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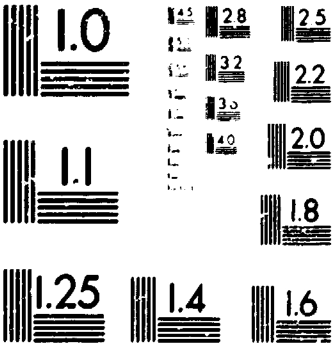

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LACTIC ACID FERMENTATIONS: BASIC PRINCIPLES AND APPLICATIONS*

prepared by

Gustavo Viniegra Gonzalez**

UNIDO Consultant

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** Professor, Universidad Autonoma Metropolitana-Iztapalapa, División de Ciencias Biológicas y de la Salud, Departamento de Biotecnología, Iztapalapa, Mexico 13, D.F.

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TABLE OF CONTENTS

I. INTRODUCTION

1. Lactic acid fermentation is a process whereby a varied group of bacteria ferment carbohydrates with lactic acid as the major end product. Lactic acid bacteria are involved the the production of yoghurt, cheeses, sauerkraut and silage. Many times they act as spoilage organisms. In particular, societies in Africa, the Americas and South-East Asia have long traditions of producing and consuming foods which have been produced as a result of lactic fermentation. As a result, significant food industries have sprung up over the ages.

2. Recent advances in the biosciences have led to much understanding of the biology, chemistry and kinetics of lactic fermentation. Present R+D as a result has been focused on exploring new materials as fermentation substrates, on methods for avoiding contamination or infection of bacterial stocks used by industry, and on the development of mathematical models for process control in applications.

3. Scientific and technological advances in lactic fermentation are, in turn, leading to many new possibilities for industrial applications. Household processes are giving way to modern computerized fermentation plants. However, what is most remarkable is that neither the old respected values nor the wisdom of the ages need to be lost with new developments. Changes, which may result in larger outputs on more varied goods, are firmly based on past achievements. It is the purpose of this paper to briefly review the historical background of the lactic fermentation, to describe the biochemical basis for process development and control, and to discuss starter cultures. After the short scientific and technical review, the applications of lactic fermentation in developing countries will be discussed as well as the possibilities for international co-operation in this field.

II. HISTORICAL BACKGROUND

4. Scheele in 1780 isolated and characterized lactic acid in sour milk (Prescott and Dunn, 1962) while Pasteur in the middle of 19th century isolated a bacterium which he considered to be responsible of acidifying milk (Kayser, 1925). Industrial lactic fermentation was already established in United States at the end of 19th century (Peppler, 1971) and the industrial use of starter cultures was common practice in Europe and United States at the beginning of 20th century (Orla-Jensen, 1921).

5. Metchnikoff (1908) recognized that yoghurt lactic fermentation reduced the _in vitro_ population of putrefactive bacteria and thought that the implantation of yoghurt bacteria in the human gut could make life longer because the possible harmful action of putrefaction could be overcome by lactic fermentation. The association between longevity and the implantation of yoghurt bacteria in the human gut has been a controversial matter because it has not been possible to show a definite gut colonization of strains of _Lactobacillus bulgaricus_ as suggested by Metchnikoff (1908). Nevertheless, this hypothesis has attracted the attention of various research workers and it has served to focus work on the inhibition of enteropathogens such as _Escherichia_, _Salmonella_ and _Shigella_ by several strains of lactic bacteria (Reiter et al., 1964; Park and Marth, 1972; Frank and Marth. 1977).

6. Research which led to an understanding of the lactic fermentation kinetics was carried out by Luedeking and Piret (1959a and 1959b) who characterized the lactic fermentation as a chemical process; a process which can be manipulated by the control of environmental variables such as pH, temperature and chemical composition of the culture medium. Their pioneer work has served as a model of fermentation kinetics applicable to various fields of industrial fermentation.

7. The biochemistry of lactic fermentation is related to a biochemical pathway described very early by German research workers, the so called Embden-Meyerhoff-Parnas pathway, which is shared by many other microbial processes (Doelle, 1975).

8. Genetics of lactic bacteria has not been studied as much as the genetics of <u>Escherichia coli</u> but it is now being investigated in various laboratories in Europe and United States.

9. One of the important problems facing the dairy industry is phage infections which seriously affect the behaviour of the microbiolculture and hence the quality of the final product. Research on phage sensitivity of starter cultures has resulted in important applications for the control of those infections (Collins, 1965).

