Food Fermentation

Fermented foods are among the oldest processed foods and have formed a traditional part of the diet in almost all countries for millennia. Today they continue to form major sectors of the food processing industry, including baked products, alcoholic drinks, yoghurt, cheese and soy products among many others. During food fermentations, the controlled action of selected micro-organisms is used to alter the texture of foods, preserve foods by production of acids or alcohol, or to produce subtle flavours and aromas which increase the quality and value of raw materials.

The main advantages of fermentation as a method of food processing are:

• the use of mild conditions of pH and temperature which maintain (and often improve) the nutritional properties and sensory characteristics of the food

• the production of foods which have flavours or textures that cannot be achieved by other methods

• low energy consumption due to the mild operating conditions

• relatively low capital and operating costs

• relatively simple technologies.

A more recent development is the separation and purification of enzymes from microbial cells, or from animal or plant sources for use in food processing. The enzymes are either added to foods as concentrated solutions or powders, or immobilised on support materials in a 'reactor' where they are re-used for extended periods. They are used to bring about specific reactions under mild conditions of temperature and pH and have found very wide applications in the food industry, for example, in the production of bakery products, fruit juices, glucose syrups and cheese.

Fermentation

Decomposition of carbohydrates by microorganisms or enzymes is called fermentation. Fermentation of food results in the production of organic acids, alcohol etc., which not only help in preserving the food but may also produce distinctive new food products.

The main factors that control the growth and activity of micro-organisms in food fermentations are:

• availability of carbon and nitrogen sources, and any specific nutrients required by individual micro-organisms

- substrate pH
- moisture content
- incubation temperature
- redox potential
- stage of growth of micro-organisms
- presence of other competing micro-organisms.

BATCH FERMENTATION

A batch fermentation can be considered to be a closed system. At time t=0 the sterilized nutrient solution in the fermentor is inoculated with microorganisms and incubation is allowed to proceed. In the course of the entire fermentation, nothing is added, except oxygen (in case of aerobic microorganisms), an antifoam agent, and acid or base to control the pH. The composition of the culture medium, the biomass concentration, and the metabolite concentration generally change constantly as a result of the metabolism of the cells. After the inoculation of a sterile nutrient solution with microorganisms and cultivation under physiological conditions, four typical phases of growth are observed as indicated in Fig.

Lag phase

Physicochemical equilibration between microorganism and the environment following inoculation with very little growth.

Log phase

By the end of the lag phase cells have adapted to the new conditions of growth. Growth of the cell mass can now be described quantitatively as a doubling of cell number per unit time for bacteria and yeast's, or a doubling of biomass per unit time for filamentous organisms as fungi. By plotting the number of cells or biomass against time on a semilogarithmic graph, a straight line results, hence the term log phase. Although the cells alter the medium through uptake of substrates and excretion of metabolic products, the growth rate remains constant during the log phase. Growth rate is independent of substrate concentration as long as excess substrate is present.

Stationary phase

As soon as the substrate is metabolized or toxic substances have been formed, growth slows down or is completely stopped. The biomass increases only gradually or remains constant during this stationary phase, although the composition of the cells may change. Due to lysis, new substrates are released which then may serve as energy sources for the slow growth of survivors. The various metabolites formed in the stationary phase are often of great biotechnological interest.

Death phase

In this phase the energy reserves of the cells are exhausted. A straight line may be obtained when a semi logarithmic plot is made of survivors versus time, indicating that the cells are dying at an exponential rate. The length of time between the stationary phase and the death phase is dependent on the microorganism and the process used. The fermentation is usually interrupted at the end of the log phase or before the death phase begins.

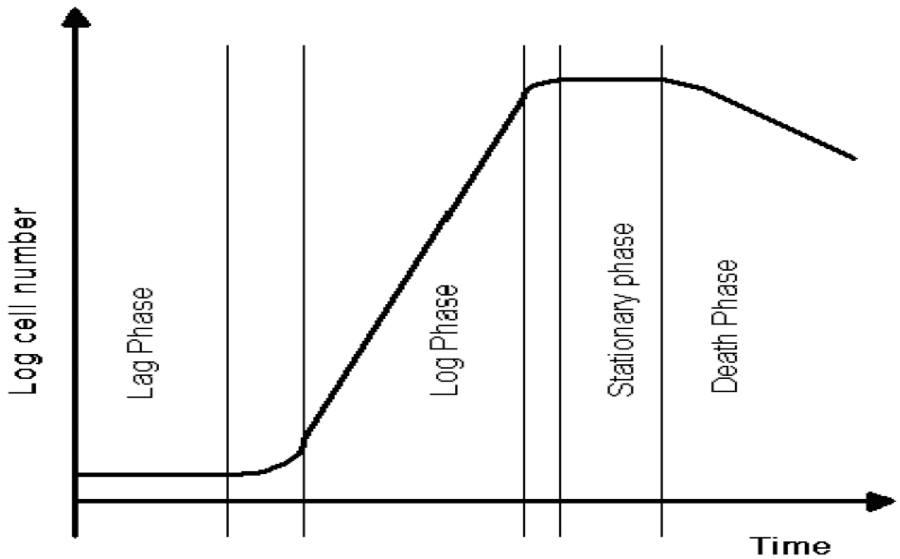

Fig. 2. Growth curve of a bacterial culture.

