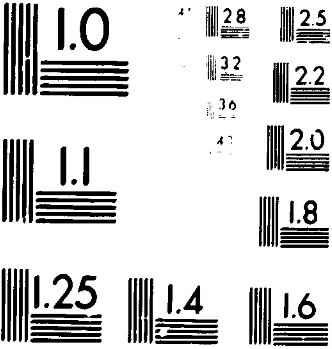
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MICROBIOLOGY OF CHEESE LACTIC FERMENTATION*

Prepared by

J-L. Bergere**

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** Director of Research, Laboratoire de Microbiologie Laitière - I.N.R.A. 78350 Jouy-en-Josas, France.

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INTRODUCTION

In all ages lactic acid bacteria (LAB) have played an important part in the production of dairy products and notably in that of cheeses. Their use moreover goes back to times when their very existence was unknown. The LAB originate from the adventitious bacterial flora of the milk that is left to develop until it causes coagulation. Then milk or whey-soured preparations were used naturally as vat bases or starters. These methods were the general rule until the beginning of our century after which they have only regressed very progressively. They are moreover still used in regions where cheese is still produced in the farm or in small factories along techniques similar to those of cheese-former days. This is the case in Europe in regions from which certain cheeses such as cooked or hard cheeses originate. But this only concerns a small quantity of the cheeses produced. In fact traditional methods of cheese production have greatly changed over the past thirty years with modifications of the conditions of production and preservation of the milk and the introduction of mechanization into cheese-making. The production times are very often shortened and the quantities of milk processed in each plant have become very high even up to 1,000,000 litres/day. The LAB from the adventitious flora of the milk and the natural "artisanal" but over-hazardous starters have been replaced by selected cultures supplied by Dairy Research Centres or specialized firms. With these starters and their more clearly defined characteristics it has been possible to rationalize production conditions and obtain better quality and more reproducible products.

Cheese production is a very important part of the dairy industry and at world scale it now stands at 10 million tons per year corresponding in value to 20 % of the total value of fermented food products (Table 1). Cheese consumption is constantly evolving even in countries which were already accustomed to consume a lot. This is the case for example in France where annual consumption per capita has increased in ten years from 14.7 to 19 kg (Table 2).

The cheese industry is therefore an important fermentation industry which uses and produces, at the same time as the cheese, large quantities of LAB without counting the other micro-organisms involved in ripening. Thus in France it is considered that cheese-making involves 500 to 1,000 t of LAB (humid weight). The world production of cheese bulk starter cultures was estimated at 1.5 million tons in 1978.

The main role of the LAB is to transform the lactose into lactic acid. The lactic acid thus produced contributes to the coagulation and texture formation of the curd by favouring the drainage of water. But as we shall see further on this is not the only role of lactic bacteria in cheese-making.

There are numerous varieties of cheese (I.D.F. Catalogue, 1981) whose characteristics above all depend on the quantity of water eliminated during the production (Table 3) and the way in which the different LAB cultures are used to obtain this. Secondly the characteristics of each of these varieties depend on the ripening conditions and the other micro-organisms which then develop inside or on the surface of the cheese.

It would be too long and tiresome to review the way in which the LAB are involved in the different types of cheese which exist at present all the more so in that there are many points in common. Thus in this review paper we shall remain at a fairly general level. We shall examine in succession the species which are involved in the main types of cheese, their properties and their role in the production of the cheese, the most important factors influencing their development together with the way of using them.

I. ECOLOGY AND CLASSIFICATION OF THE LACTIC ACID BACTERIA INVOLVED IN CHEESE PRODUCTION

Several spe[illegible] of LAB belonging to the Streptococcus, Leuconostoc, Pediococcus and Lactobacillus genera develop in cheeses, whether contributed to the milk in the form of starters or else originating from the milk's adventitious flora or the environment of the cheeseworks

(Table 4) (CHAPMAN and SHARPE, 1981 ; SHARPE, 1979 ; DALY, 1983 ; AUCLAIR and ACCOLAS, 1983).

The species involved in the greatest number of cheeses are the mesophilic streptococci of the N serological group, S. cremoris, S. lactis and to a lesser degree S. lactis subsp. diacetylactis. The first two are widely used in starters because they are homolactic and only produce very small quantities of secondary products in the milk such as acetic acid and diacetyl. In return the third one is capable of using citrate and producing CO_2 and diacetyl from it (Table 5).

The natural habitat of these lactic streptococci is still uncertain. Although they do not originate from the udder, they are invariably found in raw milk. S. lactis is the predominant species whereas S. cremoris is less frequent and present in smaller numbers. The capacity to hydrolyse the arginin has long been used to differentiate them. However this distinction is more apparent than real since repeated subcultures of S. lactis isolated from the raw milk led to the appearance of variants incapable of hydrolysing arginin. In the same way it is possible that S. lactis are simply variants of S. diacetylactis incapable of fermenting the citrate. It increasingly appears that these three species form a continuous genotypical and phenotypical variation spectrum (LAWRENCE and THOMAS, 1979).

A fourth species of Streptococcus is also important in cheese-making, S. thermophilus which is characteristic of cooked cheeses or hard cheeses but is also used today to produce certain types of soft cheese. S. thermophilus is capable of developing up to 50°C, and is relatively thermoresistant (Table 5). It does not belong to the serological group N like the former and has no group antigen. It is more sensitive to salt and acid than the mesophilic streptococci. Its origin could be intestinal owing to its thermophilic character (AUCLAIR and ACCOLAS, 1983).

Streptococci of group D, S. faecalis, S. faecium and S. durans, can develop normally in certain cheeses and have even sometimes been used as starters in hard cheeses (SHARPE, 1979).

Although less frequent than the streptococci, species of the Leuconostoc genus also develop in cheeses and are added to the starters designed to produce certain cheeses. The most current species in cheese-making are Leuc. cremoris, Leuc. dextranicum and Leuc. mesenteroides. These bacteria are heterofermentative producing lactic acid, CO_2, a little acetic acid and ethanol (Table 5). In milk Leuc. cremoris also produces diacetyl from the citrate (COGAN, 1980).

Another important genus in cheese-making is the Lactobacillus genus (Table 6). Nevertheless the two homofermentative subgroups Thermobacterium and Streptobacterium and the Betabacterium heterofermentative group are not of the same interest (SHARPE, 1979). The species in the first group, L. helveticus and its variant L. jugurti, L. lactis and L. bulgaricus are specific to cooked cheeses such as Emmental, Gruyere or Italian cheeses such as Grana (AUCLAIR and ACCOLAS, 1983). The interest of these lactobacilli lies in their capacity to produce large quantities of lactic acid, their capacity to stand up to the heating temperatures of the curd (45 to 55°C) and to develop at relatively high temperatures. These three species are present in predominant flora with other lactobacilli (L. fermentum and L. acidophilus) and S. thermophilus in France in traditional "artisanal" starters produced by macerating previously air-dried calf stomach in whey, whether heated or not, and in Italy in the natural cultures of the whey ("colture naturali in siero"). They are also used in the form of selected starters but L. bulgaricus and L. lactis are less frequently used in cheese-making than L. helveticus (AUCLAIR and ACCOLAS, 1983).

The mesophilic species in the Streptobacterium, L. casei and L. plantarum species develop frequently in cheeses such as certain pressed or cooked cheeses, either in the days following production, or during ripening but they are not or very little used as starters, their role being not clearly defined (CHAPMAN and SHARPE, 1981 ; Le Fromage, 1984).

Although species in the heterofermentative Betabacterium group, especially L. fermentum, L. brevis and L. buchneri, are present in natural starters and can develop in certain cheeses, they are considered as somewhat harmful because they can produce off-flavours and texture or gas defects due to the production of CO_2 (CHAPMAN and SHARPE, 1981; Le Fromage, 1984).

Lastly LAB can be found in certain cheeses such as Cheddar or cooked cheeses, belonging to the Pediococcus genus ; these pediococci multiply during ripening sometimes up to levels of 10^7/g. The most frequent species is P. pentosaceus (CHAPMAN and SHARPE, 1981 ; TURNER and THOMAS, 1980).

II - THE PROPERTIES OF LACTIC ACID BACTERIA AND THEIR ROLE IN CHEESE-MAKING

We shall not examine in detal the properties of the LAB but we shall show how they are involved in cheese production.

Firstly it is useful to recall that this basically consists of 3 phases :

- the formation of a gel resulting from the floculation of the casein micelles : this is coagulation or clotting of the milk ;

- the elimination of a part of the water from this gel via syneresis, i.e. the contraction of the micelles which form it : this is draining of the curd, the liquid expelled or whey does not only contain water but also the soluble substances of milk ;

- enzymatic maturation of the more or less dehydrated gel : this is ripening of the cheese for which development and metabolism of certain micro-organisms is responsible.

2.1. The formation of lactic acid from the lactose.

This is the essential role of the LAB in the transformation of milk into cheese.

The lactic acid formed is firstly involved in the coagulation by lowering the pH ; when the isoelectric point of the casein is reached (pH 4.6) floculation occurs and a gel is formed. Coagulation of the milk can be obtained also by the action of rennet. In cheese-making these two methods of coagulation are most frequently combined but one or other may predominate. So that for example in the case of fresh cheeses, coagulation is basically lactic whereas the opposite occurs in the case of cooked cheeses, where coagulation is obtained by rennet even before acidification has commenced. In the case of Camembert cheese, coagulation is obtained by the action of rennet whereas acidification is already in process.