10. Fermentations of legumes, cereal grains and starchy roots have been associated with the activity of lactic bacteria in various places of the world. Traditional Japanese soybean fermentation involves the action of lactic bacteria and has also been studied in detail (see the review by Wang and Hesseltine, 1983). Maize fermentations have been described and studied in Mexico (Cravioto et al., 1955; Ulloa, 1974; Ulloa-Sosa and Herrera, 1981; Ulloa, 1981; Velazquez et al., 1983). In Africa, a number of food fermentations have been studied including substrates such as: cereal grains, cassava roots and palm nuts (Banigo, 1969; Muller, 1981; Okafor, 1981). Many of those processes include lactic fermentation and in some cases was nutritional advantages of the activity of lactic bacteria because of the biological transformation of the original vegetable protein (Cravioto, et al., 1955).

11. Lactic acid bacteria play important roles in specialized foods. For example, the lactic acid fermentation is critical for sour dough fermentations. The sour dough fermentation is a complex biological system. A number of environmental factors such as temperature, composition of the gas phase and properties of the fermentation substrate all have been found to be significant factors in the overall fermentation process. In addition, the type and composition of the lactic acid bacteria play critical roles in flavour formation and alteration of the physical properties of the dough. Spicher (1983).

12. Silage fermentation, that is the natural fermentation of green forages, was recognized as lactic fermentation a long time ago (Kayser, (1925) but conditions that led to optimal process were not studied until recently. Work on this subject has been done in connection with industrial production of fermented feedstuffs and has led to the development of at least two fermentation patents related to the non-aseptic control of lactic fermentation (Reddy et al., 1976; Peschard et. al., 1979)

13. Applied research on silage fermentations has also led to new concepts for the understanding of the ecology of lactic bacteria (Viniegra-Gonzalez and Gomez, 1984) and might be related to development of new industrial uses of lactic acid. For example, Akedo et al. (1981) are now investigating new ways of producing chemical feedstocks such as acrylate using propionate which in turn can be produced from lactic acid.

III. BIOCHEMICAL BASIS FOR PROCESS DEVELOPMENT AND CONTROL

14. There are two major patterns of lactic fermentation: homolactic and heterolactic. They are related to the proportion of lactic acid in the final fermentation products. Homolactic fermentation is defined as a process with rather low levels of sugar concentration (less than 100 g/1), taking place under anaerobic conditions and yielding more than 70% lactic acid based on the material balance using glucose as reference substrate. Most of the homolactic bacteria belong to the genera Lactobacillus Streptococcus and Pediococcus and are characterized for having the enzyme aldolase as a constitutive part of their metabolic machinery (Doelle, 1975). Homofermenters (microbiol cultures presenting an homolactic fermentation pattern) are common in dairy and soybean fermentations, which present the following reaction stoichiometry:

$$C_6H_{12}O_6 \longrightarrow 2\ CH_3\text{-}CHOH\text{-}COOH$$

(Glucose ---> 2 lactic acid)

15. This equation indicates that in the homolactic fermentation there is no material loss of C, H or O because there is no carbon dioxide evolution.

16. Heterolactic bacteria are, on the other hand, characterized by not having aldolase but another enzyme called phophoketolase. These enzymic differences lead to a different cleavage mechanism of glucose yielding carbon dioxide as an obligated product together with a corresponding amount of ethanol or acetic acid and a low yield (less than 50%) of lactic acid. Heterolactic bacteria belong to some species of the genus Lactobacillus and also to all species of the genus Leuconostoc (Doelle, 1975). Heterolactic fermentation presents the following stoichiometric equation:

$$C6H12O6 \text{ ---> } CH3\text{-}CHOH\text{-}COOH + CH3\text{-}CH2OH + CO2$$

(Glucose ---> Lactic acid + Ethanol + Carbon dioxide)

17. Here, the important feature is the evolution of carbon dioxide corresponding to a material loss of approximately 18% of the initial weight of glucose. This type of fermentation is commonly observed in sauerkraut and other fermented vegetables.

18. It can be seen that if homolactic fermentation is desired it would be easier to obtain homofermenters in dairy products such as raw or sour milk but if heterolactic fermentation is desired, then rotten vegetables would be an appropiate natural source for such kind of organisms (Velazquez et al., 1983).

19. The nutrition of lactic bacteria has been studied for a number of species (homolactic and heterolactic) and such results have been summarized by Laskin and Lechevalier (1974). Practically all lactic bacteria require at least one amino acid and several vitamins as growth factors. This means that lactic fermentations are usually done in complex culture media having a significant amount of protein. For instance, cereal grains, soybeans, vegetables or milk are good natural substrates for lactic fermentation. Artificial culture media based on substrates such as molasses or starch need nutritional supplementation.

