a volume of substrate was loaded and inoculated with bacteria and after acetification volume was completely unloaded from the fermentor. However semi-continuous system was most commonly used and required a start-up period. Fermentor was loaded and inoculated. Once acetification had proceeded to desired level, about 40–50% of volume was unloaded, while the vinegar left behind was used as inoculum for next cycle. Advantage of this system was that there was a shortened bacterial lag time for growth, resulting in more efficient production. The continuous system was based on a constant composition of medium at a state where bacteria were in exponential growth phase and therefore have their highest growth rate, and produced a conversion of 8-9% acetic acid in 24-48 hours (Garcia-Garcia *et al.*, 2009).

Typical operation mode in industrial submerged culture was semi-continuous system which consisted of development of successive discontinuous cycles of acetification. Results indicated that at end of every cycle, a given volume of acetic acid was discharged and refilled with mash. Best temperature for industrial production of 11 to 12% vinegar was kept upto 86°F (30°C). In addition, the concentration of acetic acid produced was affected by bacterial conditions (De Ory *et al.*, 2004).

Most important feature of submerged fermentation systems was their ability to provide rapid and efficient aeration. Aeration system's ability was to break air bubbles and thus facilitated transfer of oxygen from medium to bacteria. It was found to be an essential step in order to prevent the *Acetobacter* cell death. However, even traditional open vat method could be run in a semi-continuous fashion and had been used in many parts of the world (Janssens and Swings 2002).

Production of vinegar

Vinegar sales grew at 15% from 2000 to 2002 and have been stronger than most other comparative categories including meat marinades, oriental sauces, cooking wine and sherry. Vinegar sales are somewhat seasonal, with a peak in the summer months and a secondary peak in April. There are some reports that suggest consumers are changing their vinegar purchasing habits. According to IRI (Information Resources, Inc) information from 1998 - 2004, of the 48% of households that purchased vinegar, 30% purchased white distilled vinegar, 14% purchased cider vinegar, 9% purchased red wine vinegar, 5% purchased balsamic vinegar and 3% purchased rice vinegar from Crisco Company 2005. While vinegar distilled remains the strongest in sales, although white and ciders are giving way slowly to increases in red wine, rice and balsamic vinegar (Crisco 2005). In 2005, balsamic vinegar, made of grapes, had the largest world market share with about one third, while the cider vinegar share was 7%. In Europe, there are regional standards for different vinegars, but a value for wine vinegar is a minimum of 6% acetic acid (w/v), obtained by acetous fermentation of wine. In vinegars produced from other alcoholic bases than wine, the acetic acid concentration threshold minimum is 5% (w/v) (Solieri and Giudici, 2009).

In North America, the vinegar must have an acetic acid content of at least 4% (w/v). The maximum ethanol content in vinegars has been set to a maximum 0.5 and 1% (v/v) for wine vinegar and other vinegars, respectively, by the Codex Alimentarius commission (FAO/WHO, 2000).

Uses of vinegar in food industry

The use of vinegar to flavour food is centuries old. Whether naturally produced during fermentation or intentionally added, vinegar retards microbial growth and contributes sensory properties to a number of foods. It has been used as a medicine, corrosive agent, pickling agent and can be directly consumed in diluted form as a beverage. In the food industry, vinegar is used mainly as an acidulant, but it has also many other food processing applications. It is found in hundreds of different processed foods, including salad dressings, mayonnaise, mustard, ketchup, bread and bakery products, canned foods, marinades and the current falling wine consumption have favoured an increase in vinegar production (De Ory *et al.*, 2002).

Vinegar is the world's oldest cooking ingredient and food preservation method. Vinegar's use can be traced back over 10,000 years. In fact, flavoured vinegars have been manufactured and sold for almost 5,000 years. The wide variety of vinegars available today is nothing new. Until the six century BC, the Babylonians were making and selling vinegars flavoured with fruit, honey, malt, etc. to gourmets of the time. In addition, the Old Testament and Hippocrates recorded the use of vinegar for medicinal purposes (Kehrer 1921; Conner 1976).

The use of vinegar to flavour food is centuries old. It has also been used as a medicine, a corrosive agent, and as a preservative. In the middle Ages, Alchemists poured vinegar onto lead in order to create lead acetate, called "sugar of lead", it was added to sour cider until it became clear that ingesting the sweetened cider proved deadly. Production of vinegar was also burgeoning in Great Britain and it became so profitable that a 1673 Act of Parliament established a tax on so called vinegar-beer. In the early days of the United States, the production of cider vinegar was a cornerstone of farm and domestic economy, bringing three times the price of traditional hard cider.

Types of Vinegar

The predominant type of vinegar in United States is white or distilled vinegar. Vinegar is usually described in terms of grain strength, the grain being ten times the acid percentage. For example 10% acid is referred to as 100 grain (Cruess 1958).