Lactic fermentation then plays a very important part in eliminating the water from the curds. The LAB mostly retained in curd particles after cutting ferment the lactose and produce lactic acid which dissolves the minerals and modifies the composition of the casein. The development of the acid favours contraction of the curd particles and expulsion of the water. Simultaneously components of the whey where of the lactose diffuse trowards the interior of the curd particles to replace those used by the bacteria (CHAPMAN and SHARPE, 1981 ; Le Fromage, 1984).

Draining can be facilited by cutting the coagulum into more or less small pieces, more or less strong stirring, more or less high heating and finally pressing or even milling (Table 7). According to the share of acidification amongst these operations and the moment at which it occurs in production, it plays a more or less important part in the draining ; this varies depending on the cheese produced. Thus in the case of traditional Camembert cheese whose curd is very little cut, acidification is chiefly responsible for draining in the same way as with fresh cheeses. On the contrary, in the case of Emmental, a large part of the lactoserum is first expelled by strong cutting, stirring and heating (or "cooking") at 50-55°C, the acidification mainly occurs during the pressing to complete the draining and eliminate the residual lactose and galactose (Figure 6) (AUCLAIR and ACCOLAS, 1983).

However the acidification does not only apply to the water content and pH rating of the curd, it also has an influence on the mineral composition (P, Ca) and the texture. The greater the share of acidification in the coagulation and draining, the more the curd is demineralized, friable, permeable and the less firm it is. Conversely a curd with rennet coagulation and mainly physical and mechanical draining is very little demineralized, cohesive, elastic and relatively impermeable (Le Fromage, 1984).

Lactic fermentation therefore plays a determinating part in the composition and characteristics of freshly produced cheeses and the correct evolution of the ripening phenomenon hence the quality of the end product will depend on this step.

The adaptation of the lactic fermentation to the type of cheese produced and therefore the strain of lactic acid bacteria to be used are a primordial factor. However with a given cheese, the way in which acidification takes place hence the development of these bacteria is no less important.

The metabolism of the lactose and its transformation in to lactic acid are already fairly well known and notably in the mesophilic lactic streptococci (Figure 1) (KANDLER, 1983). However there is still data to be acquired in order to obtain better mastery over lactic fermentation in production if only to produce more stable and better suited strains to this or that product, through genetic manipulation. Moreover, although the metabolism of these bacteria in culture is well known, it is impossible to be certain that they always produce the same products when they develop in the very different environments associated to the different stages of cheese transformation (LAWRENCE and THOMAS, 1979).

2.2. <u>Proteolysis</u>

Although the LAB are only slightly proteolytic as compared to other bacteria, they have a relatively complex enzymatic "equipment" owing to the number and types of proteinases and peptidases which form them and also through the cellular distribution of the enzymes (Figure 2) (LAW and KOSTAD, 1983 ; DESMAZEAUD, 1983 ; EXTERKATE, 1984).

These enzymes are of applied interest, firstly because they are necessary to the growth of the LAB in the milk and the cheese and hence to acidification (LAW and KOSTAD, 1983 ; DESMAZEAUD, 1983), and secondly because they play a part in the ripening of the cheese (LAW and KOSTAD, 1983 ; DESMAZEAUD and GRIPON, 1977).

Amino-acids are an absolute requirement or a stimulant to growth in all LAB, but in milk, the quantity of free amino-acids is insufficient to ensure normal growth and acid production. It is therefore necessary that these bacteria can also use the peptides but also partially the proteins. If the oligopeptides can enter into the cell and be transformed through the peptidases, it is necessary that the larger peptides and above all the proteins be hydrolyzed via the extracellular proteinases or present in the cell wall (Figure 2) (DESMAZEAUD, 1983). The existence of the latter has been demonstrated in particular with the mesophilic streptococci but very little is yet known concerning these enzymes themselves and their activity (LAW and KOSTAD, 1983). We know that their attachment to the cell wall depends on the temperature, the pH and the presence of the Ca^{2+} ion. We also know that the presence of $Prot^{-}$ (protease deficient) variants is fairly frequent in mesophilic lactic streptococci cultures, and that the absence of proteolytic activity results from the loss of a plasmid. These variants have limited growth and produce little acid in the milk but could be of interest in cheese-making.

Moreover the different proteolytic enzymes of the LAB also play a part in the degradation of the proteins during the ripening operation (Figure 3) (DESMAZEAUD and GRIPON, 1977 ; VISSER, 1977). Proteolysis is essential to convert the elastic curd into a ripe and more or less unctuous cheese paste. However it also entails the release of aminoacids which contribute to the formation of the cheese's flavour either directly, or above all as precursors of flavour compounds. It is chiefly the endocellular proteolytic enzymes of the LAB which are involved in this process after the lysis of the cells which occurs at the beginning of ripening. Although they are capable of degrading the entire casein, they operate slowly and their most important role appears to be the degradation of the large peptides released by the rennin in smaller peptides and amino-acids. However the contribution of the lactic bacteria enzymes to preoteolysis varies in importance according to the cheese because it also depends on the possibility that the secondary flora have of producing proteases and peptidases which are often extracellular.

Finally the mesophilic lactic streptococci proteases have been closely implicated in the formation of bitter peptides in cheeses, a defect which is fairly frequent at the present time (LAW and KOSTAD, 1983 ; STADHOUDERS, HUP, EXTERKATE and VISSER, 1983). Various assumptions have been put forward but the situation, remains complex. Various assumptions have been put forward but the situation remains complex. It is clear that the rennin, certain <u>Penicillium</u> proteases and those of the LAB can produce bitter peptides. It has moreover been diplayed in certain cheeses that the degree of bitterness depended on the number of LAB reached in the curd. Moreover the Prot$^-$ variants produce less bitterness than the parental Prot$^+$ strains. Finally the lactic streptococci exopeptidases are capable of reducing the bitterness. The role of the LAB in producing this defect is therefore certain but its importance depends on the type of cheese.

2.3. <u>Flavour production</u>

The formation of C_2 and C_4 compounds by the LAB has been closely studied owing to their role in the aroma and flavour of certain dairy products. This is especially the case for diacetyl which can be produced from the citrate in the presence of glucose by <u>S. diacetylactis</u>, <u>Leuc. cremoris</u> and certain lactobacilli such as <u>L. casei</u> (Figure 4) (SHARPE, 1979 ; LAWRENCE and THOMAS, 1979 ; COGAN, 1980 ; KANDLER, 1983). This compound is involved in the aroma of different types of fresh cheese in the same way as the acetaldehyde produced by <u>S. diacetylactis</u>, on condition that the concentration of this compound is not too high.

Nevertheless, apart from these compounds and for the other cheeses, the situation is far less clear and the role and importance of the LAB in the formation of the aroma and flavour still have to be specified and probably depend on the type of cheese. This is moreover not simple because only very slight quantities of certain compounds are sufficient to confer a flavour (Le Fromage, 1984).

The lactic streptococci certainly play a part in flavour formation since (SHARPE, 1979) cheeses produced by artificial acidification do not have the ususal organoleptic characteristics. However, at least in Cheddar cheese which has been the most closely studied, this role could be limited to creating favourable conditions (pH rating, Eh, moisture, etc.) in the preparation of the characteristic aroma by chemical ways (SHARPE, 1979). This is not necessarily the case for other cheeses in which other species of homofermentative or heterofermentative lactic bacteria are also involved, whose metabolisms are far less well known. Moreover, even the mesophilic lactic streptococci have alternative metabolic pathways (Figure 4) whose regulation is not well known (LAWRENCE and THOMAS, 1979 ; KANDLER, 1983) and which could, in the conditions of the cheese, lead to the formation of aromas or of their precursors.

Finally as has been stated previously, the LAB can indirectly contribute to producing aromas through amino-acids that they release. These one may be used by other micro-organisms to produce flavour compounds.

2.4. The production of CO^2 and the eye formation

LAB producing CO^2 such as S. diacetylactis and certain strains of Leuconostoc are considered as useful in the production of certain cheeses either for some "eye" formation in the case of Gouda for example, or to obtain a desired open texture and holes in view of the development of moulds in blue-veined cheeses (CHAPMAN and SHARPE, 1981). In the case of Roquefort for example, Leuc. dextranicum is used in addition to the acidifying streptococcal starter.

Per contra, in other cheeses, these bacteria together with the hetero-fermentative lactobacilli can be responsible for the formation of holes or blowing of film-wrapped cheeses (CHAPMAN and SHARPE, 1981). This is for example the case when the starters contain too much species using the citrate, such as S. diacetylactis (COGAN, 1980).

Finally it must be remembered that the homofermentative lactic bacteria are also potentially capable of producing CO^2 from pyruvate, lactate or certain amino-acids (KANDLER, 1983 ; SHARPE, 1979 ; LAW and KOLSTAD, 1983). This is no doubt involved in the conditions which prevail in the cheese without necessarily causing damage. It has been observed for example, in Emmental, that a quite considerable quantity of CO_2 does not originate from the propionic fermentation responsible for eye formation (FLUCKIGER, 1980).

