THE ROLE AND MEASUREMENT OF ACID PRODUCTION IN CHEESEMAKING

by

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Section one

Part I

Introductory and historical

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INTRODUCTORY AND HISTORICAL

Cheese is defined by Davis (1965) as "the curd or substance formed by the coagulation of the milk of certain mammals by rennet or similar enzymes in the presence of lactic acid produced by added or adventitious micro-organisms from which part of the moisture has been removed by cutting, warming and/or pressing, which has been shaped in a mould, and then ripened by holding for some time at suitable temperatures and humidities". No matter in what way cheese may be defined, it is one of the most nutritious and complete foods known to man.

In earlier days, cheese provided a very useful means of preserving a seasonal surplus of milk for which the farmer had no immediate outlet. It was in this way that the farmhouse cheesemaking industry started and flourished in many parts of the British Isles and it is regretted by many that this farmhouse craft is in recent years dying a slow but certain death.

There exist many tales as to the origin of cheesemaking, but it is known that cheese was being eaten in Asia several thousand of years B.C.. The origin of buttermaking is frequently ascribed to cheesemaking, i.e. that an Arab merchant who was carrying his supply of milk across the desert in a bag made from the stomach of a calf, found, at the end of his journey, butter granules (or curds and whey) in his milk bag. The references to cheese and cheesemaking are numerous in all the ancient epic writings and cheese is frequently mentioned in the Bible.

HISTORY OF CHEDDAR CHEESEMAKING IN BRITAIN

Cheddar cheese derives its name from the town of Cheddar in Somerset, where it originated hundreds of years ago. Legend has it that one day when a shepherd boy was tending his flock on the Mendip Hills he inadvertently left his can of milk in the famous Cheddar caves. After several months he returned to find an edible solid substance in the can. This was supposed to be the first Cheddar cheese to be made. Although to-day Cheddar cheese is the most popular cheese throughout the English speaking world, many other varieties were made in Britain in earlier times, as William Bulleyn writing around 1550 said "... and here in Englande be divers kindes of cheeses.....". In these earlier times the faults of the cheesemaking process were observed and pointed out. In 1557 one writer named Tusser (Maddever, 1955) warned the dairy maid of using unhygienic techniques; and of the problem created by adding too much salt to cheese he wrote,

"Leave Lot with his pillar, good Cisley alone,
Much saltiness in white meat is ill for the stone".

Cheddar cheese was, according to William Camden, writing in 1600, of such a size that it took two men to lift one on to the table. At the present time the weight of a Cheddar cheese varies between 40 and 70 lbs.

In the earlier days of cheesemaking, the milk was coagulated by immersing it in the vell of a newly killed suckling calf thus releasing rennin enzyme into the milk. The resultant curd was afterwards separated from the whey and moulded into a solid mass to be eaten fresh or matured. Due to lack of communications and transport facilities, the farm remained the manufacturing unit for many years and as the quantities of milk made into cheese were small, little progress was made in equipment improvement. With the advent of larger herds giving larger volumes of milk for cheesemaking a certain degree of specialisation has to be introduced to ensure the success of the venture. Little or no knowledge was available on the chemical, physical and biological influences that affected the cheesemaking process and it was little wonder that cheese quality varied a great deal from season to season and from locality to locality. There was quite naturally some keen rivalry between individual cheesemakers and this led to great secrecy where a successful cheesemaking recipe was sought. This tendency to retain knowledge for personal advantage was partly to blame for the slow progress that was made in the earlier days of cheesemaking. However, by means of meetings, conferences and the press, the more enlightened and more public spirited cheesemakers helped to educate their less successful colleagues in the practice of cheesemaking.

Although several distinct varieties of cheese were made in England in the earlier days, the only important cheese made in Scotland was Dunlop, taking its name from the parish of Dunlop in Ayrshire. By the beginning of the 19th century the Cheddar variety was being made in Scotland (Aiton 1811). There is little certainty as to the originator of Dunlop and Aiton (1811) stated that a cheese similar to Dunlop was made about the middle of the 17th century. Due to the profitability of making Cheddar cheese, the farmers of the South-West Scotland sought advice on the manufacture of this variety. Expert advice was indeed necessary if the cheese produced was to compete with cheese which was being imported in large consignments around that time.

In 1857 a report was published of a deputation which was sent by the Ayrshire Agricultural Association to the West country of England to enquire into the methods of making Cheddar cheese in Wiltshire, Somerset and Gloucestershire. As a result of this deputation the Joseph Harding system of Cheddar cheesemaking was adopted in Scotland (Fussell, 1955). In 1859, Harding (Lloyd, 1899) wrote on the practical aspects of cheesemaking. He stated that Cheddar cheese could be made from the milk of cows grazed on any pasture. This fact surprised the cheesemakers of the time who believed that cows grazed on certain pastures produced milk which could not be made into Cheddar cheese.

The "systems" evolved by the more expert cheesemakers lacked knowledge from the chemist, bacteriologist and the engineer or dairy equipment manufacturer. In 1891 Joseph Harding complained that "cheesemaking as a science is not understood" and referred to some of the information which he, as a practical man, wanted from science. This included "a chemical knowledge of the constitution of the curd and whey throughout the process" and Harding said "if only such knowledge were forthcoming cheese could be made upon principles scientific and consequently unerring". In 1892 Lloyd (1899) introduced his acidimeter test, a test that is used by cheesemakers at the present time. In the latter half of the nineteenth century bacteriology was in its infancy and the reason for bad flavours in cheese or how micro-organisms gained access to milk was not fully understood. In 1890 the Danish scientist Storch made the first effort to control bacterial fermentations by using selected strains of micro-organisms for buttermaking and the introduction of selected strains in the making of starter gave the cheesemaker a more reliable and predictable method of producing acid, which is essential for success in the cheesemaking process.

The dairy equipment manufacturers around the same time contributed to the progress that was being made in other fields. Tinned metal was replacing wood, curd knives were replacing curd breakers, steam heated jacketed vats were replacing wooden tubs, and before the end of the nineteenth century standard rennet was commercially produced to replace the use of home cured vells. The primitive cheese presses, which used blocks of stone raised by levers, gave way to metal ones where the leverage was operated by a screw and different weights could be applied by suspending them on the end of the lever arm.

Thus cheesemaking on the farm advanced, but when larger herds became more numerous the scale of cheesemaking operations changed to cope with the larger quantities of milk. It was as a result of extra milk becoming available to him that Jesse Williams in Oneida County, New York, opened the first cheese factory in 1851 (Fussell, 1955). Factory cheesemaking was so successful that it soon spread over a wide area of the U.S.A. and Canada, and in 1854 four more factories were organised on the Williams method. After an enquiry into the American factory system, the first operations of a cheese factory in Britain began on April 8th 1870 at Derby, and by 1874 there were at least six factories in Derbyshire. By 1880 to 1900 the factory system had become widely adopted in most dairying countries. As the number of factories grew, the number of farmhouse cheesemakers diminished and every year sees this already small number decreasing further.

With the introduction and widespread use of the factory system greater demands were made on the scientist and engineer. Tests became available which indicated the chemical and bacteriological quality of the milk. Higher standards of hygiene in milk production were necessary on the farm and the elimination of the poorer quality milks in no small way contributed to the production of a uniform quality of cheese. Pasteurisation or heat-treatment of the milk gave a relatively uniform raw material and this, together with the use of starters, gave a system which could be more easily controlled by the cheesemaker.

It has been pointed out above that by the introduction of the acidimeter test Lloyd (1899) contributed greatly to the science of cheesemaking and it is a tribute to the test that it is still widely used. It is considered however, that this test could be supplemented by other methods of measuring acidity which are subject to less serious error. The estimation of acidity by pH determination has been attempted over the last 30 years, but the technique has not gained very widespread acceptance in the cheesemaking factory. This may possibly be attributed to the methods employed in the past which were either too cumbersome and/or required a certain measure of skill (which was not normally available in cheese factories) on the part of the operator. The accuracy of the methods of pH determination, also left a lot to be desired. With the introduction of accurate and relatively simple instruments, pH control, which is already widely used in other sections of the dairying industry, could be used with advantage during the cheesemaking process. It was stated by Ling (1948) that "it is by no means established as yet that under the guidance of pH values rather than acidity tests, the quality of the finished cheese is improved". To-day, 20 years later, the situation has changed little, but it is hoped that the work detailed in this thesis will throw some light on the value of pH control in the cheesemaking industry.

THE ESSENTIAL STEPS IN CHEDDAR CHEESEMAKING

In commercial practice Cheddar cheese is usually made in vats of between 1,000 and 2,500 gal capacity.

After heat treatment to about 155°F for 15 sec the milk is cooled to 86°F and allowed to enter the vat. The formation of lactic acid in milk in cheesemaking is commonly known as ripening and to accomplish this a prepared culture of lactic acid bacteria, called a starter, is added to the milk in the vat. This early development of lactic acid in the vat renders the milk more susceptible to coagulation by rennet and helps to control the composition and quality of the finished cheese. The proper degree of ripeness of milk is considered to be an increase of acidity of 0.01 to 0.03% lactic acid over that of the fresh milk.

Colouring matter or annatto may be added to the milk at the rate of about 2 to 4 oz per 100 gal of milk, the rate depending on the natural colour of the milk. Before addition, the annatto is diluted with about 15 times its volume of water.

Adding the commercial preparation of rennin (rennet) is known as setting or renneting of the milk. The temperature of the milk at time of renneting should be about 84 to 86°F. Rennet is added to coagulate the milk; the amount added is usually 4 oz per 100 gal of milk. To ensure even distribution of the rennet throughout the vat of milk, the rennet is diluted with about 15 times its volume of water.

