Chapter

Fermentation in the Perspective of Agriculture

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Abstract

Fermentation is a multi-disciplinary concept that is defined from the perspectives of various disciplines. It connotes different meanings to microbiologist, biochemist, food and nutritionist (rumen modulator/manipulation) and soil scientist. However, the overall is that it results in the breakdown of substrates (organic or inorganic) in the absence of air to yield intermediate by-products including methane gas (loss of feed energy). The concept includes activities bothering on anaerobic and aerobic processes to enhance the breakdown of substrates to produce some useful materials and biogases. Although carbohydrates are often regarded as essential materials for fermentations, organic acids (including amino acids), proteins, fats, and other organic compounds are fermentable substrates for selected microorganisms with the production of total volatile fatty acids and their individual components (i.e. propionates, butyrates and acetates). Today, fermentative process involves the transformation of raw materials, aerobically or anaerobically, to other valuable products through the activities of microorganisms.

Keywords: fermentation, substrate, microorganism, breakdown, intermediate products

1. Introduction

Fermentation is a concept in use by many disciplines; hence it is a multidisciplinary concept that is defined from the perspectives of various disciplines involved. It connotes different meanings to scientists working in the areas of microbiology, biochemistry, food nutrition, animal nutrition and soil science. However, the overall is that fermentation is a process that results in the breakdown of substances (organic or inorganic) where there is no air (oxygen) to yield some intermediate by-products including biogas.

Fermentation finds its root in the word "ferment", which is a Latin word *fervere* meaning "to boil". It is a process of natural evolution and people use fermentation to produce wine and alcohol long before the advent of science and the understanding of biochemical processes.

Today, this ancient knowledge in combination with scientific knowledge is applied in production processes to make a variety of products that are useful for life's existence. Hence, fermentation is a metabolic process which alters the chemical composition of organic substrate following the activities of enzymes. Its primary function in microorganism is to produce energy (adenosine triphosphate, ATP) by breaking down of organic nutrients [1]. Humans use fermentation for the production of beverages and foodstuffs as well as for making wines, beers and yoghurts [2].

The concept of fermentation in today's world has grown to include those activities bothering on both anaerobic and aerobic processes that enhance the breakdown of organic and inorganic substances to produce some forms of useful materials and biogases. Although carbohydrates are usually regarded as necessary materials for fermentations, other organic compounds such as proteins, fats, and organic acids are substrates that can be fermented by specialized microorganisms. These materials serve as food and energy sources to microorganisms. Under anaerobic conditions, a fraction of the potential energy is liberated because of incomplete oxidation, leaving a heap of unoxidized organic by-products. In order to obtain as much energy obtainable under aerobic conditions, several molecules of glucose need be broken down under anaerobic conditions. Fermentation can therefore be regarded, as the breakdown of organic compounds, where oxygen is lacking, to organic intermediate products, which the cell's enzyme system could not further oxidize except oxygen is available. The product of fermentation varies as the microorganisms acting on the substrates, depending on the cell's enzymes complex and the conditions of the environment. The economic importance of these by-products marks the advent of industrial microbiology.

The knowledge of fermentation as anaerobic process brought out the difference between microbial biochemistry and biochemistry of mammalian tissues. Fermentative process was postulated to follow similar paths because the intermediate products of glucose metabolism were similar. Consequently, the fermentation of carbohydrates by microorganisms was considered similar to glycolysis by mammals. This explains why many authors employ the terms "glycolysis" for the description of one method of anaerobic breakdown of carbohydrates by microorganisms and why the terms: "fermentation" and "glycolysis" are used synonymously. These two terms are different because glycogen is not stored by bacteria and lactate was not the intermediate or end product during breakdown of carbohydrates by bacteria.

Therefore, the main aim of this chapter is to define fermentation in broader term beyond what is currently used to describe it. The specific objectives are to explore the fermentative processes in the nutrition system of ruminants and showcase how fermentation processes occur in the soil system to give rise to available plant nutrient elements.