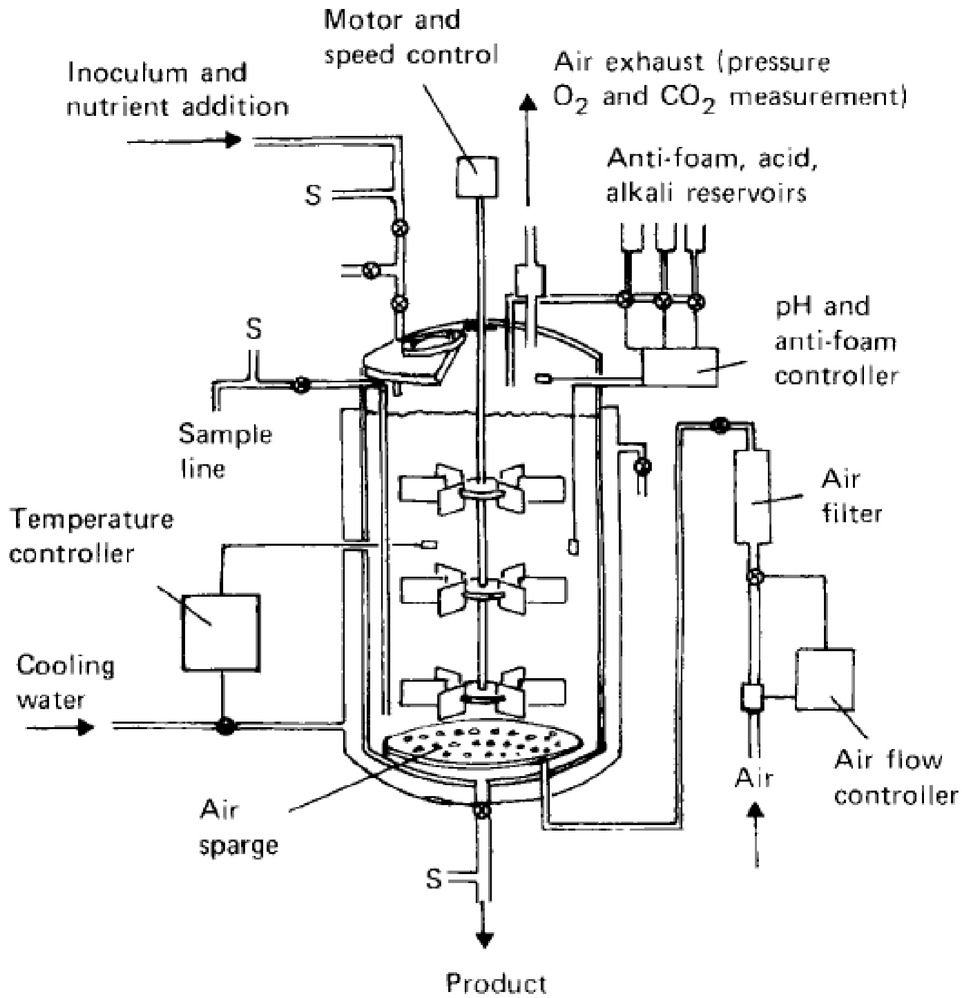

Fig. 7.5 Batch fermenter showing controls and instrumentation: S, steam sterilising points.

FED BATCH FERMENTATION

In the conventional batch process just described, all of the substrate is added at the beginning of the fermentation. An enhancement of the closed batch process is the fed batch fermentation. In the fed-batch process, substrate is added in increments as the fermentation progresses. In the fed-batch method the critical elements of the nutrient solution are added in small concentrations at the beginning of the fermentation and these substances continue to be added in small doses during the production phase.

CONTINUOUS FERMENTATION

In continuous fermentation, an open system is set up. Sterile nutrient solution is added to the bioreactor continuously and an equivalent amount of converted nutrient solution with microorganisms is simultaneously taken out of the system. In the case of a homogeneously mixed bioreactor we refer to a chemostat or a turbidistat. In the chemostat in the steady state, cell growth is controlled by adjusting the concentration of one substrate. In the turbidistat, cell growth is kept constant by using turbidity to monitor the biomass concentration and the rate of feed of nutrient solution is appropriately adjusted.