20. Nutritional requirements of lactic bacteria can vary depending on the interactions of various strains with different metabolic properties . For example, Nurmikko (1954) showed that Streptococcus fecalis and Lactobacillus casei require less vitamins when they are grown together, as compared to the vitamin requirements of isolated pure cultures. Thus there might be certain advantages of using mixed cultures instead of pure cultures of lactic bacteria.

21. The kinetics of lactic acid formation by lactic bacteria can be described in terms of three major variables: X= bacterial biomass, S= substrate (glucose, lactose, starch, etc.) and P= lactic acid. It is customary to quantify those variables in g/l using four specific rates (1/hour) : u = growth rate, q= metabolic rate and a and b, the lactic acid production rates associated to growth and maintenance, respectively. Mathematically, those relations can be expressed as following:

$$dX/dt = uX$$
$$dS/dt = -q(S)X$$
$$dP/dt = (au + b)X$$
$$q(S) = (qm*S)/(Ks + S)$$

qm = maximal metabolic rate

Ks = saturation coefficient

22. The above set of equations have been used to characterize the kinetic behaviour of lactic bacteria (Aborhey and Williamson, 1977; Hanson and Tsao, 1972). Such a type of mathematical model is used in the control of fermentors by microcomputers for the calculation of the amount of titrant to be used for pH control, and to estimate the amount of heat to be removed from the reaction system. Automatic titration of lactic fermentation could be an important aspect of process optimization since it is known from the early work of Luedeking and Piret (1959a and 1959b) that lactic acid, but not lactate, is a strong inhibitor of this type of fermentation and the dissociation of lactic acid is almost complete at pH 6.5 (which happens to be optimal for lactic fermentation). Therefore the addition of alkali seems to be the basis for increasing the rate and the yield of lactic acid formation (Keller and Gerhardt, 1975; Gomez and Viniegra-Gonzalez, 1981). Automated pH and temperature control are not

absolutely necessary for attaining a good and stable lactic fermentation since it is known that initial addition of calcium carbonate is sufficient for developing this type of microbial process (Kayser, 1925). Also, many traditional lactic fermentations do not include the addition of titrants. Apparently there is a certain compromise between the level of protein in the culture medium and the pH. For example, Viniegra-Gonzalez and Gomez (1984) have discussed this problem and have suggested the following factors influencing the reproducibility of lactic fermentation:

- pH should be between 5.5 and 7.5. (If higher, butyric acid fermentation will be favored, if lower, there will be advantages for alcoholic fermentation.)

- Carbon/Nitrogen ratio should be below 30 with a readily fermentable substrate.

- At least 15% of all nitrogen should have as its source true protein for mesophilic fermentations (20 to 30 C) or at a higher proportion if the temperature range is thermophile (35 to 50 C).

23. These requirements are easily met through the use of a variety of combinations of raw materials, chemical additions and reactor configurations. Besides, lactic bacteria are ubiquituous microorganisms to be found in many rotten vegetables, traditional foodstufs and animal excreta. Therefore, lactic fermentation is a natural process which could be easily applied to liquid and solid fermentable materials, especially if lactic acid is not to be recovered or purified but is consumed in a diluted form in the final product.

24. Scaling-up of lactic fermentation is not a difficult task because this process shows a good tolerance towards temperature variations and does not require the supply of oxygen and hence strong agitation.

25. In view of the foregoing discussion, it is apparent that the choice between "controlled" and "spontaneous" lactic fermentations would depend mainly on the final use. Food fermentations would require certain flavour

and health standards to be met by carefully selected strains of lactic bacteria whereas silage and chemical industry could use non-aseptic techniques with ill-defined populations of lactic bacteria.

IV. SELECTION AND STABILITY OF STARTER CULTURES

26. The pasteurization of milk as a sanitary measure has created a new demand for cheese industry; the development of "starter" cultures. The pasteurized milk does not ferment as fast and with the desirable flavour properties as the indigenous raw material because of the disapearance of the natural bacterial contaminants during heat treatment. Starter cultures have to be selected not only because of their acidogenic capacity but also because of its potential to produce the secondary metabolites which are responsible for giving to dairy products its distinctive flavour (Orla-Jensen, 1921).