2. Fermentation in ruminants

2.1 Ruminants nutrition

Ruminants possess rumen as part of a complex stomach hosting diverse microbial matrix (bacteria, protozoa, fungi and archaea i.e. methanogens) that helps to hasten the breakdown of all the solids (forages, roughages, crop residues, agro-industrial by-products and fibers or feed substrates) and help boost fermentation to enhance and raise productivity [3, 4]. Seasonal feed challenge in ruminants together with low intake and poor digestibility contributes to their low productivity [5, 6]. Also, fermentation that is inefficient reduces the potential satisfaction ruminants derive from the feed consumed.

It was reported that quite a number of chemical feed additives such as antibiotics, ionophores, methane inhibitors, defaunating agents, etc. have been used in ruminant nutrition to manipulate, modify or to improve rumen fermentation and degradability swith the aim of boosting or hastening the rumen efficiency [4, 7–11].

The use of banned artificial antibiotics by European Union (EU) in the diets of livestock to increase production of meat, milk and wool, as well as suppression of some microbial activities has motivated researchers' interest in the use of plants and plant extracts [7–9, 12].

It is imperative now to know that the fate of the underlining facts or factors of ruminant feeding, fiber degradation, digestion and metabolism lies on the ruminal microbial ecology or rumen ecosystem (i.e. bacteria, archaea (methanogens), fungi and protozoa) with their various activities. Ruminants establish a symbiotic relationship with rumen Microorganisms by providing nutrients and optimal environment for fermentation of feeds, degradation of fiber and synthesizing microbial protein to achieve their major target of yielding or making available the end product of digestion i.e. volatile fatty acids (VFA) as energy and protein supply to the host animal.

This end products contribute to the nutrition or nutrients the host animal (ruminants) will benefit and in this microbial fermentation process there are wastages associated like loss of methane, loss of ammonia nitrogen, inefficiencies which limits production performances and release of pollutant that can affect the atmosphere [8, 13–15].

Different kinds of studies have been conducted by many researchers to show that plant secondary metabolites (PSM) manipulate rumen ecosystem by inhibiting, suppressing and proliferation of some microbes (i.e. gram-positive or gram-negative bacteria) and at times help in defaunating (i.e. removal or reduction in the population of protozoa) in the rumen [1]. This aspect of rumen manipulation for proper feed efficiency/utilization and mitigation of methane gas from the host animal has now generated a lot of interest.

2.2 Rumen manipulation

Rumen manipulation is the modification of rumen fermentation processes, so as to improve protein and carbohydrate metabolism and at the same time reduce ammonia, carbon dioxide, hydrogen, methane production and release to the atmosphere. Rumen manipulation aims at minimizing the role of rumen microbes in fermenting ingested feed thus improving the efficiency of nutrient utilization, feed energy and nitrogen loss. The manipulation of rumen involves mitigating the fermentative action of rumen microbes on ingested feed thus increasing feed available to the true stomach (abomasum) where the digestive enzymes act on them and are later absorbed in the small intestine. Many researchers have been carried out by various researchers on the manipulation of rumen microbial ecosystem in order to improve the productivity of ruminants [7, 8, 16].

The increase in the nutrient requirement of ruminants determines changes in the composition of a feed ration. In order to maintain high production level and for the synthesis of microbial protein, ruminants require reduced proportion of green forage rich in structural carbohydrates (such as cellulose), increased proportion of starch and increased proportion of nitrogen and exogenous amino acids in a feed ration [17].

The commensalistic relationship between the host animal (polygastric) and microorganisms accommodated in the rumen becomes disturbed for a grazing and nomadic animal. The high request for nutrients, mainly carbohydrates and protein results in low symbiotic effectiveness between the animals and the microorganisms; despite the increased demand, animals are still not able to utilize excessive amounts of protein and energy. The non-degraded protein and protein digestion leads to the increased rumen ammonia (NH_3) production, while the disturbed proportions of feed (carbohydrates and changes in their fermentation) result in the increased methane (CH_4) production.