2.5. The inhibition of spoilage micro-organisms and pathogens, and the stimulation of useful bacteria.

The products of the LAB metabolism and the components that they release by autolysing in the cheeses can influence the microbial flora useful in the ripening of cheeses. They can stimulate the growth of L. casei, L. plantarum, propionic acid bacteria and other useful microorganisms (SHARPE, 1979).

Conversely the LAB play a capital part in the inhibition of undesirable bacteria (Table 8) (SIMONETTI et al., 1982 ; LAWRENCE, THOMAS and TERZAGHI, 1976 ; SHARPE, 1979 ; BERGERE et al., 1978 ; BABEL, 1977 ; HURST, 1973). This inhibition results in the competition for the nutrients, the reduction in the pH rating and the redox potential. In many cheeses it is especially important that a maximum amount of lactose, if not all, be metabolized by the LAB. The inhibition also results from the production of more or less specific inhibitor compounds : the lactate itself, the acetate, the H_2O_2 produced by certain lactobacilli or known antibiotics such as nisin produced by certain S. lactis strains or still again to be identified in the case of lactobacilli.

2.6. Defects formation

In addition to the faults referred to such as bitterness or gas production, certain LAB from starters or developing naturally in cheeses can be the cause of various flavour, aroma or colouring defects (Table 9) (SHARPE, 1979 ; le Fromage, 1984).

III - GROWTH CONDITIONS OF LACTIC ACID BACTERIA IN CHEESE-MAKING

The growth of the LAB and their acid production in milk and cheese depend on a whole set of factors. In the first place this depends on the LAB forming the starter. The latter only very rarely contains one single strain but consists of several species and often several strains per species, which differ according to the type of cheese produced (COGAN, 1980 ; DALY, 1983 ; AUCLAIR and ACCOLAS, 1983). However the balance between these strains or species can also vary between the moment at which it was constituted and that at which it was added to the cheese-making milk (COGAN, 1980 ; LAWRENCE, THOMAS and TERZAGHI, 1976). In fact, in addition to the phenomena of stimulation or inhibition between strains, their growth rates can be influenced by the conditions in which the starter was prepared : temperature, maximum acidification level, number of subcultures. With the mesophilic streptococci this can be accentuated by the development of variants having a more or less high capacity to produce the lactic acid in the milk. Moreover the capacity to resist the acid varies according to the strain.

Next, the growth of the LAB is liable to be influenced by the composition of the milk which can change depending on the stage of lactation of the cows and diet. Nevertheless this has not been clearly demonstrated and the phenomenon, if any, is certainly more important when the cheese is produced on a small scale from the milk of a single herd or animal species with seasonal dairy production than in industrial production obtained with mixed milks of all origins. The inhibitor substances resulting from bad milk-production conditions or mastitis treatments with antibiotics certainly have more effect (LAWRENCE, THOMAS and

TERZAGHI, 1976 ; Le Fromage, 1984). The natural inhibitors of milk, lactoperoxydase-thiocyanate-H_2O_2 system and agglutinins can also be involved. However these latter are to a great extent inactivated by the heating and are only important in the case of fresh cheeses.

Lastly the growth of the LAB and their acid production depend on the conditions in which the cheese is produced. Nevertheless the production processes have varied too much to be discussed here. For the most current species, the growth parameters in the milk and the relations existing between them and the acid production are fairly well known and can be controlled (COGAN, 1978 and 1980 ; TAYEB, BOUILLANNE and DESMAZEAUD, 1984). However it is difficult to extrapolate because the cellular environment in the liquid cultures is very different from what occurs in cheese-making where the nature of the environment is continuously evolving. In the curd the bacteria are included in a gel and tend to develop in colonies. In these conditions the growth and production of acid are governed by the availability of the nutrients and the diffusion of the fermentation products. Moreover, in many cheeses the greater part of the lactose is often eliminated with the whey even before lactic fermentation develops, this is especially the case for cooked cheeses. Moreover, in addition to the pH, the temperature to which the curd is sometimes subjected can be a limiting factor in the production of certain cheeses. For example in Gruyere cheese the temperature is important. When the mass of curd (50-80 kg) is taken out of the vat and pressed, its temperature is approximatively 50°C. During pressing the temperature falls slower in the centre than in the periphery of the cheese (Figure 5). Consequently the growth of bacteria is more rapid, lactic acid production is more intense and higher numbers of cells are attained in the peripheral zone than in the central one (Figure 6) (AUCLAIR and ACCOLAS, 1983). In this latter zone the temperature remains two high during the initial hours and when it is favourable, the starter will no longer have sufficient lactose available to develop optimally. These data are corrobored by the lactic acid content in different zones of the 1-day-old cheese (Figure 7). Lactobacilli is more sensitive to the high temperature and grows later than

S. thermophilus (Figure 6) but it metabolizes the galactose released by S. thermophilus (Figure 8) and controls the final pH of the cheese. Therefore these two species are required to obtain a cheese of good quality.

The growth and production of acid continue for a more or less long time according to the quantity of lactose available, the temperature at which the cheese is placed and the method and time of salting (TURNER and THOMAS, 1980 ; CHAPMAN and SHARPE, 1981). Salt is added either early onto the loose curd before pressing as in Cheddar cheese (Figure 9) or later by spreading on the 1-day old cheese as in Camembert cheese or by immersing the wheel under brine as in Emmental cheese (Figure 8).

Next, although a part of the LAB from the starter dies within the days following production, a relatively large quantity remains for a fairly long time, but this depends on the cheese. Moreover it is fairly frequent that other LAB from the milk or environment multiply during the ripening (see 1st chapter).

Apart from the different factors which have been referred to, there is another and very important one. This is the attack of the LAB by bacteriophages which is very often the cause of acidification irregularities in cheese-making and sometimes of very considerable delays in the evolution of this process (LAWRENCE, THOMAS and TERZAGHI, 1976 ; LAWRENCE and THOMAS, 1979 ; AUCLAIR and ACCOLAS, 1983). These accidents have become increasingly important with the generalized use of starters and the evolution of the cheese-making industry which every day handles increasingly large quantities of milk by multiplying the production batches in the same vat.

Means do exist to prevent the infection of the starter cultures (DALY, 1983 ; THUNELL, SANDINE and BODYFELT, 1981 ; COGAN, 1980 ; SANDINE, 1977 ; LAWRENCE, THOMAS and TERZAGHI, 1976). But it is far more difficult to avoid it during cheese-making which cannot be done from sterile milk and in aseptic conditions as is the case for the fermentation industry. The ways of guarding against these phage attacks also life in the choice of suitable starters and in the conditions of their use. However the problem is far from being solved in all countries, notably in Europe and France in particular, in view of the diversity of the cheeses produced and the various types of starter required for their production. Lactic starters and bacteriophages are the subject of other papers in this Symposium so that they will not be discussed here.

TABLE 1. PER CAPITA CHEESE CONSUMPTION IN SOME COUNTRIES (1981, KG/YEAR)

FRANCE	18.9
WEST-EUROPE (other C.)	10-14
U.S.A.	10,8
FINLANDE	8.6
NEW-ZEALANDE	8.5
CANADA	8.2
UNITED KINGDOM	6.4
SPAIN	3.8
SOUTH AFRICA	2.0
JAPAN	0.7

(Source : I.D.F.)

TABLE 2. CHEESE PRODUCTION (1983)
(THOUSAND TONS)*

WEST-EUROPE	3 870
(FRANCE	(1 230)
EAST-EUROPE	610
U.R.S.S.	665
NORTH-AMERICA	2 405
(U.S.A.)	(2 061)
SOUTH AMERICA	534
SOUTH AFRICA	34
ASIA	12
OCEANIA	268
(AUSTRALIA)	(143)
(NEW-ZEALAND)	(125)
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TOTAL	8 764

TOTAL IN THE WORLD, ABOUT 10 000.

* Source : U.S.D.A. (estimation).

TABLE 3. MAIN CLASSES OF CHEESES
WITH SOME REPRESENTATIVE TYPES AND THEIR ORIGIN

CLASSES (TYPE OF CONSISTENCY)	MOISTURE(%) MAX.	FAT IN DRY MATTER(%) MIN.	WEIGHT (KG)	RIPENING (MONTHS) APPROXIMAT.)
- RIPENED CHEESES				
- VERY HARD				
Parmesan-Grana (Italy)(1)	33-34	32	24-40	24-48
- HARD (with eyes)				
Emmental (Swiss-France)(1)	38	45	60-130	3-12
Gruyère de Comté(France(2)	38	45	20- 55	3-12
- HARD (without eyes)				
Cheddar (GB) (1)	39	48	4- 30	4-12
Cantal (France) (3)	42	45	35- 50	2-12
- SEMI-HARD				
Gouda (Holland) (1)	42,5	48	2,5-30	2- 5
Stilton (GB) (2)(7)	42	48	4 - 8	6
- SEMI-SOFT				
Saint-Paulin(France)(4)	56	40	1,3- 2	1- 2
Roquefort (France) (6)(7)	45	54	2	3-12
- SOFT				
Münster (France) (4)	60	40	0,3-0,9	1- 2
Camembert(France) (5)	56	40	0,25	1
Brie (France) (5)	56	40	1,2-2,3	1
- UNRIPENED CHEESES				
White or fresh cheeses	60-82	0 to 60		

(1) Hard, dry rind (2) hard rind with smeary surface (3) soft, dry rind

(4) soft rind smeary surface (5) soft rind with white mould

(6) no rind (7) interior : blue-green mould veins.