27. The genera of lactic bacteria more commonly used in dairy industry are Lactobacillus and Streptococcus; in particular, Lactobacillus acidophilus and L. bulgaricus together with Streptococcus lactis and S. cremoris are used mostly for lactic acid production. Leuconostoc species are sometimes added because of their flavoring properties and there are some species such as S. diacetilacis by producing aromatic compounds give some special features to the final product. Other species involved in dairy industry are S. thermophilus, S.cremoris, Brevibacterium linens, Propionibacterium shermanii, some strains of yeasts (Candida krusei, Mycoderma sp.) and molds (i.e., Penicillium camemberti and P. roqueforti). Propionic bacteria, yeasts and molds are expected to grow and help to ripen the cheese after lactic fermentation has finished. Different proportions of starter strains would give different cheese varieties and therefore, those combinations are a significant part of cheese making technology (Sellars, 1971)

28. Inoculation with starter cultures in other fermented foods is becoming an industrial practice, specially if the actual working conditions of the industrial plant permit pasteurization of raw materials. Otherwise natural contaminants would overgrow starter bacteria and the final effect would not be reproducible from one batch to another.

For instance, pickling industry could use strains of *Pediococcus cereviseae*, *Lactobacillus plantarum* and *Lactobacillus brevis* because those organisms are known to grow well in vegetables. Meat sausages can also be inoculated by *L. plantarum* and *P. cereviseae* and their use has been licensed in United States (Sellars, 1971).

29. European and Japanese food industries have also developed their own culture collections for lactic fermentation. Each collection is oriented to a specific final product and it is then related to local marketing conditions. Unfortunately, developing countries are lagging behind in this field of food industry and most of them depend either on natural fermentation or imported starter cultures. The use of natural microbial population poses a serious health problem because raw materials can be contaminated with pathogenic organisms while imported starter cultures are not always related to local food traditions and gastronomic preferences.

30. The Centro de Referencia de Lactobacilos at Tucuman in Argentina is the only center in Latin America involved in the preservation and distribution of lactic bacteria for food industry. For a subcontinent with 300 million people and a great diversity of cultural patterns this sole center is obviously not sufficient to house an adequate collection of starter cultures. This situation reflects the little attention paid to this matter in developing countries.

31. The biochemistry of flavour compounds in lactic fermentations has been intensively studied and has been found to relate mainly to the secondary metabolites of heterofermenters. Sellars (1971) After reviewing the available literature and concluded that pyruvate is the key intermediate for flavour production since it can be transformed into diacetyl and acetone which present strong aromatic properties.

32. The stability of starter cultures can be affected by the presence of antibiotics and by phage infection. Antibiotics are used in the treatment of infected udders resulting in the presence of penicillins, semisynthetic penicillins and tetracyclines as milk contaminants. Therefore, an important measure for controlling the stability of starter

cultures is testing milk samples for antibiotics presence and, most important, at the farm level to prevent the use of contaminated milk. Other contaminants having negative effects on starters are disinfectant compounds such as iodine, chlorine and ammonia derivatives. Pesticides could accumulate because of forage contamination and can be concentrated in dairy products. All these contaminations can be prevented by appropiate measures of prophylaxis being taken in the farms and at the storage and transportation facilities. As important, some degree of quality control at the manufacturing plants is required. Unfortunately, one or more of these measures are not always taken in the developing regions of the world and this lack results in frequent episodes of intoxication (Alonso-Colmenares, 1983).

33. Phage infection is another major problem affecting the stability of starters (Sandine, 1977). Lytic or virulent phages are able to destroy a large fraction of lactic bacteria in a fermentation vat. The repeated use of the same strain helps to select for specific phages atacking each particular bacteria. Fortunately, it is required to destroy more than 50% of starter population in order to affect the fermentation process in a noticeable way. This is due to the fact that bacterial populations grow according to the exponential law and are not very sensitive to the changes of the size of the initial population.

34. A practical way to control phage infection is to rotate starter strains with different phage susceptibilities (Collins, 1977; Lawrence et al., 1976). Phage sensitivity has become an important way for typing bacterial strains and is the basis for a rotational program of strains in dairy industries (Sellars, 1971). Phage typing culture service is now available in different industrialized countries such as United States, New Zealand and Australia.

35. Research in molecular biology has led to the discovery that the genetic information coding for antibiotics and phage sensitivity is mainly located in small circular non-chromosomal DNA called episomes. The knowledge of the regulatory mechanism that controls the transfer of genetic information contained in episomes has been critical in the development of techniques used in the emerging field of genetic

engineering. In fact, episomal particles are being used as "vectors" (molecular vehicles for the transfer of genetic material) for bacteria.