When the milk has coagulated sufficiently the coagulum is cut manually or mechanically by means of curd knives. The time from renneting to cutting the coagulum is usually about 35 min. The object of cutting the curd is to allow the whey to escape and the size of the curd pieces controls to a large extent the moisture content of the curd. When the coagulum has been cut the temperature of curds and whey is raised to about 100 to 104°F. This application of heat is known as scalding and the maximum temperature is reached in about 1 h from the commencement of scald. The curds and whey are continually stirred either manually or mechanically to prevent the curd pieces sticking together and settling at the bottom of the vat. The maximum temperature is usually maintained until the whey is removed from the vat.

When the cheesemaker considers that the curd pieces are firm enough, i.e. sufficient moisture has been expelled from them, the stirring is stopped and the curds are allowed to settled to the bottom of the vat. This step is known as pitching or settling of the curd. Depending on the titratable acidity of the whey and the size of the vat, whey may be drained slowly from the vat until finally all the whey is removed or run from the vat. This separation of curd from the whey was in the early days known as "dipping" but today it is generally known as "running of the vat". The titratable acidity at the running of the whey may vary from 0.20 to 0.26% lactic acid depending on the type of starter being used. After the whey has been removed from the vat and a channel about 8 in. wide cut lengthwise through the centre of the vat, the curd is cut into blocks about 6 to 8 in. wide and about 6 in. deep.

This operation of cutting the curd into blocks begins the main distinctive feature of Cheddar cheesemaking known as cheddaring. Cheddaring consists of cutting the curd into suitably sized blocks and as acidity development takes place these blocks are piled one upon the other. The depth to which the blocks are piled will determine the rate of acidity development and also the moisture content in the finished cheese. The cheddaring period usually takes about 1½ to 2 h after which the curd is milled. The titratable acidity at milling may vary from 0.65 to 0.75% lactic acid.

The objects of milling are (a) to cut the curd into small uniform pieces to that it may be salted evenly, (b) to permit the escape of more whey and possibly undesirable gases, and (c) to cool the curd. In commercial practice using non mechanised procedures the milled curd is salted about 15 to 25 min after milling. Salt is added to Cheddar cheese curd at the rate of about 2 to 2½ lb salt per 100 lb curd so as to produce a salt content in the finished cheese of between 1.4 and 1.8%. Salt aids in the removal of whey and checks excessive acid development in the cheese during maturation or curing. When the salt has been thoroughly mixed into the curd - about 20 min after the application of salt - the curd is placed in cheese hoops or moulds suitably prepared with cheese cloths, the type of mould used being dependent on the size and shape of the cheese required by the manufacturer. The most common type of mould used in Scotland today is rectangular in shape and holds about 42 lb of curd.

The cheese in the mould is subjected to pressure in a cheese press. The pressing helps to consolidate the curd and also squeezes out any pockets of whey which may have formed. In recent years the length of time of pressing has been decreased to about 16 h. After pressing the cheese is removed from the mould and wrapped in bandages or special papkaging material, e.g. waxed cellulose, is used on the rectangular shaped cheese and heat sealed. These rectangular cheese weighing about 40 lb are then placed in either cardboard or timber boxes and put in the cheese store, which is maintained at about 48^{o}F for maturing.

The length of time of maturation or curing of Cheddar cheese will depend on market requirements but Cheddar cheese may be consumed after 12 to 16 weeks of maturing.

Terms used in the description of Cheddar cheese quality

Cheddar cheese manufactured in Scotland is usually examined at about 8 to 10 weeks old by an official of the Company of Scottish Cheesemakers Ltd. who places the cheese in one of 3 grades (a) grade 1, (b) graded, and (c) no stamp cheese.

The following qualities serve as a basis for the commercial grading of Cheddar cheese.

Flavour and Aroma

van Slyke and Price (1949) defined flavour as that quality which is perceptible to the smell and taste. The sense of smell is relied on in testing flavour of cheese because where large numbers of cheese are examined tasting becomes unreliable and impracticable. Cheddar cheese flavour should be clean i.e. no off flavours, fully developed and as it is sometimes described, "nutty".

Several undesirable flavours are encountered in Cheddar cheese and are described as fruity e.g. the odour of pineapple, rancid, weed and bitter. It has been observed by the author that a flavour described by the official grader as slightly cooked or burnt is associated with an abnormally high, (greater than about 2.3% salt) salt content.

Texture

Texture refers chiefly to compactness or appearance of solidity or alternatively the amount of openness or gas space within the cheese. Cheese with no gas space is said to have a close texture and that with considerable space has an open texture. Mechanical openness may be caused by incomplete fusion of the milled pieces of curd during pressing. The texture may also be described as short and this is usually caused by excessive acidity development.

Body

Body refers to the consistency, firmness or substance of cheese. A Cheddar cheese having a good or ideal body is indicated when it feels solid, firm and smooth. A smooth-bodied cheese is free from rough particles of curd and feels smooth and velvety when a portion of the cheese is "worked" or kneaded between the thumb and fingers. A corky-bodied cheese is hard, overfirm and does not break easily when pressed in the hand. A weak-bodied cheese is soft, lacking in firmness and may be caused by excessive moisture. A curdy-bodied cheese is usually a very dry cheese and may be caused by over salting or bad salt distribution.

COMMON FAULTS OF CHEDDAR CHEESE

Scottish Cheddar cheese when officially examined 8 to 10 weeks after manufacture must satisfy the requirements of expert judges in respect to flavour and aroma, body, texture, colour and finish. Whitehead (1948) stated that "a desirable body implies the correct firmness in consistency when a piece of cheese is kneaded in the fingers and a smooth waxy 'feel' which persists as the kneading progresses". Davis (1937) described body "as that quality which is perceptible to the touch" and texture "as that which is evident to the eye excluding colour". van Slyke and Price (1932) stated that body "refers to the consistency, firmness or substance of cheese" and that texture "refers chiefly to compactness or appearance of solidity".

All the above characteristics i.e. flavour and aroma, body and texture must each reach a minimum standard in order to merit a certificate placing the cheese in either of 3 commercial grade categories. To a commercial Cheddar cheese factory the placing of their cheese in the lower grade gategories represents a considerable financial loss and it is imperative that cheese factory personnel are aware of the faults that may occur and to take the appropriate preventative measures.

The faults which may be responsible either individually or collectively for the down grading of Cheddar cheese may be classified as follows (Davis, 1955):-

(i) Physical

(ii) Chemical

(iii) Bacteriological

(iv) Physiological

(i) a. Dry body is caused by lack of moisture in the final product and may be due to a variety of reasons. If the curd is heated to too high a temperature it may result in a dry cheese. If excess salt is added it may cause excessive drying of the curd. A weak, pasty or sticky body may be caused by excessive moisture. If a normal milk is used and the starter organisms produce acid at a uniform rate then a dry or a weak-bodied cheese is the result of lack of proper control during the making process.

(i) b. The texture of a Cheddar cheese should be smooth and silky. A cheese having an open texture may be due to low acidity, pressing the curd for too short a period, excessive salting and possibly too low a temperature at time of moulding. Where a grainy or gritty texture is encountered, it is usually due to over acidity at the critical stages of running the whey and milling the curd.

(i) c. Other defects in this category are, bleached colour caused by over acidity; cracked rinds caused by mishandling of blocks of cheese or ripening the cheese in too dry an atmosphere (this is not such a problem in Scotland where the majority of cheese made is of the rindless type); sweating of the cheese which may be caused by over acidity.

(ii) a. Chemical faults are those independent of the micro-organisms in the cheese and are usually due to the presence of metals such as lead or iron. Metallic discoloration may be due to tiny particles of iron or copper. The combination of lead with hydrogen sulphide gives a black (lead sulphide) discoloration. Pink or red patches in mature cheese may be caused by using impure annatto, a substance used for cheese colouring (Barnicoat, 1937, 1945).

(iii) a. Bacterial faults are extremely difficult to control once the cheese is made and put to press. Over acidity which leads to defects in body and texture is caused by too rapid growth of the starter organisms. If a starter is working or producing acid at a rate faster than normal the cheesemaker must be able to control his make procedure accordingly. Methods of checking acid production include, manipulation of the temperature of scalding or the addition of an extra amount of salt at the later stages.

(iii) b. Gassiness in cheese - characterised by tiny pinholes on the cut surface - is usually attributed to bacteria of the coli-aerogenes group which are capable of fermenting lactose not utilised by the lactic acid bacteria. The "blowing" of cheese due to the production of large volumes of gas within the cheese, may be caused by the butyric acid bacteria.

(iii) c. Flavour defects may be defined as bitter, fruity or stinking. Bitterness in Cheddar cheese may be due to the limited proteolytic activity of the starter organisms (Mabbit, 1961) resulting in peptones or peptides which are extremely bitter compounds. It can also be caused by yeasts and atypical lactic acid bacteria. A fruity odour is usually caused by yeasts, and stinking cheese can be caused by anaerobic sporeforming bacteria, e.g. Clostridia, which are capable of forming mercaptans and amines from the proteins of the cheese. This latter fault becomes more evident when cheese is stored for a long period.

(iv) Under present day factory conditions the effect of mastitis or inhibitory substances in milk from one herd of cows is diluted by the bulking of all milks and so is not so serious as when cheese is made on the farm.

The faults occurring most frequently in Scottish Cheddar cheese were enumerated by Bryan (1957) and measures for the elimination of such faults were suggested.

In commercial practice records are kept of titratable acidities and times of the various stages of the Cheddar cheese manufacturing process. This data it is hoped would give an indication as to what grade standard the cheese would attain at 8 weeks old when graded by the official cheese grader. However, it is very disturbing to the cheese manufacturer when a cheese with an acceptable manufacturing record fails to achieve 1st grade. It frequently occurs that two cheese having similar manufacturing records result in cheese of widely differing quality. This study was undertaken in an effort to throw some light on the reasons for the discrepancies between manufacturing records and final cheese quality and on the relationship between acidities (either pH or titratable acidities) during manufacture and the quality of the cheese at about 8 to 10 weeks old.