TABLE 4. LACTIC ACID BACTERIA (LAB) IN THE MAIN TYPES OF CHEESES

	USED AS STARTERS	PRESENT OR NOT IN THE NATURAL FLORA
	MESOPHILIC LAB	
HARD-PRESSED CHEESE e.g. CHEDDAR, GOUDA (1)	S. LACTIS	LEUC. SPECIES
BLUE-VEINED CHEESE e.g. ROQUEFORT (2)	S. LACTIS SUBSP. DIACETYLACTIS	L. CASEI
SEMI-SOFT e.g. ST-PAULIN	S. CREMORIS	L. PLANTARUM
SOFT-CHEESE e.g. CAMEMBERT	WITH OR WITHOUT	PEDIOCOCCI
UNRIPENED CHEESE e.g. COTTAGE C. (1)	LEUC. CREMORIS (1)	S. FAECIUM
FRENCH WHITE CHEE[illegible])	OR LEUC. DEXTRANICUM (2)	S. FAECALIS
		......
	THERMOPHILIC LAB	
HARD CHEESE WITH EYE e.g. EMMENTAL	S. THERMOPHILUS	L. CASEI
VERY HARD CHEESE e.g. PARMESAN	WITH L. HELVETICUS	L. PLANTARUM
SOFT OR SEMI-SOFT CHEESE e.g. LIMBURGER	L. LACTIS	HETEROFERMENTATIVE Lb.
GORGONZOLA	OR L. BULGARICUS	PEDIOCOCCI
		STREPTOCOCCI D
ITALIAN PASTA FILATA e.g. MOZARELLA	MIXED STARTERS	
PROVOLONE	(MESOPHILIC WITH THERMOPHILIC)	

TABLE 5. SOME PROPERTIES OF STREPTOCOCCI AND LEUCONOSTOC FROM CHEESE

FERMENTATION OF GLUCOSE

- HOMOFERMENTATIVE (L+LACTIC ACID)
  - (ENTEROCOCCI)
  - STREPTOCOCCI
    - MESOPHILIC
    - THERMOPHILIC
- HETEROFERMENTATIVE (D-LACTIC AND ACETIC ACIDS, CO_2, ETHANOL)
  - LEUCONOSTOC

	(ENTEROCOCCI)	STREPTOCOCCI MESOPHILIC	STREPTOCOCCI THERMOPHILIC	LEUCONOSTOC
GROWTH AT 10°C	+	+	-	+
GROWTH AT 45°C	+	-	+ (AT 50°C)	-
SURVIVE 60°C,30 MIN	+	-	+	-
GROWTH IN 6,5 % NACL	+	-	-	-
	S. FAECIUM S. FAECALIS	S. LACTIS S. LACTIS SUBSP.DIACETYLACTIS S. CREMORIS	S. THERMOPHILUS	LEUC. CREMORIS LEUC. DEXTRANICUM

NH_3 FROM ARGININE : S. LACTIS AND DIACETYLACTIS

CITRATE UTILIZED : S. DIACETYLACTIS, LEUC. CREMORIS.

% NaCL INHIBITING : 4-6 % S. LACTIS, DIACETYLACTIS
2-4 % S. CREMORIS
< 2 % S. THERMOPHILUS

TABLE 6. SOME PROPERTIES OF LACTOBACILLI FROM CHEESE

FERMENTATION OF GLUCOSE

- HOMOFERMENTATIVE (LACTIC ACID)
  - THERMOBACTERIUM
  - STREPTOBACTERIUM
- HETEROFERMENTATIVE (LACTIC AND ACETIC ACIDS, CO_2, ETHANOL)
  - BETABACTERIUM

GROUP :	THERMOBACTERIUM	STREPTOBACTERIUM	BETABACTERIUM	
GROWTH AT 15°C	-	+	+	-
GROWTH AT 45°C	+	+ OR -	-	+
RIBOSE	-	+	+	+
GLUCONATE	-	+ (GAZ)	+ (GAZ)	+ (GAZ)
	L. BULGARICUS	L. CASEI	L. BREVIS	L. FERMENTUM
	L. LACTIS	L. PLANTARUM	L.BÜCHNERI	
	L. HELVETICUS			
	L. ACIDOPHILUS			

LACTIC ACID PRODUCED IN MILK :	2-2.5 %	L. HELVETICUS (DL)
	≤1.7 %	L. BULGARICUS, LACTIS (D-)
(AND ITS ISOMERS)	≤1.5 %	L. CASEI (L+)
	≤0.5 %	L. PLANTARUM (DL)

TABLE 7. MAIN FEATURES OF THE COAGULATING AND DRAINING METHODS USED IN CHEESE-MAKING

NATURAL DRAINING (ONLY DUE TO ACIDIFICATION)	VERY SLOW COAGULATION SLOW COAGULATION QUICK COAGULATION	WHITE CHEESES BRIE CAMEMBERT (TRADITIONAL)
DRAINING FACILITATED BY :	CUTTING	ROQUEFORT
	CUTTING-STIRRING	TILSITT
	CUTTING-STIRRING PRESSING	GOUDA
	CUTTING-STIRRING PRESSING-MILLING	CHEDDAR
	CUTTING-STIRRING "COOKING"-PRESSING	EMMENTAL

THE pH OF FRESH CHEESE IS 4.6 - 4.8 IN HIGH ACID VARIETIES (e.g. CAMEMBERT) AND 5.0 - 5.2 IN CHEDDAR AND EMMENTAL.

TABLE 8. INHIBITION OF SPOILAGE BACTERIA AND PATHOGENS BY LACTIC ACID BACTERIA

INHIBITION RESULTS FROM :

COMPETITION FOR NUTRIENTS e.g. LACTOSE
DECREASE IN pH AND REDOX POTENTIAL
FORMATION OF COMPOUNDS :

- LACTATE
- ACETATE (S. DIACETYLACTIS, LEUC., LACTOBACILLI)
- H_2O_2 (LACTOBACILLI)
- ANTIBIOTICS : NISIN (S. LACTIS)
  ACIDOLIN (L. ACIDOPHILUS)
  ACIDOPHILIN " "
- OR ANTIBIOTIC LIKE SUBSTANCES
  (STREPTOCOCCI, LACTOBACILLI).

TABLE 9. SOME SPOILAGE OF CHEESES BY LACTIC ACID BACTERIA

CHEESE	SPOILAGE	CAUSE	ORGANISM
CHEESE BRINES	ROPINESS SLIME	POLYSACCHARIDE	Lb.
ITALIAN GRUYERE	PINK DISCOLORATION	OXYDIZED CHEESE SUBSTRATE	Lb.
CHEDDAR GRUYERE	RED-ORANGE "RUSTY SPOT"	GROWTH OF PIGMENTED BACTERIA	Lb.
VARIOUS	BITTERNESS	PEPTIDES	STARTER STREP.
CHEDDAR	FRUITINESS	ESTERS	STARTER STREP.
HARD CHEESE	TEXTURE DEFECT BLOWING FILM	CO_2	STREP., Lb. HETEROF.
SOFT, SEMI-HARD	TEXTURE DEFECT	CO_2	LEUC.
GRUYERE-EMMENTAL	EARLY BLOWING	CO_2	Lb. HETEROF.
	SECONDARY FERMENTATION	CO_2	Lb., ENTEROC. STIMULATION OF PROPIONIBACTERIA
EDAM, GOUDA	TEXTURE DEFECT OFF FLAVOUR	CO_2 PROTEOLYSIS	Lb.

FIGURES (TITRES AND LEGENDS)

FIGURE 1.- LACTOSE AND GALACTOSE UPTAKE AND DISSIMILATION IN LACTIC ACID BACTERIA

(1) Most streptococci ; L. casei ; (2) Most lactobacilli

* Phosphoenol pyruvate dependent phosphotransferase system (PTS)

(From Kandler, 1983).

FIGURE 2.- CELLULAR LOCATION AND ROLE OF PROTEINASE AND PEPTIDASE ACTIVITIES IN LACTIC ACID BACTERIA.

Peptidases in :

- Cell wall	: Dipeptidase* - Tripeptidase*
- Cell membrane or cell wall-membrane interface***	: Aminopeptidases - Dipeptidase - Pyrrolidone carboxy-peptidase
- Cytoplasme	: Di and tripeptidases Aminopeptidases - Carboxypeptidase.**

* S. lactis ; ** lactobacilli *** S. cremoris

(From DESMAZEAUD, 1983 adapted from EXTERKATE, 1984 and LAW and KOSTAD, 1983).

FIGURE 3.- CASEIN BREAKDOWN DURING CHEESE RIPENING

(1) Rennet (2) Lactic acid bacteria (3) Other cheese micro-organisms

Proteolysis ⟶ cheese characteristics : Body/texture changes ; taste, flavour (amino-acids ⟶ flavour compounds).

(From DESMAZEAUD and GRIPON, 1977 ; VISSER, 1977).

FIGURE 4.- ALTERNATIVE PATHWAYS OF PYRUVATE DISSIMILATION IN LACTIC ACID BACTERIA.

* Citrate is metabolized only by S. diacetilactis, Leuc. cremoris

(From LAWRENCE and THOMAS, 1979).