According to the Crisco Company, vinegar varieties vary greatly from country to country. Some of the most popular vinegars and their characteristics are shown below:

- ❑ **Balsamic vinegar** is brown in colour with a sweet-sour flavour. It is made from the white Trebbiano grape and aged in barrels of various woods. Some gourmet Balsamic vinegars are over 100 years old.
- ❑ **Cane vinegar** is made from fermented sugarcane and has a very mild, rich-sweet flavour. It is most commonly used in Philippine cooking.
- ❑ **Champagne vinegar** has no bubbles. It's made from a still, dry white wine made from Chardonnay or Pinot Noir grapes (both of which are used to make Champagne).

- ❑ **Cider vinegar** is made from apples and is the most popular vinegar used for cooking in the United States. It should contain at least 1.6 grams of apple solids per 100ml of which more than 50% are reducing sugars, and at least 4 grams of acetic acid per 100 ml at 20°C.
- ❑ **Coconut vinegar** is low in acidity, with a musty flavour and a unique aftertaste. It is used in many Thai dishes.
- ❑ **Distilled vinegar** is harsh vinegar made from grains and is usually colourless. It is best used only for pickling.
- ❑ **Malt vinegar** is very popular in England. It is made from fermented barley and grain mash, and flavoured with woods such as beech or birch. It has a hearty flavour and is often served with fish and chips.
- ❑ **Rice wine vinegar** has been made by the Chinese for over 5,000 years. There are three kinds of rice wine vinegar: red (used as a dip for foods and as a condiment in soups), white (used mostly in sweet and sour dishes), and black (common in stir-fries and dressings).
- ❑ **Sherry vinegar** is aged under the full heat of the sun in wooden barrels and has a nutty-sweet taste.
- ❑ **Spirit vinegar** is made by acetic fermentation of dilute ethyl alcohol. It should contain at least 4 grams of acetic acid per 100ml at 20°C. It may be coloured with caramel. This vinegar is also called “**grain vinegar**” or “**distilledvinegar**”.
- ❑ **White vinegar** is made from the distilled vinegar. The term “distilled” is misleading, because the vinegar is not distilled, but it is made from alcohol which is distilled.
- ❑ **Wine vinegar or Grape vinegar** made from grapes by acetic fermentation is called “wine vinegar” or “grape vinegar”. It can be made from white, red, or rose, wine. These vinegars make the best salad dressings. It should contain at least one gram of grape solids, 0.13 gram of grape ash and 4 grams of acetic acid per 100ml at 20°C.

Vinegar quality

The vinegar qualities depend on process conditions including acetification speed. The rate of fermentation influences the sensory properties of

the final vinegar, but some believed there were no differences between vinegars obtained at different fermentation speeds. Experts usually detected important sensory differences between vinegar manufactured by the submerged and generator processes (Nieto *et al.*, 1993).

At least two criteria were kept in consideration to assess the quality of vinegar. The first quality criterion was based on establishing that vinegar was actually vinegar (and not just diluted acetic acid). Discriminating analyses that were used to distinguish samples of vinegar involved measuring selected chemical constituents, including minerals, alcohols, acids, phenolics, and other volatile compounds. Using such an approach, it was even possible to differentiate fermentation process used to produce vinegar e.g., traditional versus quick acetification methods (Tesfayeet *al.*, 2002).

Vinegar Aroma

The characterization of vinegar included a wide range of values obtained from physicochemical and sensory parameters. Various researches characterized the quality of vinegars using different analytical parameters as well as sensory analysis (Carnacini and Gerbi 1992).

The other main characteristics on which vinegar quality was based were those that related to flavour, aroma, and other organoleptic properties. Vinegar flavour was particularly influenced by the raw ethanolic material from which it was made. And although acetic acid was by far the predominant flavour present in vinegar, other volatile flavour compounds were also present that contributed to the overall flavour profile of vinegar. In addition to this, the flavour and aroma were dependent on the method of process, aging time and raw material used in the mash (Morales *et al.*, 2001).

Health aspects

Phenolic compounds present in apples could prevent different chronic disorders such as cancers and cardiovascular diseases (Dai and Mumper 2010). Maaza and Murooka (2009) explored the utilization of vinegar in food preparations as well as used to treat wounds and infections. It could also be used in food preservation due to its low pH that retarded microbial growth and contributed sensory properties to a number of foods.

Leeman *et al.* (2005) reported that vinegar possessed an antiglycemic effect and decreased the glycemic index in a meal that could provide health benefits in both healthy and in diabetic patients.

Ostman *et al.* (2005) studied that vinegar could be used to bear on wounds, ulcers, arthritis, high blood sugar, high cholesterol, urinary tract and yeast infections, sun burn, insect bites, warts and hiccups.

De Ory *et al.* (2002) reported that vinegar could be used as a medicine, corrosive agent, pickling agent and could be directly consumed in diluted form as a beverage. In food industry the use of vinegar as an acidulent possessed many food processing applications including salad dressings, mayonnaise, mustard, ketchup, bread and bakery products, canned foods, marinades, etc. They also reported that vinegar provides an aid in dieting by creating a feeling of fullness that resulted in less food intake.

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