36. A greater understanding of lactic bacteria molecular biology might lead to the control over the ecology and biochemistry of starter cultures in relation to some of the problems discussed above. For example, it is known that bacteria of similar species (with high levels of DNA homology) can exchange episomal information. Thus Pseudomona sp. or enterobacteria can exchange information related to metabolic activities or antibiotic resistance. Unfortunately the field of genetic engineering and molecular biology of lactic bacteria is rather new and few research workers have started to work in problems such as phage resistance and their associated biochemical traits, for instance, flavour production, antibiotic resistance and acidogenic abilities. Genetic engineering of lactic bacteria is studied at least in various laboratories of United States (Univ. of Minnesota and MIT), France (CNRS, INSA Lyon, INRA and Transgene) and Argentina (Fac. Ciencias Exactas, Univ. Buenos Aires) and may be expected to produce results of importance in relation to the ecology of starters.

V. LACTIC FERMENTATIONS IN DEVELOPING COUNTRIES

37. Pozol is one of the traditional fermentated foods of Latin America that has been studied extensively. It is made of fermented maize which is previously cooked with lime (Ulloa, 1974; Ulloa, 1981; Ulloa-Sosa and Herrera, 1981). Cravioto et al. (1955) discovered a significant nutritional improvement in corn grains by this indigenous fermentation. They showed that the concentration of essential amino acids such as lysine, tryptophan and threonine, increased by the action of naturally occuring bacteria. These results have been confirmed by Erdman et al. (1977) when they have analyzed the amino acid composition of various strains of lactic bacteria and found high levels of the most common limiting nutrients. Cravioto et al. (1955) was able to show that the protein quality was not only improved with respect to the chemical amino acid composition, but more importantly, the biological value of

such protein increased. Taboada et al. (1971) showed that in pozol fermentation nitrogen fixation by bacteria could occur. They demonstrated this fact by using acetylene reduction technique and were able to isolate the microorganism responsible for the nitrogen fixation. Ulloa (1974) described the presence of a high number of lactic bacteria in pozol and Velazquez et al. (1983) found those bacteria basically belonging to the genera Pediococcus and Leuconostoc, some Lactobacillus and a very few Streptococcus. Approximately half of the lactic bacteria isolated from pozol by Velazquez et al. (1983) were able to grow on starch as the only carbon source and some of them could use mineral salts as nitrogen sources. In relation to the nitrogen fixation of pozol fermentation, Munoz-Gonzalez and Viniegra-Gonzalez (1981) showed a positive interaction between lactic bacteria and Azotobacter chococcum (a free living organism). They gave some evidence of possible protection of nitrogenase from oxygen inhibition by lactate utilization. These limited biochemical and microbiological studies indicate that pozol is a complex fermentation process which involves interactions between various kinds of lactic bacteria, and appears to be the only traditional fermentation with a nitrogen fixation capacity which has been described. Further studies on the mycology of pozol (Ulloa-Sosa and Herrera, 1981) have resulted in the isolation of molds with potential applications for the solid fermentation state of another cassava (Barrios et al., 1984). Ulloa (1981) has reviewed a number of traditional corn fermentations indigenous to Mexico, such as "atole agrio" (sour corn gruel) and "sendecho" which have not yet been investigated. The possibility is that these may yield results as interesting as those of pozol. Unfortunately the traditional use of pozol is disappearing in Mexico but there is interest in revaluating this traditional process and using it as a source of industrial microorganisms for the manufacturing of weaning food and animal feedstuffs (Barrios et al., 1984)

38. Muller (1981) and Okafor (1981) have reviewed a number of traditional African fermentions of cereal grains (millet, sorghum and maize) cassava, palm and other tropical products. Several of them are known to be lactic fermentations and are used as infant food, for instance, ogi is cited as the traditional infant food of Nigeria (Banigo, 1969). Sour beers of various African countries, including sorghum beer

which is mass produced in South Africa are also lactic fermentations. The nutritional advantages of lactic fermentation of cereal grains is well known i.e., the case of a traditional product "mahewey" made by the lactic fermentation of sorghum by controlled inoculation of Lactobacillus delbrueckii (Schweigart and Fellingham, 1963; cited by Okafor, 1981).

39. There seems to be a growing interest on industrialization of traditional lactic fermentations of cereal grains, cassava and other tropical products. The nutritional advantages have been indicated here but there is yet a need for a more coherent developmental policy in order to have industrial development of those processes. There is a need for reassessing the value of traditional fermentation as an alternative food process for use instead of complicated industrial processes such as amino acid supplementation of cereal grains and energy consuming processes such as drying and canning. It would be of particular significance to rescue traditional processes for infant feeding because the introduction of expensive foreign processes tends to downgrade the quality and make more expensive this kind of foods.

