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The story of vinegar

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Vinegar may not enjoy the same elevated reputation as fine wine and cheese but it is a fermented food with comparable variety and some interesting microbiology. An important food preservative, vinegar is used in pickling, where its low pH and ethanoic (acetic) acid content inhibit spoilage and pathogenic microorganisms to improve keeping quality and safety, but is also highly valued for its contribution to flavouring and seasoning foods. Large quantities are used industrially in the production of sauces, ketchup, relishes, salad dressings and other formulated food products.

Vinegar is produced by a two-stage fermentation; in the first, sugars are fermented anaerobically into ethanol by yeast, usually *Saccharomyces cerevisiae*, while in the second, aerobic stage ethanol is oxidised to ethanoic (acetic) acid by acetic acid bacteria. It is the ethanoic acid they produce that gives vinegar its characteristic sour flavour. There are clear similarities between the first stage of vinegar manufacture and the production of alcoholic beverages and it is very likely that vinegar is of similar antiquity, having first been discovered thousands of years ago when alcoholic beverages were spoiled by souring. This is why the vinegar traditional to a particular area frequently uses the same raw material as the local alcoholic beverage. For example, the use of malted barley to produce both malt vinegar and beer in the UK, grape juice to make wine vinegar and wine in France, Italy and Spain, and palm sap to produce vinegar and toddy in countries in South and Southeast Asia. In fact, the name, vinegar, derives from the French *vin aigre* for sour wine.

The fermentation of sugar into alcohol by yeast follows the glycolytic pathway. Overall this transformation can be approximated by the chemical equation:

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$$

Alcoholic fermentation. The fermentation process can be very efficient, giving ethanol yields in excess of 90% of the theoretical value, although some sugar is diverted into the production of biomass and other products such as glycerol and succinic acid. The vinegar brewer strives for the maximum conversion of sugar into ethanol, but in the production of alcoholic beverages ethanol yields can be lower since factors such as flavour and body are more important. At the end of the first stage, a high strength alcoholic solution is produced. Generally, this is then used directly in the second stage, known as acetification, after the acid (acetic acid) is produced, though sometimes it is distilled to separate and purify the ethanol if a colourless, spirit vinegar is required.

The bacteria responsible for acetification are motile, Gram-negative rods of the genera *Acetobacter*, *Gluconoacetobacter* and *Glucono-bacter* (**Figure 1**).

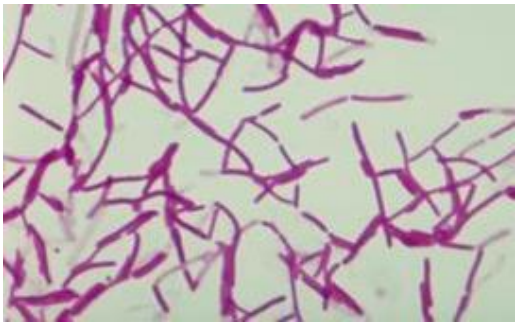

Figure 1. Acetic acid bacteria

A key metabolic characteristic is their ability to oxidise ethanol to ethanoic (acetic) acid; a reaction catalysed by two enzymes, ethanol dehydrogenase and ethanal (acetaldehyde)

dehydrogenase. In doing so the bacteria are able to produce energy in the form of ATP *via* an electron transport chain:

$$C_2H_5OH + O_2 \longrightarrow CH_3COOH + H_2O$$

Acetification. The oxygen they require is supplied in the form of air and the various techniques of acetification differ in how this is managed. In the Orleans method, the bacteria grow as a surface film on the acetifying liquid held in a vessel open to the air. In the Quick Vinegar Process, the process is accelerated by increasing the area of contact between the bacteria, the acetifying liquid and the air. The bacteria grow as a film on the surface of an inert support material such as wood shavings held in a false-bottomed vat. The liquid (called gyle) is sprayed over the bed of material and trickles through it against a counter current of air, either pumped through the bed or drawn up by the heat of the reaction within it. The acetifying liquid is collected in a sump at the bottom and recirculated until acetification is complete (**Figure 2**). Submerged Acetification is similar to many other modern industrial fermentations such as penicillin production, where the microorganism grows dispersed in a liquid medium and air is supplied in the form of small bubbles introduced into the suspension. Submerged acetification gives the fastest production rates because it achieves the best rate of oxygen transfer to the bacteria, but all three processes are still in practical use since each has its own advantages.

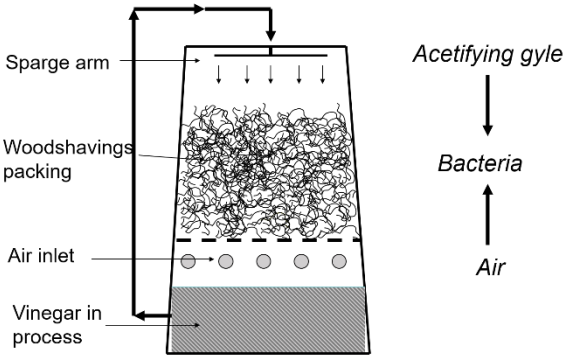

Figure 2. The Quick Vinegar Process

Vinegar production does not require strict asepsis like many other fermentations since the pH is low and the ethanoic acid being produced is inhibitory to competing micro-organisms. Levels of acid up to 14% (w/v) are achievable in most types of acetification, depending on the initial alcohol concentration. Once complete, the product is diluted down to the required strength; table vinegars typically contain about 5% ethanoic acid but stronger products are produced for use in pickling.

Some types of acetic acid bacteria also produce copious quantities of cellulose and this can be a problem when it occurs in conventional vinegar production. It is however the principle component of the pellicle used in the production of Kombucha tea, which involves a mixed culture of yeasts and acetic acid bacteria held in a cellulose matrix. In the Philippines bacterial cellulose is a product in its own right. Thick mats of gelatinous cellulose produced by acetic acid bacteria grown on coconut water or pineapple juice are washed free of any residual ethanoic acid, cut into cubes and stored in sugar syrup for use as a dessert called *natta*.

AUTHOR PROFILE

Martin Adams is Emeritus Professor of Food Microbiology at the University of Surrey. After a BSc at the University of Warwick, he obtained MSc and PhD degrees in Microbial Chemistry from the University of Manchester. Before joining Surrey in 1984, he spent 10 years in the Microbiology and Fermentation Section of the Tropical Products Institute in London. He is a past President of the Society for Applied Microbiology and represented the society on MiSAC for many years.