Section one

Part II

Acid production in Cheddar cheesemaking

(a) extent and rate of acid production

(b) factors affecting rate of acid production

ACID PRODUCTION IN CHEESEMAKING

(a) Extent and rate of acid production

Lactose is the only sugar found in cow's milk in significant quantities and is present to the extent of 4.7 to 4.9%. The most important factor affecting the amount of lactose in milk is the presence or absence of infection in the lactating cow. Mastitis depresses the secretion of lactose while increasing the amount of chlorides in the milk.

The manufacture of cultured milks and cheeses and the differentiation and inhibition of certain micro-organisms all rest on the fermentation of lactose. So far as is known (Marth, 1962) lactose is not used directly by any organism, but is broken down first into glucose and galactose. It appears that the main feature of lactose fermenting organisms is their possession of a lactase rather than unique mechanisms of glucose metabolism. A fact which seems to suggest that there is more than one pathway to lactic acid is that micro-organisms can produce various forms of this acid. The amount of lactic acid produced by lactic acid bacteria during the fermentation of lactose may range from 75 to 95% of the total acidity (Jenness and Patton, 1959).

The conversion of lactose to lactic acid may be illustrated simply thus:-

$$C_{12}H_{22}O_{11} + H_2O \longrightarrow C_6H_{12}O_6 + C_6H_{12}O_6$$

$$2C_6H_{12}O_6 \longrightarrow 4C_3H_6O_3$$

Pyruvic acid is the final intermediate and it is reduced to lactic acid by the enzyme lactic acid dehydrogenase and by the reduced co-enzyme diphosphopyridine nucleotide. In the homofermentative group (of Lactobacteriaceae) 90% or more of the carbohydrate fermented (under acid conditions) is converted to lactic acid (Foster, Nelson, Speck, Doetsch and Olson, 1958).

Rate of acid production

The rate of transformation of lactose into lactic acid is of very great importance in the cheesemaking process, since it controls the changes in mineral composition and in the texture and other physical properties of the curd (McDowall and Dolby, 1935a).

van Slyke and Bosworth (1915) made experiments on the souring of milk to which a culture of Bacterium lactis acidi and Bacterium lactis aerogenes had been added and found that from 70 to 93% of the lactose fermented was converted to lactic acid. Orla-Jensen (1919) stated that the true lactic acid bacteria form only traces of succinic acid and volatile acids and that the total acid formed could be calculated as lactic acid without great error. The hydrolysis of lactose to glucose and galactose was caused by only a few bacteria and then mostly in old cultures containing many dead cells.

Lampitt and Bogod (1933) have presented an extensive review of the literature on the subject of fermentation of lactose together with results of experiments made with a number of species of bacteria which showed the relation between their period of incubation in milk and the resultant titratable acidity and lactic acid contents of the milk. Appreciable quantities of lactic acid were formed by only two of the species investigated, i.e. Streptococcus lactis and B. lactis aerogenes. Their results indicated that with Str. lactis there was considerable production of lactic acid without much corresponding change in titratable acidity. The curve for B. lactis aerogenes indicated that the greater part of the acidity produced was due to acids other than lactic acid.

McDowall and Dolby (1935b) have shown that a mixed starter culture when containing both acid and aroma forming organisms under conditions of continuous growth in milk gave an almost complete conversion of lactose into lactic acid. In some instances, in the early stages of the fermentation, a considerable quantity of the lactose appeared to be converted to substances other than lactic acid. They carried out determinations of titratable acidity, lactose and lactic acid at various stages during the souring of milk by starter cultures, both with and without the addition of a neutralising agent. Throughout the experiment they obtained a close agreement between the increase in acidity and the amount of lactic acid formed.

The production of lactic acid from lactose within the curd during the cheesemaking process increases the mineral content of the whey exuding from the curd but an absolute relationship between titratable acidity and lactate content of whey is not to be expected (McDowall and Dolby, 1935a; Moir, 1930). The changes in acidity noted by the cheesemaker are, however, frequently quite anomalous in that during the later stages of the process, the acidity may remain constant or show a marked fall, whereas the physical characteristics e.g. the feel of the curd, indicates that the acid production within the curd is proceeding steadily. Such decreases in acidity were attributed to the belief that there was an increase in the fat content of the later wheys, but analyses of wheys showed that the change in fat content was not sufficient to account for the decrease in acidity (McDowall and Dolby, 1936).

van Slyke and Bosworth (1907) estimated the lactose and lactic acid contents of curd at various stages during the cheesemaking process, and of cheese at various times during maturation. They noted a rapid decrease in lactose content of the curd until a few hours after the cheese was hooped, and then a more gradual fall until after 2 weeks the lactose had almost completely disappeared. The lactic acid showed a corresponding rise in concentration reaching a maximum about the time the last of the lactose was decomposed.

In preliminary experiments, McDowall and Dolby (1936) found that the concentration of lactose in the whey invariably decreased steadily up to the salting stage, after which it showed a very abrupt fall, the difference in the percentage lactose/water in the wheys immediately before and immediately after salting being about 1.2 to 1.4 i.e. 30 to 35% fall in concentration. There was a slight rise in the lactose/water concentration in the later wheys after salting. The acceleration in the concentration decrease produced at salting corresponded to the fall in concentration of the mineral constituents which the same writers had already reported (McDowall and Dolby, 1935a). McDowall and Dolby (1936) carried out further experiments in which they determined the titratable acidity, lactose and lactic acid contents of curd and whey samples which were taken simultaneously at various times during the cheesemaking process. Where milk of high fat content was used, the resultant adnormally high fat content of the whey near the milling stage caused so much dilution of the other constituents of the whey that a considerable lowering of the acidity was obtained. The concentration of lactic acid (actually lactate) in the whey increased steadily up to the salting stage, the actual values at the later stages of the process were roughly twice the corresponding values of acidity calculated as lactic acid. After salting there was a slight fall in lactic acid concentration, much less abrupt than was noticed with the acidity, followed by a slow steady rise. The fall in concentration of lactose in the whey after salting corresponded with the fall in acidity and with the fall in concentration of minerals. It was suggested by McDowall and Dolby (1935a) that this fall in concentration might be ascribed either to an osmotic diffusion of water from the curd or to a liberation of bound water from the curd by the dehydrating action of the salt. The results they obtained from lactose and lactic acid determinations proved that the fermentation of lactose to lactic acid in the cheese vat was nearly quantitative.

(b) Factors affecting rate of acid production

Factors affecting the rate of acid production in the cheese vat are:

1 the amount of starter used and the rate at which starter bacteria breakdown lactose

2 the presence or absence of inhibitory substances such as

(a) Antibiotics or

(b) Bacteriophage

3 the scalding temperature and rate of temperature increase

4 the lactose content of the milk

5 the size of the cut curd pieces

The acidity of a cheese in the early stages of manufacture may influence the whole course of maturation. The first attempts to control acid and flavour development in butter and cheese consisted of using clean-flavoured sour milk as starter. The starters in use today in cheese factories may be single-strain cultures of *Str. lactis* or *Streptococcus cremoris*. Two or more strains of these organisms may be used together or the acid producing species such as *Str. lactis* or *Str. cremoris* may be combined in a mixture with *Streptococcus diacetilactis* or the *Leuconostocs*.

Dolby (1941) studied the effect of type of starter culture and the effect of the amount of starter on acid development. To determine the effect of type of starter culture, 5 starter cultures were used. The results obtained indicated that where the rates of fall of pH in the curd during the later stages of the process were the same, the resultant cheese had the same pH value even where starters of different types were used. He found that a variation in the amount of added starter affected the rate of acid production more in the early stages than in the later stages of the process. A change in the amount of inoculation altered the length of the initial period during which there was little increase in acidity. Once the acid production had reached its maximum rate, which occurred near the drying stage, there was not a great deal of difference in the rates of acidity increase. In the later stages, the rates tended to approach the same value. It was concluded that wide differences in rate of acid production in the early stages of cheesemaking were permissible , provided that the process was controlled carefully at the stage of removing the whey from the vat.

That the culture added to the milk in the vat should produce sufficient acid at a convenient rate is a practical necessity of cheesemaking. To this end, the selection of suitable strains (Jago and Swinbourne, 1959; Whitehead and Bush, 1957), control of 'phage infection (Reiter, 1957; Hargrove, 1959; Meanwell and Thompson, 1959) and other causes of slowness (Wright and Tramer, 1958) and the stimulation of acid production under adverse conditions continue to be the main subjects for investigation. The attainment of a correct acidity in the curd at the pressing stage is also a factor controlling subsequent bacteriological, enzymatic and chemical changes. In this sense the rate of growth of the statter organisms in cheese milk has an indirect influence on flavour production (Mabbitt, 1961).

The comparatively recent demand for a rapid Cheddar cheese process has led to the use of higher temperatures for scalding thd curd and has encouraged investigations into the use of the heat-tolerant enterococci, Streptococcus faecalis or Streptococcus durans, as starters (Feagan, 1958). Good Cheddar cheese can be made with these bacteria provided the variables of the making process are manipulated to ensure a correct acidity in the uncured cheese. It follows that even changing the species of starter will have a minimal effect on flavour provided the acid development is controlled. Nevertheless some strains or combinations of species have been found to produce improvements in cheese flavour (Freeman, 1959; Emmons, McGugan and Elliot, 1960).

Dolby (1941) determined the effect of scalding temperature on acid production. He found that the use of a high scalding temperature (104°F) restrained the growth of the starter culture to such an extent that acid development in the later stages of the making process was definitely retarded and that the pH of the young cheese was considerably higher than the pH of young cheese made with lower cooking temperature.

Antibiotics in milk are the cause of much concern to those who use lactic cultures (Overby, 1954). Acid production by even the more resistant strains of Str. lactis usually is inhibited demonstrably by 0.25 i.u. of penicillin/ml of milk. Str. cremoris is even more sensitive. A culture inhibited by antibiotics is slow in effecting an increase in acidity. The time required for the inoculum to initiate rapid growth may be such that undesirable organisms may have developed in numbers detrimental to the quality of the product.