TYPES OF FOOD FERMENTATIONS:

1. **Lactic Acid Fermentation**

Lactic acid fermentation is an anaerobic intra-molecular oxidation-reduction process. Both homofermentative and heterofermentative lactic acid bacteria participate in food fermentation. In some cases, yeasts and moulds also participate along with lactic acid bacteria.

$$C_6H_{12}O_6 \rightarrow 2\ CH_3CHOHCOOH$$

In general, bacteria prefer low or no acid medium for their growth. The lactic acid bacteria, however, can grow in acid medium and can also produce acid through their action on the substrate. They can grow in the presence of 8 to 10 percent salt. Advantage is taken of these two factors in pickling. The growth of undersirable organisms is inhibited by adding salt, while allowing the lactic acid fermentation to proceed.

Fermentation takes place fairly well in a brine containing approximately 5% salt but proceeds somewhat slowly with 10% salt. To some extent it continues up to 15%, but at 20%, all fermentation stops.

Temperature is another important factor in lactic acid fermentation. Lactic acid bacteria are most active at about 30°C. It is therefore, essential that the temperature of the product undergoing lactic acid fermentation should be keep as close to 30°C.

Examples: Cheese, Yoghurt, Sauerkraut, Pickles etc.

2. **Alcoholic Fermentation:**

Ethyl alcohol can be produced by fermentation of any carbohydrate containing a fermentable sugar, or a polysaccharide that can be hydrolyzed to a fermentable sugar. Cider is one of the examples of alcoholic fermentation. It is brought about by yeasts.

The equation that describes the net result of alcoholic fermentation by yeast is given below:

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

Here a sugar is the substrate and the process is anaerobic. *Saccharomyces cerevisiae* is commonly employed for fermentation. It is imperative that the yeast must have a high tolerance for alcohol and must grow vigorously and produce a large quantity of alcohol.

Examples: Wine, Beer, Cocoa, Coffee etc

3. **Acetic acid Fermentation:**

The production of vinegar (acetic acid) from fruit juices is perhaps one of the oldest organic acid fermentations known. Acetic acid is produced by the oxidation of ethyl alcohol by bacteria such as *Acetobacter aceti, A. orleansis, A. schutzenbachi* and others. The biochemical reaction by which they form acetic acid from ethyl alcohol is as follows:

$$CH_3COOH + 2O_2 \longrightarrow 2CO_2 + 2H_2O$$

Examples: Vinegar production

Effect on foods

The mild conditions used in food fermentations produce few of the deleterious changes to nutritional quality and sensory characteristics that are found with many other unit operations. Complex changes to proteins and carbohydrates soften the texture of fermented products. Changes in flavour and aroma are also complex and in general poorly documented. Flavour changes include reduction in sweetness and increase in acidity due to fermentation of sugars to organic acids, an increase in saltiness in some foods (pickles, soy sauce, fish and meat products) due to salt addition and reduction in bitterness of some foods due to the action of debittering enzymes. The aroma of fermented foods is due to a large number of volatile chemical components (for example amines, fatty acids, aldehydes, esters and ketones) and products from interactions of these compounds during fermentation and maturation. In bread and cocoa, the subsequent unit operations of baking and roasting produce the characteristic aromas. The colour of many fermented foods is retained owing to the minimal heat treatment and/or a suitable pH range for pigment stability. Changes in colour may also occur owing to formation of brown pigments by proteolytic activity, degradation of chlorophyll and enzymatic browning.

Fermented Foods:

Fermented foods are now regarded as part of our staple diet. Today the fermentation technology has moved from artisanal practices and empirical science to industrialized and life science driven technology. The main substrates used in the commercial production of the most familiar fermented products are cereals, milk, meat, cucumber and cabbage. Fermented foods are the products of acidic, alkaline or alcoholic fermentation, and are mediated either by bacteria, yeasts, moulds, or mixed (bacteria and yeasts) microbial cultures

Cereal-based Fermentation

Fermented cereals play a significant role in human nutrition in all parts of the world where cereals grow. Among all food fermentations (e.g., milk, meat, fish, vegetables, soya or fruits), cereal fermentations reach the highest volume. The major cereal based foods are derived mainly from maize, sorghum, millet, rice or wheat. In terms of texture, the fermented cereal foods are either liquid (porridge) or stiff gels (solid). Some examples of cereal porridges (gruels) include ogi, mahewu and mawe, the cereal gels are for example kenkey, kisra and injera. LAB play a critical role in cereal fermentations.