40. Another important aspect of human nutrition in developing countries is the prevalence of lactose intolerance by a large number of villagers and poor city people (Lisker, 1981). Lactic fermentation of milk is a simple and useful procedure for conserving the nutritional energy of milk and helping to consume milk proteins by popular sectors.

VI. ECONOMIC IMPORTANCE OF LACTIC FERMENTATION IN FOOD INDUSTRY

41. The economic importance of lactic acid fermentation can be illustrated by the statistics compiled the the Food and Agricultural Organization (FAO). They show that, on the average, approximately 2.5% of all the milk produced throughout the world is converted into cheese. Further, the world average proportion of cheese to milk has increased from 2.4% to 2.7% in the period 1974-76 to 1980-82 (Table I). In general, developed countries seem to transform more milk into cheese; around 3%

compared to only 2% of developing countries (Table I) though considerable differences exist, probably due to differing cultural patterns of consumption. As an illustration, in South East Asia only 0.1% of milk seems to be transformed into cheese as compared to the very high level of 7.3% of the Middle East and the intermediate level of 1.8% in Latin America (Table II).

TABLE I

World trends in cheese and milk production (million tons)

Type of	1974-1976			1980-1982		
country	a=cheese	b=fresh milk	(a/b %)	a=cheese	b=fresh milk	(a/b %)
World	9.6	394.5	(2.43)	11.69	431.66	(2.71)
Developed	8.2	332.4	(2.47)	10.12	359.32	(2.82)
Developing	1.4	62.1	(2.25)	1.57	73.34	(2.14)

(Data Source: FAO Production Yearbook 36 (1983)).

TABLE II

Production figures for 1982 (thousand tons)

Region	cheese	fresh milk	% of cheese to fresh milk
DEVELOPING COUNTRIES	1,403	69,029	2.03
Africa	37	6,078	0.61
Latin America	624	34,583	1.81
Middle East	724	9,912	7.30
South East Asia	18	18,392	0.10
DEVELOPED COUNTRIES	7,660	234,208	3.27
North America	2,520	69,653	3.62
West Europe	4,709	142,730	3,30
Oceania	264	11,845	2.23
Other regions	166	9,980	1.66

(Data Source: FAO Production Yearbook 36 (1983)).

42. Other important use of lactic fermentation in dairy industry is the production of fermented milk, for instance, yoghurt and cottage cheese. The trend in United Sates has been towards substitution of butter milk by yoghurt and also to increase the per capita consumption of fermented milk (Table III).

43. The economic importance of starter cultures in the dairy industry can be estimated by utilizing the fact that 1.0% to 1.5% of the total weight of milk used in cheese production is made up by liquid starter cultures (Sellars, 1971). For United States alone, the estimated demand of starter cultures was 97,200 tons in 1965. Significant amounts of starter cultures are also prepared for yoghurt, butter milk and other fermentation products.

TABLE III

Per capita yoghurt consumption in selected countries (1973).

Country	Kg/year
The Netherlands	13.5
Switzerland	9.9
Finland	7.6
France	7.2

(Source: Kositowski (1977) "Cheese and fermented milk foods", 2nd Ed., Edward Bros. Ann. Arbor, Mich. cited by R.C. Chandan in Reed (1983)).

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44. Milk is not the only food product which can be transformed by lactic fermentation. Cabbage, cucumbers, olives are also adequate substrates for this fermentation process and are increasingly utilized by the food industry. For example, in United States during 1977, more than 800,000 tons of those produces were fermented (Table IV).

45. In other countries soybean fermentations are also of economic significance. For example, in Japan in 1974 nearly 2 million tons of fermented soy products were generated, involving the consumption of 252,900 tons of soy beans and 300,700 tons of cereal grains (Reed 1983).

TABLE IV

USA production of some fermented food (thousand tons/year).

Year	a=cabbage	b=cucumbers	c=olives	a+b+c
1966	161.6	[illegible]84.0	56.7	702.2
1967	246.1	539.4	12.6	785.3
1968	208.7	508.0	77.4	798.1
1969	200.3	465.3	66.0	731.6
1970	239.5	529.9	46.8	816.2
1971	211.5	506.8	49.5	767.8
1972	178.3	514.0	21.8	714.1
1973	197.2	538.9	63.0	799.1
1974	253.3	537.3	52.7	843.3
1975	215.8	606.8	60.3	882.9
1976	208.5	570.5	72.0	851.0
1977	207.5	565.4	38.7	816.6

(Source: USDA (1979) cited by R.H. Vaughn in Reed (1983)).