FIGURE 5.- TEMPERATURE CHANGES IN GRUYERE CHEESE DURING PRESSING (AMBIENT TEMPERATURE 24°C)

(From AUCLAIR and ACCOLAS, 1983).

FIGURE 6.- GROWTH CURVE OF THERMOPHILIC BACTERIA IN GRUYERE.

L. helveticus colony counts : o —— o center, • —— • periphery

S. thermophilus colony counts : △ —— △ center, ▲ —— ▲ periphery

(From AUCLAIR and ACCOLAS, 1983).

FIGURE 7.- LACTIC ACID CONTENT IN A 1-OLD-DAY GRUYERE CHEESE.
(From AUCLAIR and ACCOLAS, 1983).

FIGURE 8.- LACTOSE FERMENTATION AND LACTATE FORMATION AND FERMENTATION DURING THE MANUFACTURE AND THE RIPENING OF EMMENTAL CHEESE.
(From AUCLAIR and ACCOLAS, 1983).

FIGURE 9.- COUNTS OF MESOPHILIC STREPTOCOCCI IN MAKING CHEDDAR CHEESE
(1) Pitching ; (2) milling ; (3) pressing after salting
(From CHAPMAN and SHARPE, 1981).

Figure 1

LACTOSE AND GALACTOSE UPTAKE AND DISSIMILATION IN LACTIC ACID BACTERIA

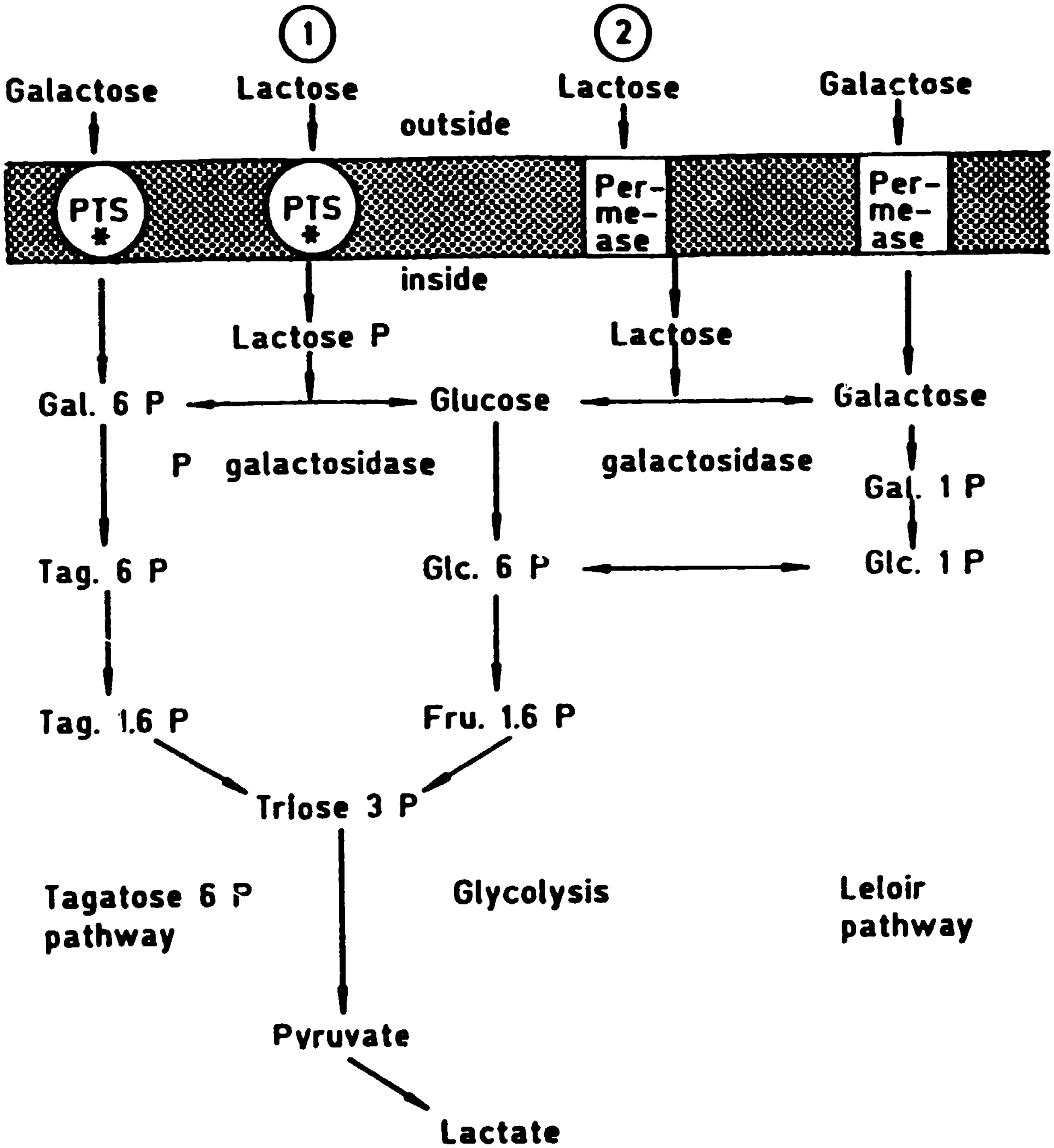


Figure 2

CELLULAR LOCATION AND ROLE OF PROTEINASE AND PEPTIDASE ACTIVITIES IN LACTIC ACID BACTERIA

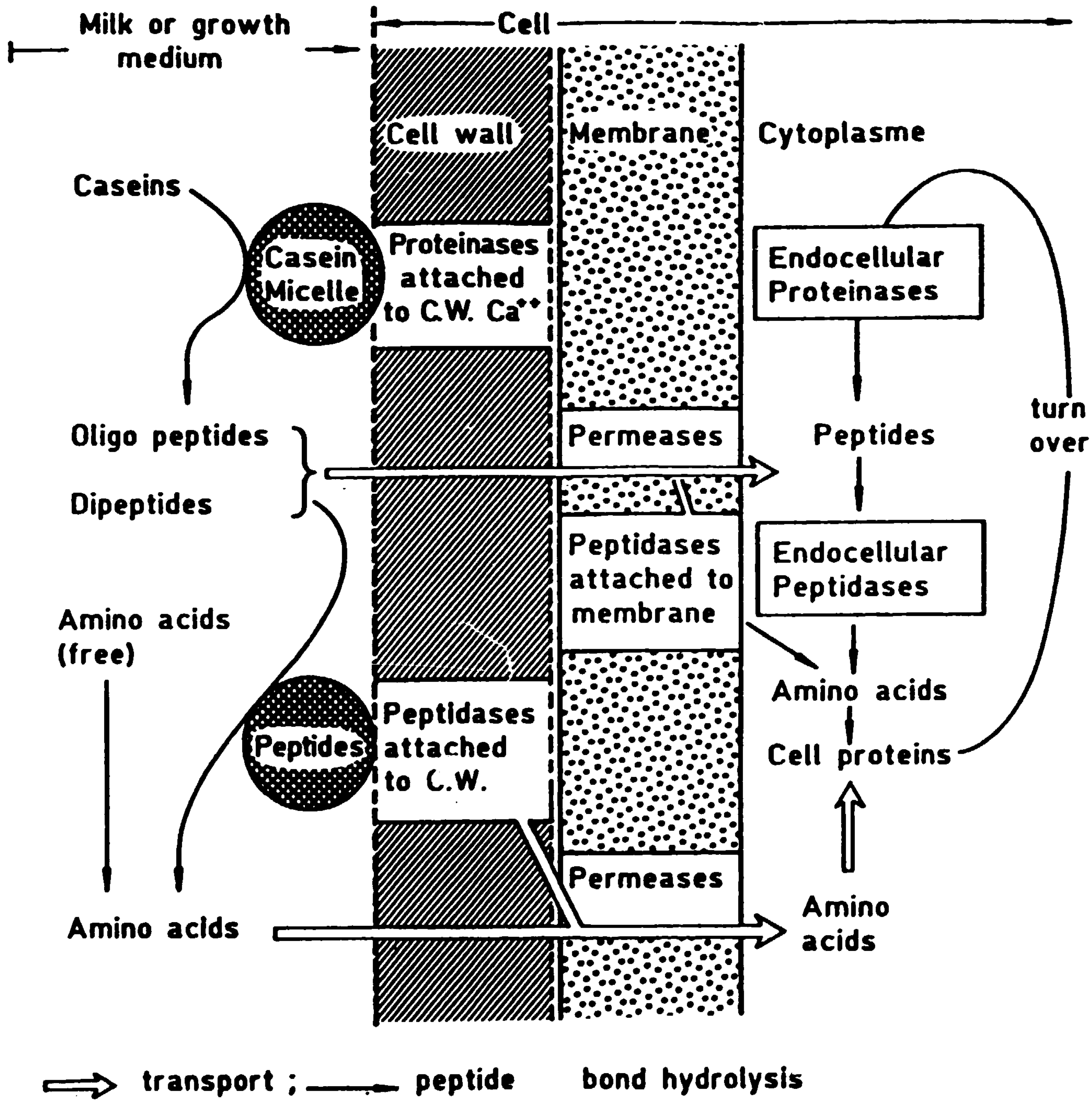


Figure 3

CASEIN BREAKDOWN DURING CHEESE RIPENING

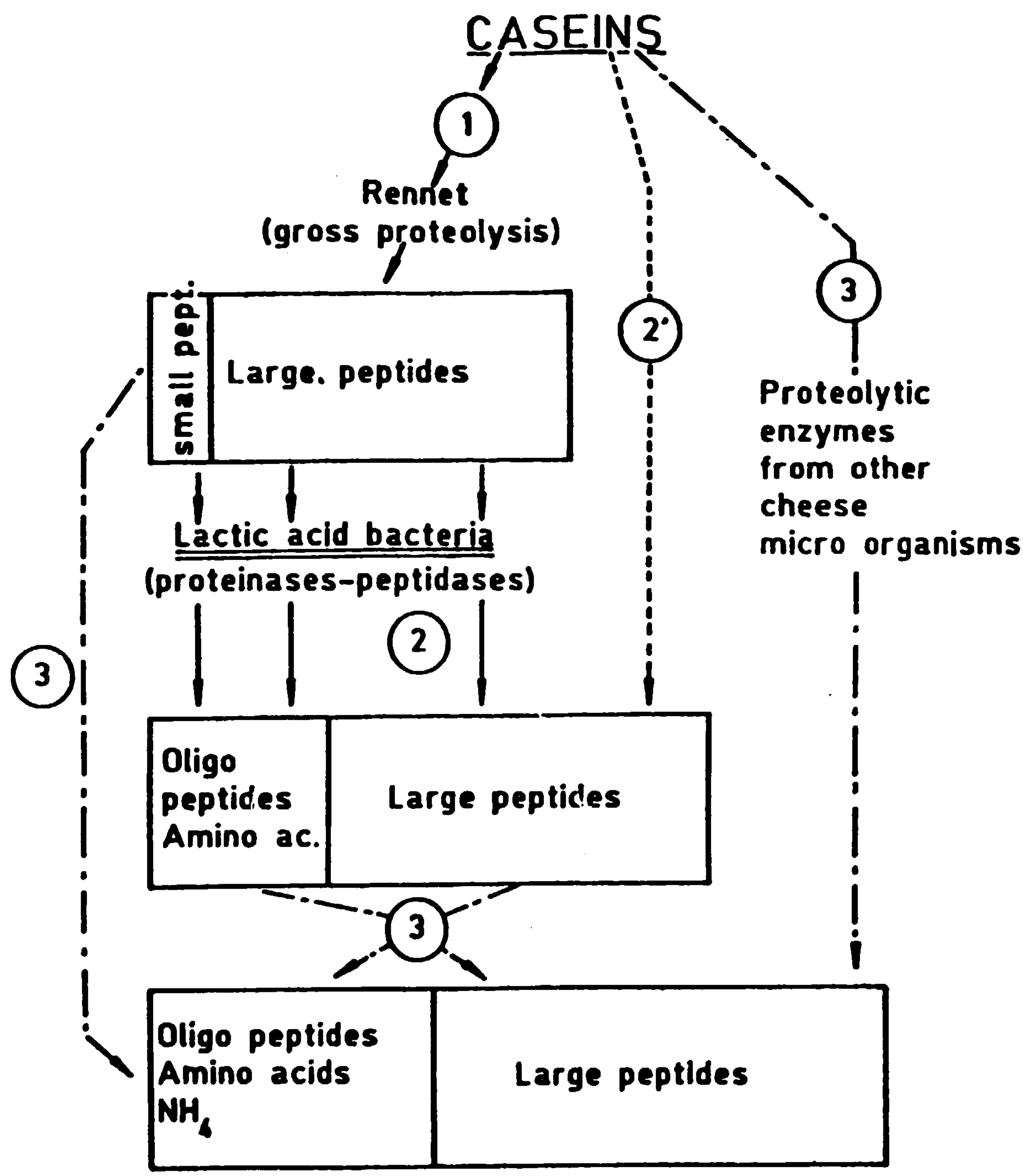


Figure 4

ALTERNATIVE PATHWAYS OF PYRUVATE DISSIMILATION IN LACTIC ACID BACTERIA

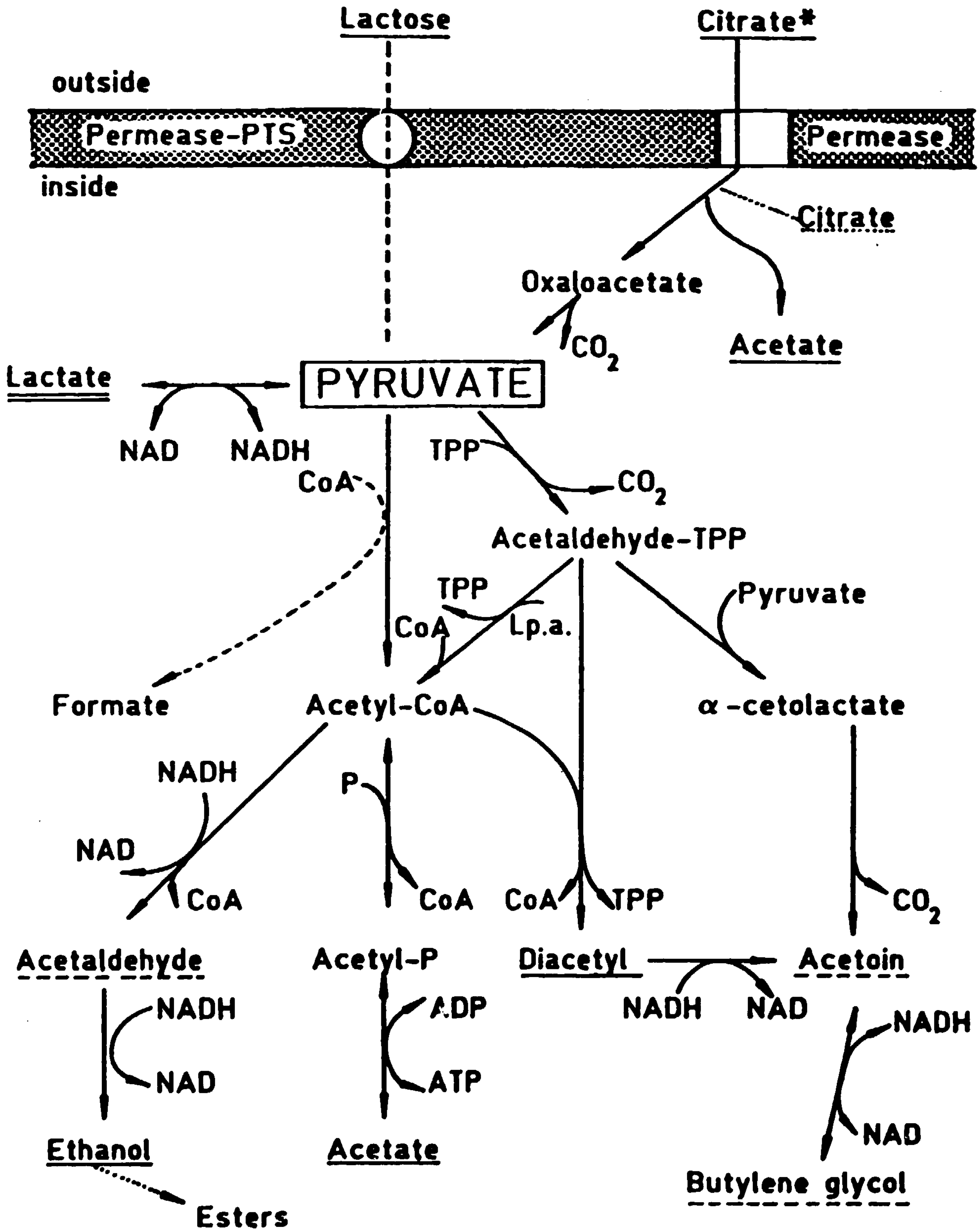


Figure 5

TEMPERATURE CHANGES IN GRUYERE CHEESE DURING PRESSING (AMBIENT TEMPERATURE 24°)