Bacteriophage is one of the most important causes of slow acid production, and in most instances complete failure, in the vat (Babel, 1946b). Due to the possible build up of 'phage, single strain starters on the average are more liable to 'phage attack than mixed strain starters (Kosikowski and Mocquot, 1958). In New Zealand where single-strain starters are generally used, it has been found that they have the desirable characteristics of even acid production from day to day and give a close textured cheese. The organisms within the mixed-strains are just as sensitive to 'phage attack as the single-strains. An attack of bacteriophage resulting in failure of acid production can be very costly to the cheese industry as has been pointed out by several writers (Elliker, 1951; Whitehead, 1953).

The rate of raising the temperature of the curds and whey may be varied according to whether the acidity is low or high. Too rapid heating of the curd causes the outer layers of the curd to become excessively firm and results in poorer drainage from the interior. If the milk is excessively acid it is advisable for the cheese-maker to cut the curd as small as possible and to start heating as soon as possible, and even before cutting is finished. Temperatures of 100 to 102°F are average for cheese factory conditions and are usually lower in Spring and higher in Autumn. Too high heating, i.e. 104°F will weaken Str. lactis and Str. cremoris and delay acidity development at the later stages of the manufacturing process (Babel, 1946a). The agitation during heating should not be too vigorous when the curd pieces are soft.

The size of the curd pieces when cut is an important factor influencing the moisture and fat content of the finished cheese (Feagan, Erwin and Dixon, 1965). When a cheese with low moisture and relatively low acidity is desired, the curd is cut into small pieces and heated to a fairy high temperature.

The lactose content of bulked milk does not usually vary a great deal, consequently little attention is given to the quantity present in cheese milk. However, of greater importance is the rate of lactose breakdown and the presence of other sugars such as galactose, mannose and glucose which are present to the extent of at least 0.05% (Anantakrishnan and Herrington, 1948; Reynolds, Henneberry and Baker, 1959). The sugars are fermented rapidly and it is reported that glucose and galactose - component sugars of lactose - cannot be found in Cheddar cheese after a few days from pressing (Fagen, Stine and Hussong, 1952).

The effect of acidity at the stage of removing the whey from the vat on the lactose content of cheese was investigated by Dolby (1941). His results showed that in the later stages of the process, curd which had been left in contact with the whey for a longer period, i.e. whey removed at a higher acidity, had a higher lactose content than curd of the same pH value from which the whey had been removed earlier. The author stated, that while the curd remains in the whey there is an equilibrium between the lactose in the curd and the lactose in the whey. The whey thus provided a reserve of lactose which prevented any great decrease in lactose concentration in the curd. After the whey had been removed, this reserve was no longer available and the lactose content of the curd fell rapidly as the fermentation proceeded. If the whey was removed at a low acidity, the reserve of lactose was removed at an early stage and the lactose content of the curd at salting or hooping was lower than that in a corresponding lot of curd from which the whey had been removed at a high acidity. Curd containing 0.69% lactose and 0.84% lactose when the whey was removed from the vat resulted in cheese having pH values of 4.91 and 4.84 respectively at 14 days.

The lactose content of the curd at the end of the making process is a further factor affecting the acidity of the mature cheese. It has been shown previously by McDowall and Dolby (1936) that under normal conditions the whole of the lactose in a cheese was fermented within a few days. The lactose content of the curd when the cheese is put into the press will thus control to a great extent the change in pH of the cheese during the early part of the maturing process.

The milk used for cheesemaking should be of high quality both chemically and bacteriologically. Wilson, Hall and Lochry (1941) carried out laboratory investigations to show that in making Cheddar cheese from raw milk of inferior quality, a relatively high acid development is advisable but if the milk is of good quality the acidity at milling should not exceed pH 5.50.

Many papers have been published on the curd tension of milk, especially in relation to mastitis. Sanders, Matheson and Burkey (1936) have investigated the curd tension of milk in relation to cheesemaking and have shown that in 300 samples of milk the pH was definitely related to the coagulation time and to the curd tension. Sommer and Matsen (1935) also found that mastitis milk, which is characterised by a high pH, caused a marked decrease in curd strength and an increase in renneting time. The resultant cheese was pasty and weak bodied.

The calcium and phosphorus content of cheese curd has an effect on the final body of the cheese apart from the nutritional aspect. Guittoneau and Chevalier (1934) found that cheese made from milk renneted at pH 6.4 retained 69% of the calcium and 57% of the phosphorus while if coagulation occurred at pH 5.4 only 12% of the calcium and 37% of the phosphorus were retained in the cheese.

The effect of acidity development in milk and whey on the mineral content of the cheese has been studied by numerous investigators. (McDowall and Dolby, 1935a; Dolby, McDowall and McDowell, 1937; McCammon, Caulfield and Kramer, 1933).

Section one

Part III

The relationship of acidity to the quality of Cheddar cheese.

THE RELATIONSHIP OF ACIDITY TO THE QUALITY OF CHEDDAR CHEESE

The importance of the level of acidity in determining the quality of cheese has been emphasised by Dolby, et al., (1937) who have shown that there is a general average relationship between the grader's classification as "sweet" or "acid" and the pH or titratable acidity of the cheese.

Leitch (1923) who studied Cheddar cheese stated that the degree of acidification of the curd was the factor which exercised the greatest control over the texture of the cured cheese.

van Slyke (1901) found that excessive moisture produced a cheese of undesirable softness, while lack of moisture resulted in a dry and crumbly texture. It appears then that moisture and acidity exert an influence upon the texture and ripening of cheese. This point was also demonstrated by Watson (1929) in his study on Swiss cheese.

Brown and price (1934) studied the relationship between hydrogen ion concentration, titratable acidity and quality of Cheddar cheese. The measurements of hydrogen ion concentration and titratable acidity were made at critical points of the curd-making process. These points included the times of receiving the milk at the dairy, adding the rennet, cutting the coagulated curd, beginning and ending of the scalding process, removing the whey, and cheddaring, milling and pressing of the curd. The soft coagulum was used for pH measurements until the curd was cut. All acidity measurements were made on the whey between the operations of cutting the coagulum and milling of the curd. Determinations of pH were made on the curd at the stages of milling and pressing of the curd. When the cheese was scored after 2 months, it was placed in one of three groups, i.e. below 87 points, 87 to 90 points and over 90 points. Maximum points obtainable were 30 for flavour, 40 for body and texture, 10 for colour and 20 for the appearance of of the cheese. They stated that the differences in acidity - 0.185 to 0.191% lactic acid and pH 6.7 to 6.4 - at the time of adding the rennet were not great enough to predict the quality of the mature cheese. This was true whether the acidity was measured by pH measurement or by titration. At the stage of removal of the whey from the vat and at the cheddaring stage, however, the differences in acidity between the three groups of cheese were considerably greater. Regardless of the method of measurement of acidity, the highest scoring group of cheese was less acid at every stage of the manufacturing process, while the lowest scoring group of cheese had the greatest acid development at every point of comparison. Brown and Price (1934) concluded that there was a definite relationship between the quality of the cheese and the acidity changes during the process of manufacture. The pH values of the cheese in each group showed a definite decrease during the first 3 or 4 days after making. One of the most significant features was the regularity with which the best cheese maintained a pH above 5.0 during the entire maturing period. When the acidity of a cheese on the 3rd day after it was made was between pH 5.05 and pH 5.20 it was almost certain that it would not show acid defects at any later date. The average pH values of the curd at milling for the three groups, 90 points and over, 87 to 90 points and less than 87 points were 5.29 $\pm$ 0.027, 5.29 $\pm$ 0.014 and 5.12 $\pm$ 0.023 respectively. The corresponding average titratable acidities of the whey at milling were 0.556 $\pm$ 0.028, 0.692 $\pm$ 0.028 and 0.781 $\pm$ 0.027% lactic acid.

Babel and Hammer (1939) carried out pH determinations on several lots of cheese aged 90 days and stated that there was no definite correlation between pH and quality.

Olson, Vakaleris, Price and Knight (1958) found that Cheddar cheese with a high pH was undesirably firm in body at every age. Cheese having a pH value of 5.34 at 90 days was "sweet" whereas a cheese of pH value 5.06 at the same age was considered normal. Phillips (1935) studied the relation of acidity at the different stages of the manufacturing and maturing processes to the development of bitter flavour. He found that when the pH value of the cheese was 4.9 at 4 days, bitter flavours subsequently developed. It also appeared in the majority of the lots of cheese of pH 4.95 and in a part of the cheese of pH 5.00 but not in the cheese of higher pH values. Off-flavours developed in some of the cheese having pH values at 4 days of from 5.15 to 5.25. In these the salt content was lower than in the cheese which did not develop the off-flavours, indicating the possibility of a critical salt concentration for Cheddar cheese. No relation was found, however, between bitterness and salt concentration within the limits of salt used. Price (1936) concluded that bitter flavour in Cheddar cheese seemed to be associated with the development of a slightly excessive amount of acidity. Price (1936) stated that the development of high acidity in cheese may be caused by using milk in which too much acid had been permitted to develop or it may be caused by the use of a very active starter. Dawson and Feagan (1960b) determined the pH value of 181 cheese at 3 weeks old. The pH values ranged from 5.00 to 5.75 and the incidence of bitterness over this pH range was as follows:

pH range	% bitterness
5.00 - 5.09	38
5.10 - 5.19	68
5.20 - 5.29	74
5.30 - 5.75	41

The results of Dawson and Feagan (1960b) did not correspond with the work of Czulak (1959) who stated that cheese which had a pH value at 1 week old above

5.2 seldom produced bitterness and that in cheese with a pH value of 5.0 or less bitterness was frequently found.