Dairy-based Fermentation

Fermented dairy products represent about 20% of the total economic value of fermented foods produced world-wide. The market share of such products continues to grow. Dairy industry is a prime user of various LAB strains such as Lactobacillus, Lactococcus, and Leuconostoc. Cow, sheep, goat, and mare milk has been adopted as a raw material for dairy-based fermentation. The LAB, which are naturally present in air, raw dairy material, and containers are responsible for the fermentation. The LAB for dairy-based fermentation are desirable for their ability to create homogenous textures and particular flavour providing different traits attributed by different microbes. Yoghurt is the most popular fermented milk in the world. It is mostly prepared from cow milk which is fermented by two species of LAB: Streptococcus thermophilus and Lactobacillus delbrueckii subsp. bulgaricus. Manufacture of acidophilus milk (North America), laban (Middle East), leben (Arab World) and dahi (India) is very close to that of yoghurt. Kefir and koumiss (Central Asia) are fermented milks made with kefir grains composed by little clumps of yeast, lactic acid bacteria and milk proteins. Cheeses, another popular fermented diary product, are still made from non-pasteurized milk and may even depend on natural lactic flora for fermentation; most are produced on a commercial scale using the appropriate starter culture. These can contain mesophilic Lb. lactis subsp. lactis and Lb. lactis subsp. cremoris or thermophilic Streptococcus thermophilus, Lb. helveticus, and Lb. delbrueckii subsp. bulgaricus, depending on the specific application.

Meat-based Fermentation

Fermentation is a traditional processing and preservation method that provides relatively stable meat products with acceptable sensory characteristics. Fermented meat is produced with the addition of microbes when different condiments are mixed together with meat. The microbiota involved in the fermenting process is diverse and complex, and closely related to the ripening technique. The LAB are usually present in high hygienic quality raw meat at low amounts and dominate the fermentation later.

Their presence effectively prevents harmful bacterial growth and controls the fermentation processes. During the fermentation, acids and alcohols are produced, leading to a decrease of pH. Meanwhile, proteins are broken down into peptides and amino acids. The characteristics of fermented meat include special flavours, a longer shelf-life, and convenience for consumption. A variety of fermented meat products are available such as fermented sausage, bacon, and ham.

Fish-based Fermentation

There are two kinds of fermented fish products available worldwide; i.e., fish sauce and fish paste. In Southeast and east Asian countries, fish sauces (i.e., nuoc-mam, nam-pla, patis, budu, bakasang, etc.) are very popular. Some fish sauces are made from raw fish, others from dried fish, some from only a single species, others from a variety of fishes. The most common microorganisms isolated from fish sauce are Bacillus, Lactobacillus, Pseudomonas, Pediococcus (all bacteria), Debaryomyces and Hansenula (yeasts).

The bacteria involved in fish paste fermentation are mainly halophilic bacteria such as Lentibacillus jeotgali (Korean fermented seafood), Gracilibacillus thailandensis (from Plara), Paenibacillus tyraminigenes (from Myeolchi-jeotgal, a traditional Korean salted and fermented anchovy), Piscibacillus salipiscarius (from Plara), etc.

Vegetable-based Fermentation

Plant-based foods contribute to the core daily dietary intake in Asia. Traditionally, people fermented mixed vegetables such as cabbage, radishes, cucumbers, turnips and beets. The LAB can bind to the surface of vegetables without decomposing cellulose or proteins, contributing to the characteristics of the final product in addition to preservation. The traditional method for fermentation is to place vegetables into clean containers and add ingredients for natural fermentation. Addition of salt is indispensible even if the vegetable species or manufacturing processes differ from region to region. This facilitates the production of flavour, controls against undesirable microorganisms, extracts water and nutrients, and constitutes soft tissue. Finally, anaerobic environment, salt addition and acid production result in unique features of the products and a high degree of hygienic safety.

Soybean-based Fermentation

Soybean is one of the most widely cultivated plants in the world and is a good source of protein and essential amino acids, particularly, lysine. China is the place of origin of the soybean, which may date back to more than two millennia, and it has a long tradition of soybean production and processing, especially in the preparation of the main product of soybean, tofu. Fermented soybean products with high nutrition and health benefits have gained much attention. During the fermentation process, useful active substances are released through metabolic processes of microorganisms, providing additional health benefits. Resources and expertise in producing and developing soybean-based fermented foods are abundant. Typical products are sufu, stinky tofu, and lobster sauce. The characteristic aroma and flavour of soybean-based fermented foods are partially generated by LAB.

Fruit-based Fermentation

Traditionally, fruits have been fermented to produce low alcoholic beverages like wines which are produced and consumed all over the world. Wines are produced mainly from grapes but other fruits like plum, peach, pear, apple, citrus, strawberry, etc. are also used in it production. The fermentation is carried out by *Sacchromyces cerevisiae* var. *ellipsoideus*. Several types of wines are made like table wines, sweet and dry wines, fortified wines, sparkling wines. The wines are distilled to make brandy also. Wine yeast, *Sacchromyces cerevisiae* var. *ellipsoideus* and several of its strains like UCD 595, UCD 502 and UCD 522 are employed to conduct alcoholic fermentation of foods to make wine. The process consists of preparation of must, culture preparation, fermentation, siphoning, clarification and maturation.