Both the aforementioned gases (NH_3 and CH_4) belong to the group of gases called greenhouse gases (GHG) whose level of production in the rumen and the amount emitted to the atmosphere is linearly dependent on the composition of a feed ration [17]. Rumen manipulation also helps in keeping a low hydrogen pressure in the rumen by reducing carbon dioxide thus reducing methane production. Protozoa play a negative role in protein availability and utilization by ruminants [18] by consuming and digesting a substantial number of ruminal bacteria thus reducing the amount of bacterial protein available for enzymatic digestion in the duodenum [19, 20].

Protozoans have the ability to perform the processes of proteolysis and deamination and tampering with the rumen to eliminate the protozoan populations in the rumen which is been referred to as defaunation, which may results in an increase in the amount of nitrogen (microbial source).

Thus, it can be said that the main objective of rumen manipulation is to improve rumen fermentation processes, improve feed efficiency and utilization, reduce nitrogenous wastage, and reduce methane production with emission into the environment thereby ensuring that the total energy available to ruminants is not reduced. Methane (CH_4) production/formation is a product of an enteric fermentation in the rumen of ruminant animal which is widely referred to as a loss of feed energy and suppressing its formation is a very big challenge to ruminant scientist (nutritionist and rumen manipulators).

Ruminants have evolved over thousands of decades to utilize cellulose and polysaccharides by means of a (foregut) pre-gastric fermentation system which yields methane and there is no system to halt methane production [21]. Thus, production of methane (feed energy) in the rumen and its release into the atmosphere, decreases feed utilization. The energy loss derived from the process of feed fermentation is reported to be between 2 to 12% of feed gross energy [22]. Patra *et al.* [23] also reported that methane loss represents about 12% of the gross energy of feed fed to the animals. Donald and Ward [24] also reported that about 95% of the global animal enteric methane is from ruminants which are a consequence of their large population, body size and feed intake. Hence, decreasing the production of enteric methane in ruminants without altering productivity in the animal is desirable both as a strategy to reduce global greenhouse gases emissions and as a means of improving feed conversion efficiency [25, 26].

The process of methanogenesis occurs mainly in the rumen in the presence of microorganism and in an anaerobic environment. The (host) animal provides necessary nutrients needed and environmental conditions that is suitable for the fermentative activities in degrading the solids or substrates (carbohydrate and protein) by the microorganisms thereby synthesizing microbial protein in order to supply energy and protein to the host animal [7, 27].

As a result of interspecific symbiosis between methanogens and bacteria, protozoa or fungi, transfer of hydrogen originating from the cells of the above-mentioned microorganisms to methanogens occurs. Methanogens use CO_2 in the reduction of H_2 and the energy obtained in the process is used for the formation of Adenosine triphosphate (ATP). Owing to the process of methane production in the rumen, low concentration of H_2 is maintained in the rumen environments and this probably affects carbohydrate transformations in the rumen [28, 29].

The methane produced must be expelled together with CO_2 through the process of eructation. Methanogens identified to be present in the rumen of ruminant are of the genus *Methanobrevibacter* and *Methanosarcina.* The main species are: *Methanobrevibacter ruminantium, Methanosarcina barkeri, Methanosarcina mazei and* [30]. However, the development of modern molecular techniques establishes that a ruminant species determines the type of methanogen that prevails in their rumen.

Many authors have suggested the implementation of strategies that can help to mitigate the adverse effects of the process of methanogenesis which occurs in the rumen of ruminant animals on the environment. These mitigation effects can be achieved directly by decreasing the amount of emitted methane per unit of consumed feed and indirectly by increasing the animal performance with the same level of methane emission [31]. Similarly, the reduction of hydrogen production can be achieved without any adverse effect on feed digestion. Alternatively, more favorable utilization of hydrogen by host (animal) and reduction of both the number and the activity of methanogens [26] could go a long way to mitigate the adverse effects of methanogenesis.