Tretsven (1948) altered the pH of cheese by the introduction of certain gases. Cheese was found to mature slightly more slowly in carbon dioxide than in nitrogen or in vacuo and much more slowly when the pH had been increased by ammonia. A commercially produced fresh Cheddar cheese treated with hydrochloric acid to reduce the pH to 4.2 failed to show any characteristics of a normal ripened cheese in 15 months. He concluded that the body, texture, colour and flavour were affected by and could be controlled in part by the hydrogen ion concentration.

Bills and Day (1964) stated that taking into account the pH of Cheddar cheese (pH 5.0 to 5.5) and the dissociation exponents (pKa^s) of the major fatty acids (4.76 to 4.90), it is conceivable that a considerable portion of the total free fatty acids (FFA) exist as salts in equilibrium with the acids. Consideration of the strong odour of butyric acid in contrast to its odourless salt leads to the conclusion that a lower pH may play some role in intensifying the fatty acid contribution to Cheddar cheese flavour by affecting the ratio between acid and salt.

Dahlberg and Kosikowski (1948a) while studying the possibility of using Streptococcus faecalis as a starter organism determined the acidity of cheese during the manufacturing process and the maturing period. Cheese was milled at a pH of from 5.38 to 5.54 (corresponding titratable acidities were 0.52 to 0.38% lactic acid). The pH of all cheese at 1 day old varied from pH 4.9 to 5.1, i.e. irrespctive of considerable variations in acidity present in the whey when the curd was milled. As the cheese matured there was a gradual increase in the pH ranging from 5.13 to 5.29 for cheese held at 50°F and from 5.19 to 5.33 for cheese held at 60°F. Having used three different starters i.e. a commercial lactic starter, a Str. faecalis starter and a mixture of equal parts of commercial and Str. faecalis starter, they concluded that the acidity of the ripened cheese was not affected by the type of starter, as the range of pH on all samples of cheese at 6 months old was from 5.13 to 5.33. It was as a result of their studies (Dahlberg and Kosikowski, 1948)) that they suggested that commercial lactic starter was not necessary for making good Cheddar cheese.

Mabbitt (1961) stated that good Cheddar cheese could be made using Str. faecalis or Streptococcus durans as starters provided that the manufacturing process was carefully controlled so as to obtain a correct level of acidity in the young cheese. Mabbitt (1961) went on to say that "even changing the species of starter will have a minimal effect on flavour provided the acid development is controlled". Cheese flavour was studied by Reiter, Fryer, Sharpe and Lawrence (1966) who concluded that starter was the main agent responsible for the development of the basic cheese flavour.

Dahlberg and Kosikowski (1947) made an attempt to relate flavour intensity of Cheddar cheese with volatile acidity and soluble protein. They obtained pH values of 5.20, 5.10 and 5.00 for cheese aged 14, 9 and 2 months respectively, that had flavour ratings of sharp, medium and mild respectively. They concluded that there were no relationships among intensity of flavour, total volatile acidity, soluble protein content, pH and age of cheese, except for a direct relationship between age and soluble protein.

Morris (1955) carried out experiments with the short process for Cheddar cheesemaking (Czulak, Hammond and Meharry, 1954). A typical pH value of the cheese when removed from the press of 5.28 was obtained which had fallen to 5.16 after 3 weeks. The comments on grading at 3 weeks were that the cheese had a slightly unclean flavour and slightly open texture. It seemed that the pH attained by the cheese had a very considerable influence on its quality. The pH generally was higher than was considered desirable in

Cheddar cheese made in the normal way, but was subject to somewhat unpredictable variation. Occasions of "fruity" flavour defects arose with cheese having a pH value greater than 5.3 when pressing had been completed, and generally the lower the pH attained by the cheese, the better seemed to be both its initial quality and its keeping quality. The curd developed acid very rapidly and milling took place at an acidity of 0.40% lactic acid. Morris (1955) stated that there was a need for greater knowledge and experience of the factors determining the pH and the quality of "short time" process cheese.

Many workers have tried to relate scores for flavour with biochemical substances formed during the manufacturing process and the maturing of commercial Cheddar cheese. A large number of chemical compounds have been found in Cheddar cheese which may be expected to contribute to the flavour. These include free fatty acids, free amino acids, esters, alcohols, acidic and neutral carbonyl compounds, carbon dioxide, ammonia and hydrogen sulphide. However, attempts to link development of desirable Cheddar cheese flavour to a specific compound or a group of related compounds have not met with uniform success (Dacre, 1953a, 1953b; Bassett and Harper, 1958).

Kristoffersen, Gould and Harper (1959) reported on a study to establish more clearly the factors causing lack of uniformity in flavour production in Cheddar cheese. In addition to the chemical analyses for hydrogen sulphide, ammonia, free fatty acids and free amino acids, the moisture and salt contents and pH were determined. The analyses showed that moisture, salt and pH values were within the ranges usually encountered in Cheddar cheese. Generally these values displayed no relationship to quality although the pH of certain of the C grade (third grade) and undergrade cheese was somewhat high for the age of the cheese. The following average figures were obtained on 25 cheese for the moisture and salt contents and pH values of the 4 grades:

Grade	Moisture, %	Salt, %	pH
A	36.5	1.66	5.33
B	36.5	1.65	5.35
C	37.4	1.46	5.36
"Undergrade"	37.0	1.67	5.35

The results of the chemical analyses obtained by these workers indicate the great complexity of the Cheddar cheese system. The wide variations in products resulting from ripening indicated widely different fermentation processes, some of which seemed to yield to the same basic cheese quality. Kristoffersen et al. (1959) stated that "the key to quality may not be large concentrations in all products, but rather formation of particular important flavour yielding components which may act in unison to yield the most desirable results".

Raadsveld and Mulder (1949) studied the influence of pH on the maturing of cheese. Two series of cheese of different pH values prepared from the same raw milk were examined. The cheese were analysed for moisture, salt and pH and the rheological properties of the cheese were also examined. Although the cheese had been immersed in brine for the same time, the salt content of the more acid cheese was always considerably higher than that of the less acid cheese. They concluded that the pH and the salt content exercise considerable influence on the rheological properties of cheese. The results of an organoleptic test for flavour showed clearly that the pH of the cheese influenced the development of flavour.

Pimblett (1962) carried out experiments based on a standard method of Cheddar cheesemaking derived from normal factory production methods, but set to a fixed time schedule. The cheddaring time was varied from 1 to 3 h and these variations in the length of the cheddaring period had little influence on the grading score but the short cheddaring time gave slightly higher moistures and correspondingly higher yields. Little attention was paid to actual acidity at milling, but it was found that the milling acidity did not directly affect the quality of the final product. Milling acidities varied from 0.5 to 1.1% lactic acid. The author stated that the curd could be milled at almost any stage during cheddaring without apparent influence on the quality of the cheese at grading.

Baron (1947) made a study of the measurement and control of some of the physical factors which affect the body of the maturing cheese. Rheological tests were made on the coagulum during the manufacturing process and also on the cheese during maturation. The time intervals between certain stages of the manufacturing process were not varied as was done in a later study (Baron, 1949). As a result of her study (Baron, 1947) she concluded that the milling acidity affected the properties of the mature cheese in that the higher the acidity the firmer the cheese as measured by the ball compressor instrument of Scott Blair and Coppen (1941). Baron (1947) also concluded that the time interval from the stage of settling the curds in the whey to the milling of the curd had some influence on the properties of the finished cheese and that the fat content of the milk had no definite effect on the properties of the cheese.

Czulak and Hammond (1956) studied the acid development and pH in the "short time" method of Cheddar cheese manufacture (Czulak _et al._ 1954). Czulak and Hammond (1956) stated that cheese having a high pH when pressing had been completed tended to develop a "fruity" and unclean flavour. As a result of their observations on experimentally and commercially made cheese they further stated that although all cheese having a high pH when it was removed from the press would not necessarily develop a "fruity" or unclean flavour a cheese having a pH value greater than 5.3 at this stage of manufacture almost invariably gave these defects. Czulak and Hammond (1956) suggested that the effect of pH was indirect and that it conditioned some other factor, probably the bacterial flora derived from the milk. The pH of cheese when removed from the press made by the traditional method was in the range 4.9 to 5.0 as compared with 5.1 to 5.3 with the "short time" method. After 4 months, the former cheese had a bitter flavour while the latter had a clean mild flavour. The authors modified the procedure of the "short time" method to ensure a satisfactory pH at the more critical stages of the manufacturing process. They accepted the experimental evidence of Dolby (1941) that the acidity at running of the whey influenced to a considerable degree the pH of the cheese but Czulak and Hammond (1956) stressed that the acidity at the time of removing the whey had a practical meaning only if it was expressed in terms of an increase as compared with the acidity at the time of cutting the coagulated curd.

Budd and Chapman (1960) determined the pH of the whey at time of pressing from cheese cheddared by a continuous method and also by the traditional method. The pH of whey from the former cheese varied from 4.82 to 5.04 pH while that of the latter varied from 4.84 to 5.02 pH. The corresponding titratable acidities ranged from 0.55 to 0.69% and 0.53 to 0.68% lactic acid. The cheese were graded at 4 to 6 weeks old and both were accepted as good quality Cheddar cheese. The method for pH determination was not stated, but it was thought (Budd and Chapman, 1960) that a pH of less than 5.0 when the cheese was removed from the press would give rise to acid defects during maturation and storage. As a result of previous findings (Scott Blair, Coppen and Dearden, 1941), Scott Blair, Coppen and Dearden (1942) studied the effect of varying the point when the curd was allowed to settle in the whey and the rate of scald on the physical properties and general quality of cheese made from milk of varying titratable acidities. The titratable acidity at the time of adding the rennet to the milk was varied from 0.14 to 0.17% lactic acid and the titratable acidity when the curd was settled in the whey varied from 0.09 to 0.18% lactic acid. The mature cheese were subjected to various chemical and physical tests. It is significant that an attempt was made to determine the pH of the cheese but because the results were unsatisfactory they were not included. The acidity when the curd was settled in the whey was found to be as important as the rate of scald but that far more properties of the cheese were governed by the former than by the latter. The acidity at the time the curd was settled was closely correlated with firmness and moisture content.