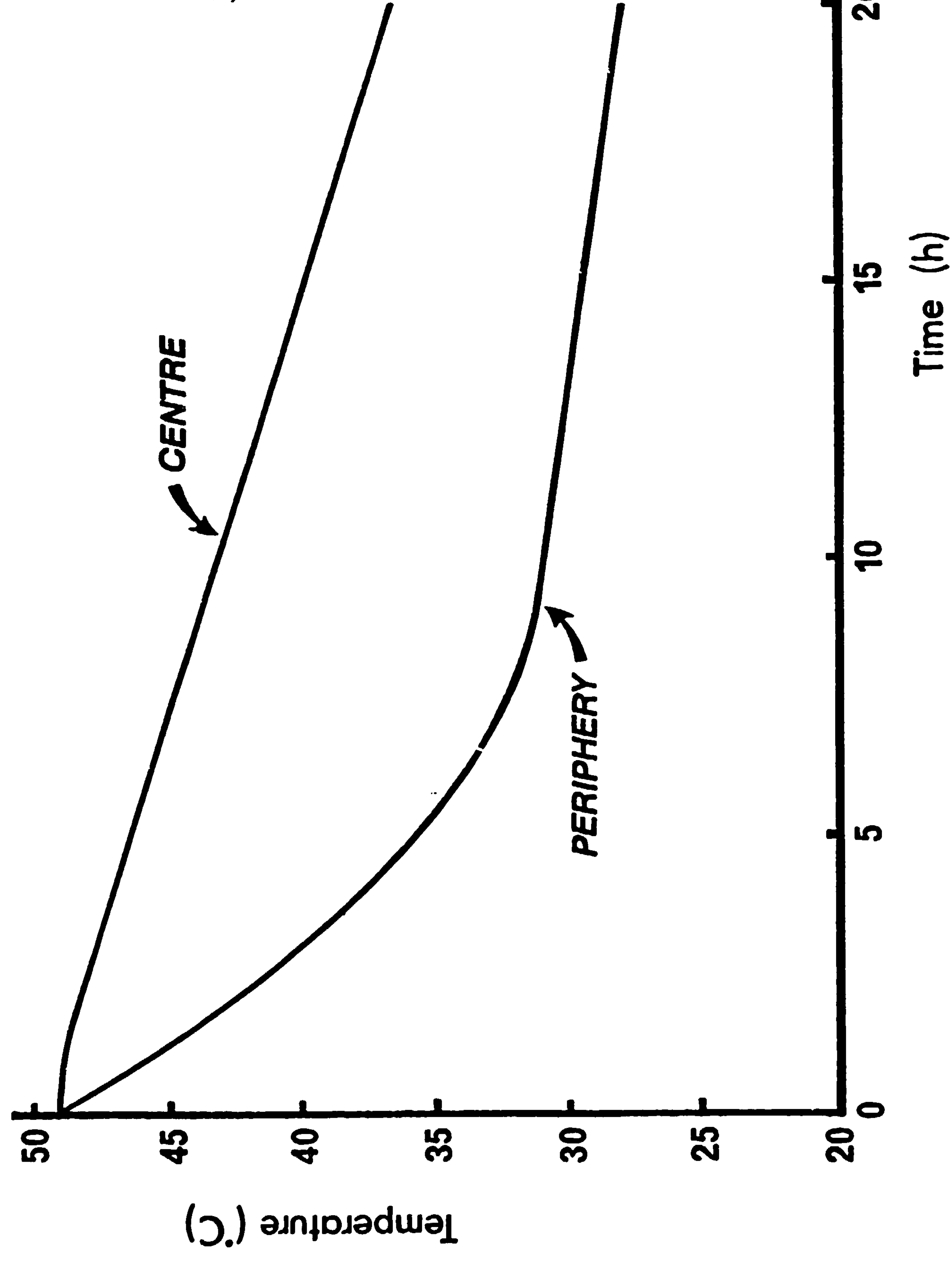


Figure 6

GROWTH CURVE OF THERMOPHILIC BACTERIA IN GRUYERE

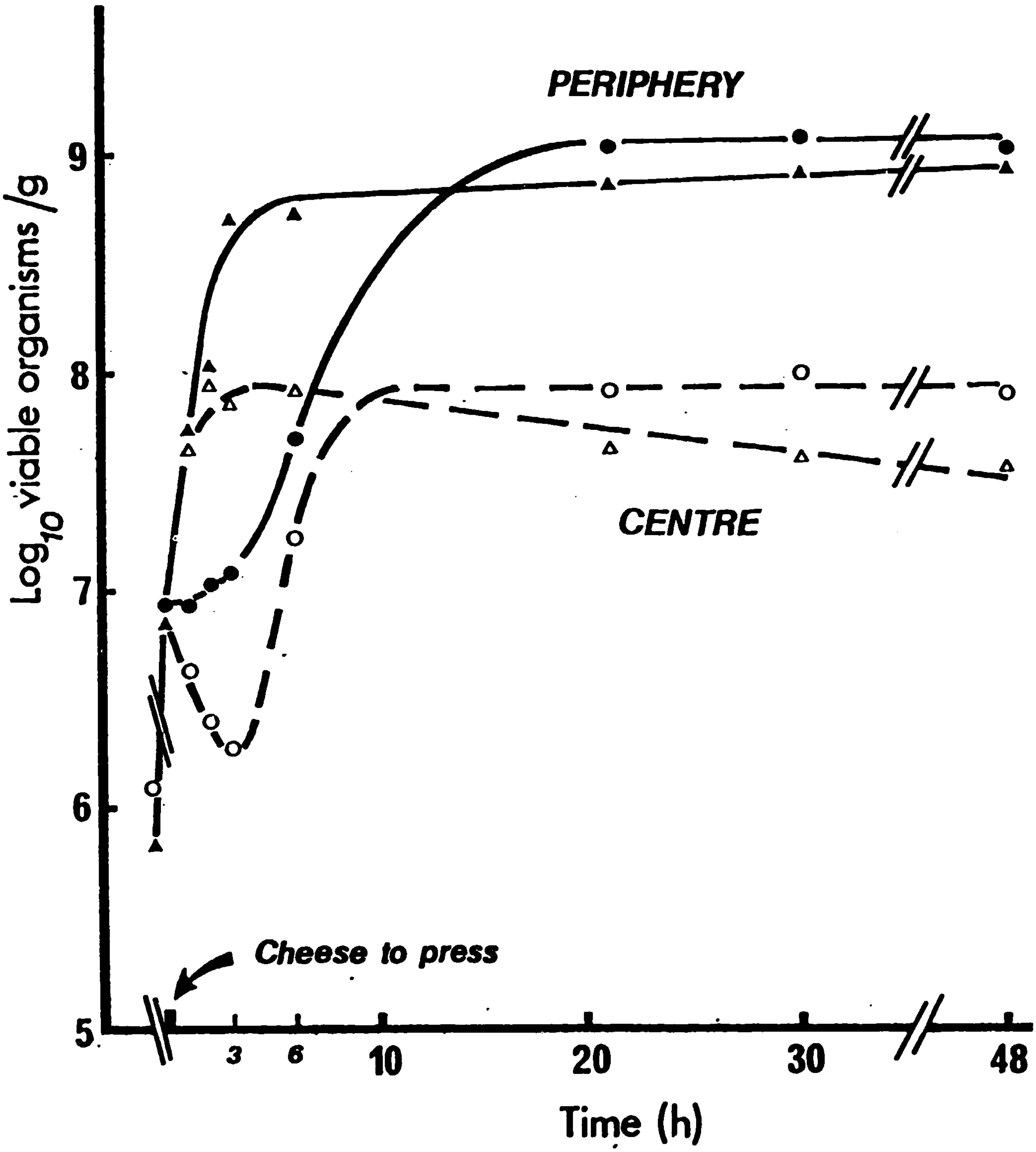


Figure 7

LACTIC ACID CONTENT IN A 1-OLD-DAY GRUYERE CHEESE

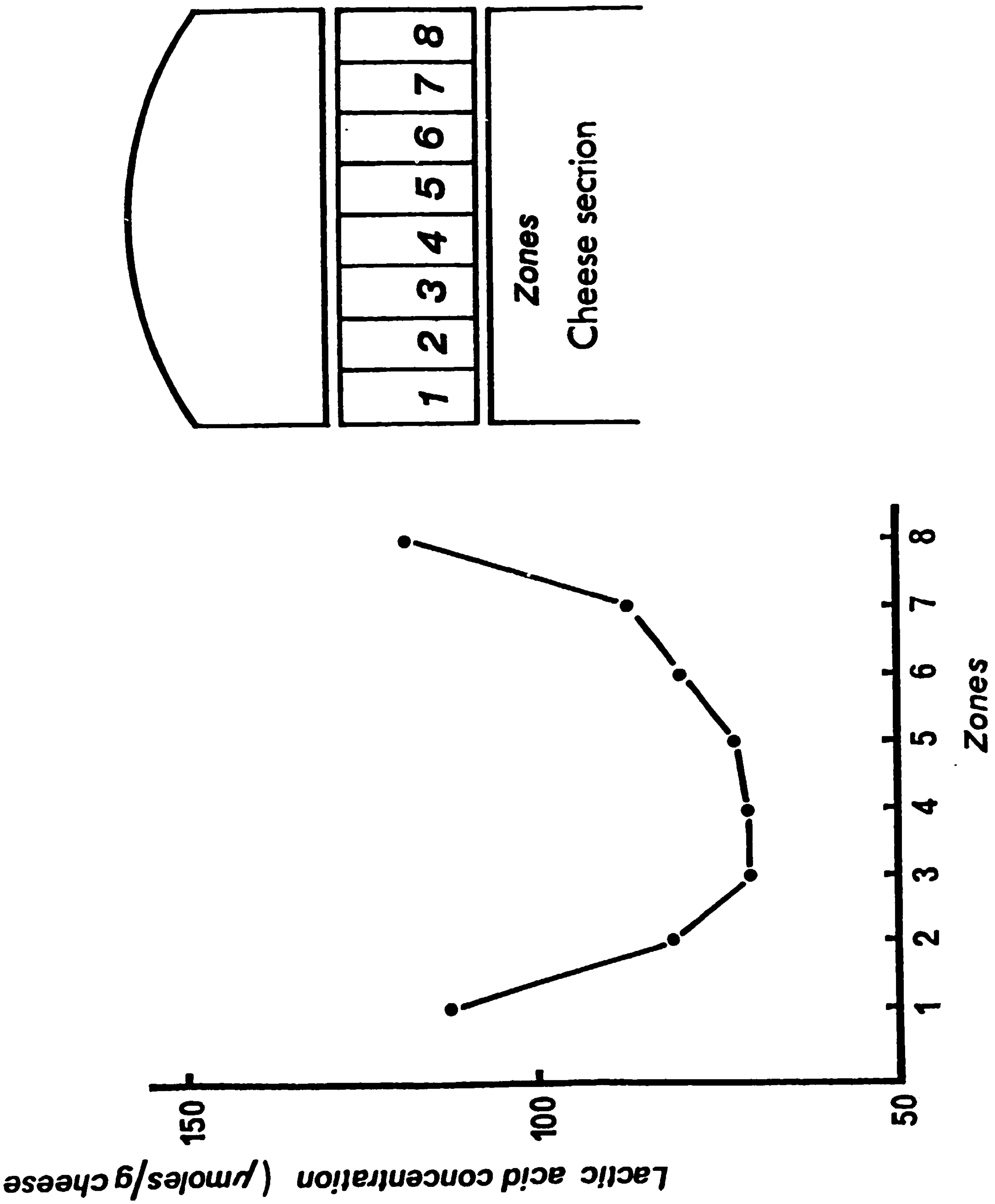


Figure 8