Many research centres in the world conduct research on the methods of reducing methane emission to the atmosphere. Lately the interest in the use of phytofactors to achieve the aim has increased. While the current focus is specifically on diminishing methane production from digested feed. It should be noted that from an environmental viewpoint, the final interest lies in controlling methane emission of the entire system and this entails several contexts, some of which are well suited to human intervention [7, 32, 33]. For example, feeding practices which increase feed efficiency of ruminants will ultimately decrease emissions of methane per unit animal product [34]. Faniyi *et al*. [8, 33] and Monteny *et al.* [35] explained that the rate of methane production by ruminants depends on the level of feed intake and the fraction of ingested energy lost, as methane is being reduced with higher feed intake. This is mainly due to increased passage rate in the rumen. The focus now is on nutritional intervention aimed specifically at controlling the yield of methane per unit feed ingested which is referred to as the relative yield of methane. Despite the rigidity of the rumen towards suppressing methanogenesis, it is possible to reduce the yield of methane. There are two main complementary approaches to effectively reducing methane production:

The first approach takes advantage of the reliability that not all feed components ferment in the same way in the rumen thereby yielding different quantities of methane per unit carbohydrate fermented. It is often assumed that concentrates yield relatively less methane than forages per MJ (mega joules) of GE (gross energy) intake [22, 36, 37]. It is well known that the rapid degradation of carbohydrates leads to the production of volatile fatty acids (VFAs). In the synthesis of this VFAs, hydrogen is produced, much of which undergo chemical reactions with methanogenic bacteria thereby leading to methane production. The formation of volatile fatty acids among feedstuffs and diets determines the amount of excess hydrogen in the rumen, which is ultimately converted to methane by methanogenic bacteria. Thus, replacing structural fiber with non-structural carbohydrates shifts volatile fatty acid formation patterns to less of acetic acid and more of propionic acid formation. Therefore, increase in dietary starch at the expense of fiber in a ruminant ration reduces the loss of methane per MJ of GE intake by redirecting or reducing equivalents from methane to propionate production [38]. Related to this approach is the administration of some feed additives such as dietary enzymes or probiotics, which potentially enhance digestion and consequently reduce rumen methane production. It has been demonstrated that the addition of enzymes such as Cellulases and hemicellulases to the diet of ruminants have reduced *in vivo* methane production by 9 and 28% respectively possibly by reducing the acetate to propionate ratio [39].

A second approach involves the use of specific ingredients or additives aimed at specifically reducing production of methane. These are compounds which directly or indirectly inhibit methanogen function. Several chemicals inhibit methane production experimentally (e.g. several halogenated methane analogues such as chloroform and bromochloromethane, [40], and statins [41]. However, these substances have drawbacks as many cause only a transient decline in methane production and they are toxic to the host. Some plant secondary metabolites and plant extracts fall in this category e.g. anthraquinones, which is a major secondary compound of rhubarb, depress rumen methane production [8, 27, 32, 36, 42, 43]. Fatty acids particularly medium chain fatty acids such as myristic and lauric acids preferentially inhibit methanogenic bacteria [39]. Host's immunization against its methanogens has also been examined [44] with favorable but unrepeated results.

Although, there are substances such as ionophores and some plant extracts which cause indirect inhibition of methane formation by causing impairment in the microorganism's habitat or availability of substrates to methanogens (e.g., tannins and saponins). This approach is less dependent on providing alternative hydrogen sinks. Ionophores decrease hydrogen availability and therefore methane production [7, 12, 36, 45]. Some plant extracts such as tannins, saponins and so on also cause differential inhibition of some bacterial species acting in a similar way as ionophores [13].

3. Fermentation in soil systems

3.1 The soil system

The soil systems comprise of organic (5%), inorganic (45%), water (25%) and air (25%) components. These components are always in equilibrium. However, the soil serves as repository for all forms of waste, be it solid, organic and inorganic. The organic matter content of the soil is the portion that contains plant tissues and animal remains occurring at different decomposition stages. Majority of agriculturally productive soils contain about 5% content of organic matter.

Organic matter comprises of components in three major categories:

i. Plant residues and living microbial biomass.

ii. Detritus (often referred to as active soil organic matter).

iii. Humus, which is the stable component.

The first category comprises of microorganisms which break down residues of plants and animal remains as well as detritus. Humus represents the stable portion that is resistant to further degradation, hence, it is the final product of decomposition.