46. Another interesting industrial application of lactic fermentation is the development of fermented ingredients for the feed industry. Alvarez et al. (1979) has developed a lactic fermentation process for molasses by inoculating it with cow dung which has originated a new agroindustry based on lactic fermentation. A similar process was developed by Reddy et al. (1976) in order to use whey as a byproduct of cheese making. More recently, Zaragoza (1984) has developed large scale ensiling of cassava tubers as an alternative process of feed conservation instead of expensive meal drying.

47. The economic potential of lactic fermentation in the feed industry is not yet fully appreciated. In addition to the potential offered by the large volume of fermented forages that are commonly classified as part of the agricultural sector, there i a new potential in transforming and recycling agrondustrial and animal waste for refeeding cattle grown for milk or beef purposes. In Mexico, alone, more than 1.2 million tons of molasses blended with urea, chicken litter and corn stover are fed to cattle. This market is ready for more efficient animal feed production and one possible way of improving feed production is to partially recycle manure, together with cheap agroindustrial byproducts such as molasses and cheese whey.

48. The industrial use of lactate mineral salts is widespread in a variety of industries such as dying, pharmaceutical, galvanic coating and chemical (Prescott and Dunn, 1962). Many developing countries import lactate salts although they export fermentated materials, such as molasses, from which lactic acid could be produced.

49. Akedo et al. (1981) have suggested the conversion of propionate into acrylate and it is known that propionate can be produced from lactate. More recently Akedo et al. 1983 demonstrated the direct conversion of lactic acid to acrylic acid. This will introduce lactic acid as a new chemical feedstock for chemical industry. Pipyn and Verstraete (1981) have also suggested to use lactate as an intermediate for industrial production of biogas using municipal and industrial waste waters as raw materials. Munoz-Gonzalez and Viniegra-Gonzalez (1981) proposed lactate as a starting raw material for non-symbiotic nitrogen fixation, using free living bacteria. Such proposals as these suggest new industrial uses for lactic acid and fermentation processes besides the traditional process of cheese and yoghurt production.

VII. POTENTIAL IMPACTS OF LACTIC FERMENTATION IN DEVELOPING COUNTRIES

50. A significant feature of the agricultural sector of developing countries with the possible exception of China and South East Asia is the

low productivity of animals. African and Latin American countries are typical examples of such a kind of animal farming with very low levels of meat and milk production per animal unit. As a result of such inefficient farming, a strong competition has evolved between animal and human nutrition. Unfortunately, animal products have a better market value than staple food, which in turn has become the driving force for displacing basic agriculture by animal farming.

51. An alternative to such nutritional competition is the development of intensive and non-competitive animal farming, in which lactic fermentations could be useful in the following ways:

- improved utilization of feedstocks employing silage fermentations of local by-products and surplus materials;

- recycling of waste materials using lactic fermentation as a sanitation procedure;

- conservation and upgrading the nutritional value of valuable food products, either from animal, vegetable or mixed nature by efficient lactic acid fermentations;

- development of new food products by expanding animal products for example: cheese made from cow milk extended by the addition of soy bean milk.

52. The potential of such alternatives may be illustrated by the following cases:

- In Mexico Cassava has the potential to be a substitute for imported sorghum as a food additive in the diet of swine, poultry and dairy cows. The current economic bottleneck is the high fuel cost for drying cassava chips. As an alternative, Zaragoza (1984) has developed a simple cassava silage stablization process for pig feeding which is competitive in an energy basis with diets based on sorghum.

- In Mexico imported soy beans are often required to feed swines. Yet, such farms produce large amounts of manure rich in protein. Partial recycling of swine manure could reduce soy bean utilization by 20 per cent, and one of the simplest procedures for recycling the manure in silage by a silage fermentation process.

- Cereal grains such as maize or sorghum are deficient in essential amino acids such as lysine and tryptophane. It has been demonstrated that lactic fermentations of such materials increases the protein value of zein (Cravioto et al. 1955). In the case of maize or sorghum this could be the basis for decentralized amino acid enrichment of staple food.

- Milk production is often uneconomical for the farmer because of the low price paid by the processors. On the other hand, cheese production is one of the simplest transformations for upgrading milk and adding commercial value. Upgrading of artesanal cheese-making processes in developing countries such that the farmer may play a more active role could increase small consumption and improve the quality of dairy products in the urban markets.