LACTOSE FERMENTATION AND LACTATE FORMATION AND FERMENTATION DURING THE MANUFACTURE AND THE RIPENING OF EMMENTAL CHEESE.

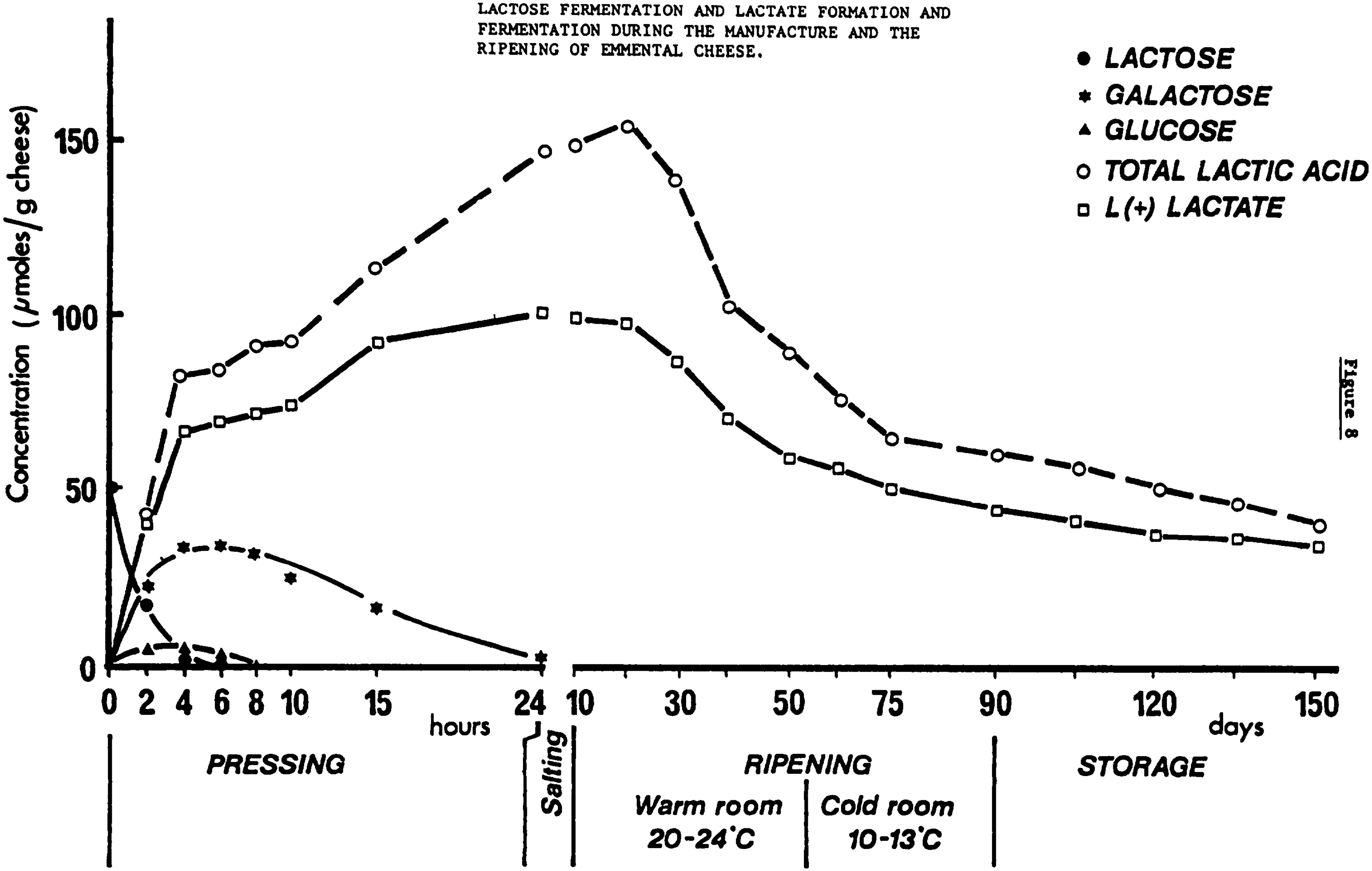
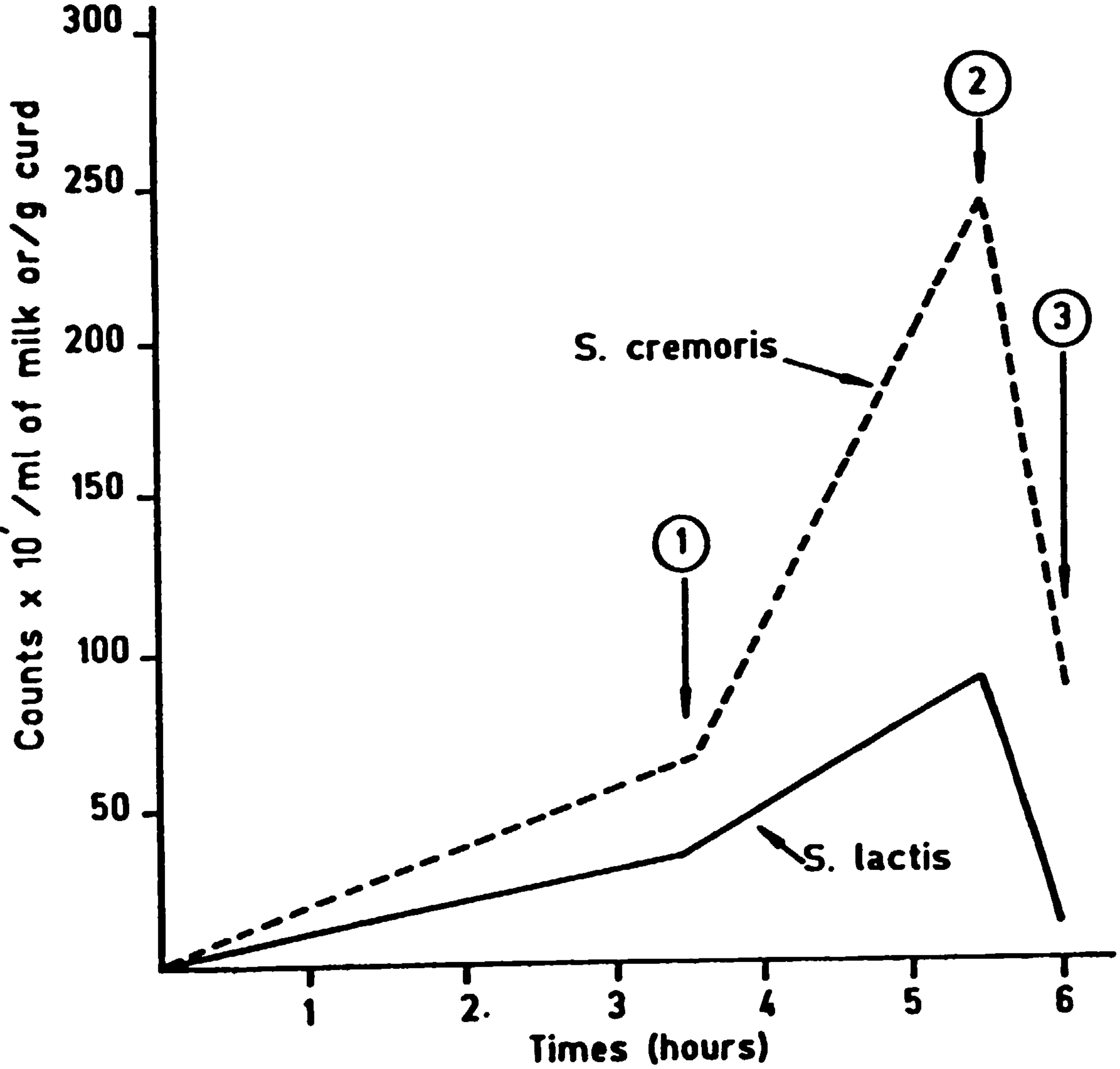


Figure 9

COUNTS OF MESOPHILIC STREPTOCOCCI I" MAKING CHEDDAR CHEESE



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