The first two categories of organic matter play a significant role in determining the fertility status of soil. This is because their breakdown account for the mineralized nutrients (such as NO_3^-, PO_4^{2-}, Ca^{2+}, Mg^{2+} etc.) available for the nutrition of crop-plants. The humus component has little contribution to the fertility status of soil, and it is called "stable organic matter". However, it is still very relevant to soil fertility management because it enhances the structure and tilth of soil as well as providing surfaces for cation exchange. Humus is responsible for the soil's dark coloration. The most important way of adding organic matter to the soil system is by the process called composting.

3.2 Composting

The term "composting" is used worldwide with differing meanings. It was defined narrowly by some textbooks as aerobic form of decomposition mainly by aerobic or facultative microbes.

There are two categories of composting, consequent upon the mode of decomposition.

These categories include anaerobic composting, often referred to as *dry fermentation* or anaerobic digestion [46] and aerobic composting, often referred to as *aerobic fermentation* [47].

In anaerobic composting (also known as anaerobic digestion), decomposition occurs where oxygen is absent or in limited supply. During this process, anaerobic micro-organisms (mostly bacteria) play prominent roles in the breakdown of substrates resulting in production of intermediate by-products such as organic acids, methane, and other gases. As the bacteria "work," they generate biogas. Generally, different materials exhibit different digestibility and the more digestible the organic matter is, the more biogas is produced. In the absence of oxygen, the intermediate compounds accumulate and are not further metabolized. These (intermediate by-products that are not fully oxidized) present some phytotoxic properties and very pungent odors. Anaerobic composting occurs under a low-temperature condition; hence, the process does not eliminate pathogens and seeds of weeds. The process also occurs at a slower pace than aerobic composting. These drawbacks offset the advantages of the process, such as: low energy requirement and no loss of nutrients during the process.

Aerobic fermentation or composting, on the other hand, occurs where oxygen is available. The facultative or aerobic bacteria are involved in the breakdown of substrates to release some plant nutrients, heat, biogases, and stable materials (humus). Although intermediate by-products are also produced during aerobic composting, these by-products are further oxidized to yield some useful ions or nutrients for plant growth with little or no danger of phytotoxicity, free of odor and leaving materials resistant to decomposition such as lignified materials (cellulose and hemi-cellulose). The resultant end-product is regarded as compost. The heat generated (due to high temperature regime) facilitates decomposition process within a very short time frame. Moreover, this process destroys many micro-organisms that can cause diseases to crop-plants and humans, as well as weed seeds, owing to the sufficiently high temperature. There are tendencies for loss of nutrients under this process, but it remains an efficient and a more useful method of composting than the anaerobic process for agricultural production and productivity.

Composting of waste is a form of *aerobic fermentation* mode of decomposing solid wastes under controlled conditions of pH, moisture contents, particle size, C/N ratios, etc. [47]. The process resulted in the formation of humus, usually regarded as compost, which serves as a source of nutrients to crop-plants. It involves the accumulation of organic waste in a form of heap. Usually, the waste materials can be shredded to manage the particle size. The accumulation is a multi-layered heap of organic wastes in a windrow, subjected to regular turning to ensure good aeration; and addition of water in order to regulate temperature (heat). Facultative bacteria and fungi feed on the substrate to ensure decomposition and release of ammonium ions and other nutrients required by crop-plants for growth and development.

4. Conclusion

Fermentation is a beneficial process in the field or study of agriculture. It is of great importance in animal and plant nutrition systems. In animal nutrition, the process is basically anaerobic and requires a process called rumen manipulation to enhance better productivity of ruminant animals. However, fermentative processes can either occur aerobically or anaerobically in soil systems resulting in the release of nutrients for the enhanced productivity of crop-plants. Hence, fermentative process involves the transformation of raw materials (organic or inorganic substrates), whether aerobically or anaerobically, to other valuable products through the activities of microorganisms. This implies that fermentation could occur either in aerobic (presence of oxygen) or anaerobic (absence of oxygen) conditions.

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