Feagan and Dawson (1960) made attempts to manufacture Cheddar cheese by the rapid method of Whitehead and Harkness (1959) but little success was obtained until the starter inoculum was increased to 4%. Cheese was also made by the orthodox method and it was found that similar pH values were obtained for the normal and rapid schedules at 3 weeks and 3 months, but there was a higher moisture content, poorer flavour and considerably more openness in the cheese made by the rapid method. Typical pH values at 3 weeks were 5.29, 5.32 and at 3 months 5.10, 5.13. This seems to indicate that the pH value of a cheese cannot be related to its quality.

Making Cheddar cheese employing high scalding temperatures with commercial starters was attempted by Dawson and Feagan (1960a). They found that such cheese had an open texture which was considered due to the fermentation of residual sugar by non-starter organisms. The pH was determined on the milled curd and on the cheese at the end of pressing and at 3 weeks and 3 months old. The cheese made using high scalding temperatures were milled at an acidity ranging from 0.30 to 0.38% lactic acid, while cheese manufactured in an orthodox fashion had a milling acidity ranging from 0.37 to 0.76% lactic acid. The pH values obtained may be tabulated thus:

Time of sampling	Method of manufacture "High temperature"	"Orthodox"
pH: Milling of curd	5.47 - 5.81	5.31 - 5.70
After pressing	5.31 - 5.77	5.11 - 5.58
3 weeks	5.28 - 5.75	5.04 - 5.66
3 months	5.14 - 5.62	5.15 - 5.47

In most cheese made by the "high temperature" method, the pH when the cheese was removed from the press was higher than in the cheese made by the orthodox method. This was probably linked with incomplete fermentation which meant that the cheese would have a higher lactose content. This could promote the growth of the gas producing non-starter flora resulting finally in openness. However, it was observed that the pH at 3 weeks was not an important factor in the openness of the "high temperature" cheese. For the cheese manufactured in an orthodox fashion there was a significant correlation ($r = 0.435$, $P < 0.01$) between pH and the texture at 3 weeks old.

At 3 weeks, the "high temperature" cheese was of slightly better quality than the "orthodox" cheese. At 3 months, its quality was poorer. This result was in agreement with previous studies on "high temperature" cheese (Bevan, Dawson, Feagan, Howey and Park, 1959).

Although acid development is essential to good cheesemaking, too much acidity can adversely affect the flavour. This was shown by Franklin and Sharpe (1963). They scored cheese for flavour after 3 months and showed that the flavour tended to improve as the acidity of the cheese decreased within the range pH 5.35 to 4.95. The average pH of all cheese at 3 months ranged from 5.08 to 5.17.

Breene, Price and Ernstrom (1964) made Cheddar cheese by direct acidification of the cheese milk with commercial lactic acid and by a conventional procedure. They carried out the investigation to learn whether the properties and composition of Cheddar cheese could be reproduced by batch methods using shortened and simplified procedures that would meet the requirements for mechanisation. Data were collected on the inter-relationship of moisture, pH and lactose content of cheese made by the conventional procedure. The average pH obtained at milling of the curd for 6 lots manufactured by a conventional procedure was 5.28 and after 2 to 4 days the average pH was 5.02. The corresponding lactose contents were 1.08% and 0.25% respectively. They found little difference between lactose levels at 1 to 4 days old in acceptable and acid lots of cheese. A definite relationship was established, between pH and moisture contents after 4 days. In lots where the cheese had a pH at 4 days of 5.1 the moisture content was lower at the milling stage and at 4 days than it was in lots which were more acid. A higher than normal level of lactose in the curd when it was placed in moulds did not appear to cause acid defects when moisture was properly controlled.

Brown and Price (1934) showed that it is the hydrogen ion concentration (H^+) and not the titratable acidity which controls the contraction of curd. It was found that the best cheese were obtained when rennet was added to the milk at pH 6.47, the coagulum was cut at pH 6.51, the scalding took place at pH 6.30 to 6.35, the whey was removed from the vat at pH 6.12, the cheddaring process took place at pH 5.97, the whey coming from the cheese at pressing had a pH of 5.25 and when the pH changes during maturation were at a minimum and the value remained for the whole period greater than pH 5.0. They found that cheese having a pH of 5.05 to 5.20 after 3 days did not show acid defects at any later date.

Spicer and Burgwald (1935) studied the pH of young cheese with a view too the prediction of acid development in storage and found that taste and feel would only predict 65% of those cheese developing over acidity. They found that the acidity developed in storage was related to the acidity at milling. These authors made pH determinations at 3 to 10 days after making and found that if the pH were 5.07 or greater no acid developed in storage. However, if the pH values were less than 5.07 the cheese became acid.

As the minerals in the cheese contribute largely to its buffering power, they must play an important part in fixing the pH of the cheese. A study of acidity in cheese should therefore take into account the effect of variations in mineral contents. McDowall and Dolby (1935a) stated that by increasing the acidity of the milk prior to the addition of rennet, though it did not noticeably affect the acidities in the later stages of the process, definitely caused a sufficient loss of minerals in the early wheys to give a markedly lower calcium content in the cheese. This was in agreement with the results of McCammon _et al_. (1933). The effect of the higher acidity at the time of adding the rennet on the extent of calcium loss may be, in part at any rate, the explanation of the necessity for an adequate ripening period before the addition of rennet. The effect of excessive acidity during the making process in causing a rapid breakdown of the cheese and frequently of imparting a bitterness to the cheese, may also be related to the resultant changes in mineral content.

Dolby _et al_. (1937) found that the acidity of whey when it was removed from the vat influenced the mineral content and the body of cheese. The acidity of cheese was dependent on the acidity of the whey when it was removed and the amount of lactose remaining in the curd. The measurements of pH and titratable acidity indicated that the cheese made at a high running acidity were the most acid and those made at a low running acidity the least acid. Grading results on the cheeses at 14 days and at maturity supported these conclusions. The cheese made when the whey was removed from the vat at a high acidity were definitely over acid while those made when the whey was removed from the vat at a low acidity were "sweet". The lactose content of the curd at the end of the making process was a further factor affecting the acidity of the mature cheese. When lactose was added to the cheese curd after milling it resulted in a more acid cheese at maturity, although there was some unchanged lactose present after 4 months.

The presence of coliform organisms in Cheddar cheese and their role in the blowing of cheese of this type have been studied by Crossley (1942, 1946), Yale and Marquardt (1943)and Yale (1943) all of whom came to the conclusion that the presence of coliform organisms did not necessarily lead to blowing of the cheese. Other factors, such as numbers of organisms and the consistency of the curd, were involved. Yale (1943) found that a high acidity in the vats favoured the starter at the expense of the coliform organisms, but it seemed that a high temperature favoured the latter. In practice, the use of active starters and as low a scalding temperature as possible should help to control gas production in Cheddar cheese. Too high an acidity, however, although suppressing coliform organisms, may cause other faults.

Although cheese has very rarely been responsible for the outbreak of food poisoning, the acidity developed during storage has seldom been considered from a public health point of view. Fabian (1947) studied cheese and its relation to disease. In general, it would seem that cheese having a pH about 5.0 will not sustain pathogenic bacteria for a time equal to that of the normal storage time for adequate maturing, i.e. 60 to 90 days.

Hynkla, Hood and Gibson (1947) studied the influence of acidity on the development of lipolytic flavour defects in Cheddar cheese. They found that the activity of milk lipase may be inhibited or its activity confined to the glycerides of non-volatile fatty acids by contact with acid over a period of time. Cheese prepared under conditions where acid was allowed to exert its effect on milk lipase, scored slightly higher than cheese prepared under conditions where the inactivation of milk lipase did not occur. They also found that homogenisation increased the sensitivity of milk lipase to acid conditions.

The relationship of pH to some curd characteristics of milk was studied by Storrs (1941). He found that the curd surface area of any milk appeared to be lowest at the highest pH level at which complete coagulation will first appear, while at any pH below that required for complete coagulation the curd surface area increased as the pH was lowered. Storrs (1941) stated that as the body of the final cheese product depended on the quality of the curd the pH at which the coagulation takes place is of importance.

In the dairying industry as in other industries new methods offering more accurate and reliable means of measuring the quality of the manufactured product are constantly being sought. Irvine (1944) made an effort to relate the quality of cheese to its pH. As the titratable acidity correlated with the quality of the cheese he compared titratable acidities with pH measurements. He found that from the time the starter culture is added to the milk until the curd is salted they were closely correlated. Although there was agreement between cheese quality and pH, Irvine (1944) considered it best that the pH reading should supplement the titratable acidity rather than supplant it.

One of the desirable characteristics of a starter is that it should produce acid at a uniform rate. If acid production is proceeding at a fast rate, modification in the cheesemaking process must be made to enable curd firmness to overtake acidity. Dolby(1941) found that variations in acidity of the whey when it was removed from the vat had a marked influence on subsequent working and cheese quality and that removing the whey from the vat at pH 6.03 instead of the normal pH of 5.68 increased the making time by 1 h. The effect of stirring the curd after the whey was removed reduced the moisture content by 2% and resulted in a higher pH of the stored cheese. Salting the curd at a low pH resulted in a harsh mealy body and loss of flavour.

Work has been carried out (Annual report, 1962) on the influence of acidity on cheese quality. It was found that the average pH values of cheese from various pairs were similar which suggested that the differences in flavour were not due to the amount of acidity produced although the rate of acid production might have been important. Statistical examination of the average flavour scores and pH values of 66 cheese at 3 months showed that there was a positive relationship between pH and flavour; the flavour tended to improve as the pH increased within the range 4.95 to 5.35. There was no obvious correlation between flavour and salt content of the cheese.