- Lactic acid is an imported raw material for food industries in developing countries. Local production is a way to reduce importation; the extensive use of this lactic acid as a safe food preservation and flavour agent in a great variety of industrialized foods would add to local economies. Locally produced lactic acid would decrease import costs.

- Milk powder is extensively imported by developing countries, thereby adding to the burden of commercial deficit in the food sector and distorting milk prices. An alternative approach would be to enrich milks with other low cost proteins. Lactic fermentation is a procedure to add flavour to extended milk and to increase digestibility of vegetable protein.

53. In addition, there are a number of applications of lactid acid that can have a pronounced influence in a developing country. For example,

lactic acid can be polymerized and used as a biodegradable and safe drug delivering polymer. Such a polymer can be employed for health care as well as for agriculture.

54. Lactic acid can be used for chemical synthesis. Since the optical activity can be controlled by the judicious choice of a fermentation process chiral intermediates of value to the organic chemist can be developed.

VIII. INTERNATIONAL CO-OPERATION FOR DEVELOPING INDUSTRIAL USES OF LACTIC FERMENTATION.

55. The background information provided above indicates the pressing need for strengthening the local scientific and technological capabilities of developing nations in order to maximize many of the potentials offered by the use of lactic fermentation in food process industries. To achieve the need, the following has to be achieved:

- Scientific personnel has to be trained in the fundamentals of the lactic acid fermentation processes. The training should emphasize the principals for up-grading traditional fermentations, and for product and process development of fermented products.

- A research network should be formalized that allows for effective communications of important basic and applied research fundings related to such fermentation processes. In this network, endusers and potentional implementors of the new technology should be included.

- Evaluation of supportive economic measures for industrial development of fermented foods. Novel approaches including tax incentives of R&D activities, preferential interest rates for medium and small fermentation industries, promotion of manufacturing of processing equipment for fermented foods, marketing and other institutional services should be evaluated as to their effectiveness for transfer of technology.

- Establishment of international agreements, committed to the further development of the food fermentation field with its relationships to advances in biotechnology. Topics for international co-operation could include:

  - Creation or utilization of existing facilities for distribution,conservation, genetic improvement and phage typing of of lactic fermentation strains ("starters").
  - Publication and dissemination of R&D results
  - Training
  - Symposia and International Workshops

- Promotion of innovative technological process for the transfer in the production and operation of advanced and conventional equipment in the fields of dairy processing, solid state fermentation food conservation and packing.

56. Several countries and international agencies have already showed interest in promoting the aforementioned proposals. For instance, the representatives of the Latin American Network of Biotechnological Centers agreed on April, 1984 that field of lactic fermentations is one of the priorities for the regional development of Biotechnology. Some agreement has been expressed by Latin American research workers in relation to the cooperation between this area and Spain. Also, the French-Mexican agreement of Biotechnology (CONACYT-ORSTOM) has identified lactic fermentations as an essential part of its R&D activities. During the 6th GIAM Conference (Global Impacts of Applied Microbiology) fermented foods were thoroughly discussed and this subject has also emerged as part of the deliberations for the creation of the International Center for Genetic Engineering and Biotechnology. International agencies, such as, International Development Research Center (IDRC), Organization of American States (OAS), UNESCO and International Fundation for Science (IFS) are currently sponsoring and initiating R&D activities related to fermented foods as one of their priorities.

57. There is surely a receptive attitude throughout the world for starting specific regional projects oriented toward the improvement of

local food industries. Optimal utilization of lactic fermentations processes as one of the key elements of food conservation and transformation is critical to the development of scucessful and acceptable processes.

IX. CONCLUSIONS

58. Lactic fermentations are of great economic importance because of their wide use in the stabilization and transformation of many natural products. Not only are dairy products involved, but meat, pickles olives and many other materials are processed by lactic acid fermentation.

59. A number of lactic fermented foods involving cereal grains and starchy materials (cassava for example) are traditionally used for infant and breakfast food in developing countries. Their use can be expanded with unique advantages over non-fermented materials.

60. Fermented feedstuffs and other materials can be industrialized using lactic fermentation.

61. Scientific knowledge of lactic fermentation is advancing in the fields of process control, genetic engineering and product design. Fundamental advances in the understanding of the molecular biology of these microorganisms is likely to impact on various aspects of the fermentation process. For example, improvements in flavour, nutritional quality, organilaptic properties, as well as in the efficiency of the process of interest are surely to occur.

62. There is sufficient interest in this important area to justify the role of international agencies in co-ordinating and implementing the recent developments in this field.

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