The composition, pH and colour of Cheddar cheese made in Ontario province of Canada was investigated by Irvine (1951). This worker determined the fat, moisture and salt contents, pH values and colour intensities of 386 samples of Cheddar cheese. The average moisture and fat contents were 35.15% and 33.36% respectively, there being little seasonal or other variations. The colour intensity which was measured on a Lovibond tintometer did not vary appreciably. The pH ranged from 4.9 to 5.5 with no regional or seasonal variation. The best quality cheese had a salt content of about 1.6% and a pH 5.05 to 5.20. "Acid" cheese had a lower pH and often a pale colour, high moisture and low fat content. "Fruity" and "open" cheese had a higher pH. "Unclean" defects were all found in cheese of low salt content .

Yamamoto, Asao and Chikuma (1953) and Yamamoto, Chikuma and Yoshino (1954) studied several aspects of the manufacture of skim milk Cheddar cheese. One experiment was related to the effect of the temperature of scalding curd upon the water content and quality of semi-skim milk Cheddar cheese. When whey was removed from the vat at a low titratable acidity a scalding temperature of 30°C gave maximum water retention but a crumbly acid cheese. There was little difference between 33°C and 36°C scalding temperatures regarding water retention or texture but the higher temperature gave a higher pH and was therefore preferrred. With a scalding temperature of 33°C, the use of 2 or 4% starter did not affect cheese quality. Another experiment was related to the effect of the acidity at milling and the amount of starter on the quality of cheese. Milling acidities of 0.3, 0.4 and 0.5% lactic acid were compared in the manufacture of semi-skim milk Cheddar cheese. A good body, flavour, texture and adequate water content were obtained using a milling acidity of 0.4% lactic acid. Variations in starter culture quantity had little or no effect on cheese quality.

Cheddar cheese is not manufactured from separated milk in Scotland but the foregoing experiments are mentioned in order to indicate the comprehensive studies made by Yamamoto and co-workers on whole and skim milk Cheddar cheese.

During the years 1955 to 1958, Yamamoto, Chikuma and Yoshino (1955a, 1955b) and Yamamoto, Takahashi and Yoshino (1956, 1958) carried out 4 particularly important experiments on,

1 the acidity regulating method for making Cheddar cheese

2 the effect of the acidities at setting and dipping on the quality of cheese

3 the effects of the acidity at milling and the amount of starter on the acidity of cheese

4 manufacturing cheese by the acidity regulating method.

A resume of these experiments is as follows:

1 Cheddar cheese was made in which the timing of certain operations was determined by acidity. Rennet was added to milk after the addition of starter and enough hydrochloric acid to bring the acidity to 0.2% lactic acid equivalent; whey was drained from the cut curd when its acidity had increased by 0.035% lactic acid from the time the coagulum was cut; the curd was milled when the whey acidity reached 0.45% lactic acid. The time between renneting and milling the curd was about $4\frac{3}{4}$ h. The method was compared, using both raw and pasteurised milk with one developed by the U.S. Bureau of Dairy Industries. The former used more starter and less rennet, the yeild of cheese was greater and its quality higher, and the composition of the cheese were similar.

2 Renneting at an acidity of 0.18% lactic acid instead of 0.20% lactic acid in Cheddar cheesemaking did not affect the composition or quality of the cheese. Renneting at 0.22% titratable acidity made the flavour and body of the cheese slightly inferior. The flavour was better when the acidity of the whey was allowed to increase by 0.03 or 0.04% lactic acid after cutting the coagulum, then when it only increased 0.02% lactic acid.

3 Milling acidities of 0.35%, 0.45% and 0.55% lactic acid were compared in the manufacture of Cheddar cheese with regard to the effects on the moisture content of the curd and flavour and quality of the cheese. A low moisture content corresponded to a high acidity and vice versa. No significant differences in quality of the cheese were observed when the curd was milled at acidities of 0.45% and 0.55% lactic acid. Further trials showed that the manufacturing time was influenced, but cheese quality was not, by variation in the amount of starter culture used.

4 Cheddar cheese was manufactured by the acidity regulating method (1). Titratable acidity and pH values of milk were 0.20% lactic acid and 6.39 at the time of rennet addition; values for whey were 0.134% lactic acid and pH 6.36 when the coagulum was cut; 0.169% lactic acid and pH 6.08 when the curd was pitched or settled and 0.45% lactic acid and pH 5.57 when the curd was milled. The time for renneting to milling of the curd was approximately 4½ h. The average moisture content was 37.23% withaa pH of 5.31. The ripe cheese was of uniformly good quality and flavour, texture and body scores averaged 93%, 91% and 95% respectively.

Section two

Materials and methods

Part I

The acidity of milk and cheese

The titratable acidity test

pH

The titratable acidity of milk

Methods for the pH determination of cheese

Methods for the determination of the titratable acidity of cheese

Titratable acidity of cheese

THE ACIDITY OF MILK AND CHEESE

Before the introduction of the acidimeter by Lloyd (1899) cheesemakers had no conception of the measurement of acidity, although for centuries they had unconsciously made use of several properties which in reality afforded an indirect measure of acidity. Methods for measuring acidity in cheese-making may be classified as follows (Davis and Thiel, 1940).

1 Indirect and empirical

(a) "lactic acid"aroma

(b) rennet test

(c) hot iron test

2 Titratable acidity

3 pH or hydrogen ion concentration

A Colorimetric

(a) Wulff tester

(b) dilution method

B Potentiometric

(a) quinhydrone electrode

(b) glass electrode

1 Indirect and empirical

(a) The accuracy of measurement of acidity of milk or whey by its aroma is entirely dependent on the human element and is as a consequence considered inaccurate and unreliable.

(b) It was in the year 1895 that Harris conceived the idea of the rennet test. Monrad proposed a new set of apparatus for the test (Harris used tea-cups and teaspoons as measures) which left less chance for error. The test involved the addition of rennet to a known quantity of milk with the noting of the time required for curdling. The Marschall form of the rennet test (Decker, 1905) consisted of draining milk, to which was already added some rennet solution, through a narrow orifice at the bottom of a graduated vessel. When the milk had thickened sufficiently, the milk ceased to flow and the graduation mark to which it had flowed was noted. These rennet tests were also used to determine the strengths of various rennet solutions. As the coagulation of milk is greatly dependent on temperature and salt balance, the rennet test is limited in its application.

(c) The use of the hot iron test as a means of determining the point at which to mill Cheddar cheese has decreased over a number of years, though many older cheesemakers still consider it superior to the titratable acidity as a test at this stage of the process. Cheese curd begins to show elasticity as soon as acid is produced in appreciable amounts. This property becomes more and more noticeable as the acidity increases until finally the curd can be stretched considerably or, if heated, it can be drawn out in long strings. van Slyke (1928) attributed this "plastic and ductile" quality of cheese curd to the presence of monocalcium paracaseinate. There are many conditions which can lead to inaccuracies when using the hot iron test. To mention but two, the temperature of the iron is not strictly controlled and the application of a constant pressure on the cheese against the hot iron is seldom attained. By increasing or lowering the pressure, strings of curd of varying lengths may be drawn. These possible sources of error greatly reduce the value of the test. However, it has the advantage over the titratable acidity at milling time that it is more easily carried out as whey is sometimes obtained at this time only with difficulty.

2 Titratable acidity

It is well known that the titratable acidity of fresh normal milk may vary through wide limits (Sharpe and McInerney, 1926) due to the influence of a number of factors (van Slyke and Baker, 1918, 1919; Rice and Markley, 1924). The titratable acidity test is commonly used to measure acidity during the cheesemaking process. Optimum levels of titratable acidity in the starter, milk or whey have been established for nearly every operation in the manufacture of many varieties of cheese but defective cheese is sometimes made even though these schedules of optimum titratable acidities have been carefully observed (Brown and Price, 1934). Measurements of titratable acidity during the making process actually indicate, that the maximum acidities, which may be safely attained in the manufacture of cheese from milk with high solids content, may be unsatisfactory if applied to milk which is low in solids-not-fat. The limitations of the titratable acidity test are well known and results are only comparable when the procedure is exactly defined.

The foregoing tests which indicate, but do not measure acidity accurately, attain their greatest value when used every day by the same operator on the same milk supply.[1]

3 pH or Hydrogen ion concentration

Ordinary titration against a standard alkali solution measures the percentage acid in a solution, while hydrogen ion concentration, or pH, measures the intensity of activity of the acid. The activity of the acid depends on the extent to which dissociation has taken place as well as on the concentration of the acid. The determination of the pH value of a solution gives a better measurement of acidity for many purposes than titration against standard alkali.

The importance of pH as a method of measuring the acidity of biological fluids has been long recognised, and its application in dairy work has extended greatly in recent years. The chief methods in use for the determination of pH are (A) colorimetric, and (B) electrometric.

(A) Colorimetric

In the colorimetric method, an indicator, which gives a colour varying with hydrogen ion concentration, is added to the solution to be tested and the colour developed is compared with that developed in a "buffer" solution of known pH when the same amount of the same indicator is added.

(a) Wulff tester

The Wulff tester has been investigated by Aschaffenburg (1938) who has shown that an accuracy of about ± 0.1 pH unit can be obtained. The principle of the tester, viz. to insert strips of a water diffusible membrane containing indicators into the liquid to be tested and to compare the colour of the strips with standard colours mounted on a sliding scale, makes the test particularly suitable for determinations in which turbidity and colour are liable to interfere with methods based on the direct comparison of liquids, The technique is simple and a determination can be completed in 2 to 3 min. However, Aschaffenburg (1938) found the test unreliable for milk by comparison with a potentiometric method using a glass electrode. In addition, the tester was unsuitable for use during the initial stages of cheesemaking when the pH changes are small.

(b) Colorimetric dilution method

The turbidity of milk and whey prevents the use of comparator methods in the ordinary way. Sharpe & McInerney (1926) suggested the dilution of milk or whey before using a comparator. The dilution effect on the pH values of butter serum was investigated by Hunziker, Cordes and Nissen (1931) and McDowall and McDowell (1937) used the colorimetric dilution method for cream plasma. Davis and Thiel (1940) adopted the dilution method as the most practicable method of sufficient accuracy to justify its use in cheese-making. The method described involved dilution of the milk or whey 20 times, the addition of indicator, and the determination of pH in a comparator. Using a quinhydrone electrode as a standard, they found a mean error of about 0.05. This method, although simple, rapid and cheap is subject both to chemical and physical errors. The difficulty in assessing a correction factor for dilution, the choice of a suitable indicator and the problem of matching slightly differing coloured test tubes militate against its use where accurate control is required.

(B) Potentiometric determination of pH

When the limitations of the titratable acidity test due to variations in buffer value became known, a search was made for methods to estimate the true acidity of milk or whey. The use of colorimetric methods became widespread, but White (1946) and Davis and Thiel (1940) have shown that such methods do not give reliable pH values. The difficulty in selecting suitable electrodes was a prime factor in delaying the introduction of electrometric methods for pH determination. That the electrode assembly should be durable, easy to maintain and to manipulate is an obvious necessity. Sammis and Santschi (1924) used an electrometric method to serve as a comparison for the colorimetric determination of pH and considered the latter method satisfactory for cheese factory purposes. Watson (1929) while working with Swiss cheese, used the quinhydrone electrode. The two electrodes used for the whey and plug samples of cheese were (A) the Cullen and Biilmann capillary electrode and (B) the Knudsen cheese electrode. The method using the quinhydrone electrode for following changes of pH in Swiss cheese was previously described by Watson (1928). Brown and Price (1934) determined the hydrogen ion concentration of milk and whey with the Biilmann type of quinhydrone electrode. The electrode was adopted because only a small sample is required and the reading may be taken immediately.

These advantages are highly desirable in as much as the amount of material available for testing is limited at times during the process and because the acidity bhanges so rapidly that any delay in obtaining the measurement would introduce errors. The above writers adopted for use the quinhydrone electrode described and used by Watson (1927). A Leeds-Northrup, type K, potentiometer and a 0.1 normal calomel electrode were used by Brown and Price (1934). The hydrogen electrode was also used to measure the pH of the cheese and they concluded that the hydrogen electrode was entirely unsuitable due to the necessary dilution of the cheese which had a variable effect on the pH.

While studying the buffer capacity of wheys Dolby and McDowall (1935) determined the pH with a Cole direct-reading potentiometer using a quinhydrone electrode in conjunction with a quinhydrone reference cell. Parks and Barnes (1935) concluded from their results using different electrodes that the hydrogen ion concentration of dairy products may be determined by the glass, quinhydrone or hydrogen electrodes with an accuracy that is within experimental error. With the use of the antimony electrode, the results were from 0.307 to 0.646 pH units higher than those obtained with the other electrodes. They emphasised the effect of citric acid, lactic acid and lactose upon the antimony electrode and put this effect forward as a possible reason for the high values obtained with that electrode. Doyle (1938) used a quinhydrone electrode to prove its suitability for the determination of the pH of both cheese and aqueous extracts of cheese. He showed that results obtained by the colorimetric method were in very close agreement with the potentiometric values. Sanders (1938) demonstrated a modified quinhydrone electrode, sample tube and calomel half cell which were developed chiefly for use on dairy products such as milk, whey and cheese.

The electrode was a plain gold-plated platinum wire and the conventional stopcock in the calomel half cell was replaced by a sealed-in platinum wire. Dolby, McDowall and Riddet (1940) determined the pH value of Cheddar cheese using a quinhydrone electrode. Their method corresponded to the British Standards Institution method (1938) except that 1 ml of water was added to 5 g of cheese in forming the paste. Johnston and Doan (1943) introduced a direct reading pH meter. The electrode assembly consisted of a sealed and internally shielded glass electrode and a calomel electrode. The Beckman instrument was checked against a potentiometer employing a quinhydrone electrode. They found that the quinhydrone electrode gave slightly lower readings. Davis and Scott Blair (1940) while suggesting that a colorimetric method for the determination of pH should be introduced into cheese factories, pointed out that electrometric methods, based on the glass or quinhydrone electrodes, were preferable. They also found that the glass electrode was quicker and more convenient than the quinhydrone, but that the former normally required about 20 ml of whey, which is difficult to procure during cheddaring, and that the quinhydrone could be used with the curd itself - an important advantage.

The suitability of different electrodes for pH measurements in dairy industry applications was investigated by Rehak (1954). Three different electrodes were investigated for pH measurement of milk, starter cultures and cheese. He found that glass and quinhydrone electrodes gave similar results, but the antimony electrode generally gave considerably higher (by pH 0.15 to 0.25) values. Rehak (1954) considered that the quinhydrone electrode was the most suitable for general use in the dairy industry. For continuous pH measurements in cheesemaking, however, he recommended antimony electrodes. In the same year Meyer and Michels (1954) studied pH of cheese using a glass electrode, a quinhydrone electrode and a colormetric method. They considered that the most satisfactory method for the direct measurement of the pH in cheese was by the glass electrode. Olson _et al._ (1958) determined the pH of processed cheese by means of a Leeds-Northrup portable potentiometer, saturated calomel half-cell, and gold electrode - similar to the method of van Slyke and Price (1949). Morris, Jeseski, Combs and Kuramoto, (1963) determined pH of the Blue cheese using a Beckman Model N pH meter with a glass electrode and a calomel electrode.

With the advent of automation and its application in other fields, Kosikowski (1963) introduced the recording pH meter to the dairy industry, which eliminated the necessity of continuous titratable acidity determinations being made. Once the recording line is set at a given temperature to that of a known buffer the instrument will record pH consistently for days. One (combined) electrode is used. Later on Kosikowski (1964) effected design changes of the recording meter the most important being the doubling of the sensitivity of the instrument.

THE TITRATABLE ACIDITY OF MILK

The titratable acidity test

The titratable acidity test was introduced by Lloyd (1899) in the course of his investigations in cheesemaking in the south-western districts of England during the years 1892 to 1898. Although the titratable acidity test is extensively used by cheesemakers and in creameries and dairies to check the freshness of milk received from the producer, it is one of the least standard and most variable of tests which may be applied to milk. Since it is one of the simplest tests to perform, too often its performance is entrusted to the most unskilled of workers with no thought for the technical complications underlying the test. It is only when one compares results with those obtained by other workers that these complications of the test come to light. Until the inherent difficulties and complications of the test are more generally recognised, results will continue to differ between workers. A standard method (British Standards Institution, 1963a) does, however, exist for the titratable adidity test and the adherence to this procedure is of prime importance in obtaining reliable results.

FACTORS AFFECTING THE ACCURACY OF THE TITRATABLE ACIDITY TEST

The figure obtained for the acidity of milk depends on several factors e.g. the buffers present, interaction of salts and interference by proteins. As well as depending on composition, buffer value and the effect of mastitis, the acidity figure will also be affected by the alkali used, or by diluting the milk with water (Barkworth, 1940). If the time of titration is prolonged, then carbon dioxide may be absorbed from the air and affect the phosphate system. Two of the most important factors affecting the accuracy of the titratable acidity test are, amount of indicator added to the milk and the detection of the colour at the end point. It has been said that there is a correlation between fat content and titratable acidity (Sharpe, 1934) but this may be due to the higher colouring which is given to milk as the fat content increases.

<u>Dilution of sample with water</u>

That the addition of water to a sample of milk lowers the titratable acidity has been shown by Rice and Markley (1924). Dilution with an equal volume of water caused an average decrease of 0.02% and dilution with 9 volumes of water an average decrease of 0.06%. The greater part of the dilution effect is attributed to a decrease in the amount of tri-calcium phosphate precipitated during the titration. As one would expect, a lower pH is observed at the phenolphthalein end point in the diluted milk. As far as is known the dilution of the milk sample with water is not a common error but nevertheless it has to be guarded against.

<u>Amount of indicator</u>

The indicator used in the titratable acidity test is a 0.5% (w/v) solution of phenolphthalein in alcohol.

Probably no one factor has a greater effect on the result of the titratable acidity test than the amount of indicator used. Any quantity from 3 drops to 1 ml is generally used. It would be expected that by the addition of a constant quantity of indicator results obtained within each laboratory will be comparable. However, problemes arise when results are compared with those of a different laboratory. This point was well illustrated in 1964 during a survey by Mulcahy (1966) of testing procedures used in Ireland. An attempt was made to compare results of titratable acidity tests but due to variations in concentration of indicator used from creamery to creamery this was impossible.

In order to demonstrate the effect of different quantities of indicator, the following experiment was made by the author. Different quantities - 0.1 to 5 ml - of an 0.5% (W/v) solution of phenolphthalein (3 drops are equal to 0.1 ml using a 1 ml graduated pipette) were added to 10 ml portions of the same milk sample and titrated to a faint pink tint using N/9 sodium hydroxide. The pH (hydrogen ion concentration) of each titrated mixture was then obtained. The results are recorded in Table 1 and they show quite clearly the effect of using different amounts of indicator. In this case, for the same sample of milk, titratable acidities from 0.144% lactic acid equivalent to 0.180% lactic acid equivalent were obtained. Similar results have been found by Davis (1961).

The use by cheesemakers of inaccurate methods of measuring amounts of indicator gives rise to some concern. It might be suggested that individual ability to detect the end point is the greatest source of error, but it is certain that differences in the amount of indicator used contribute to the unreliability of results of titratable acidity tests.

Table 1

The effect of different quantities of phenolphthalein on the titratable acidity of milk

Phenolphthalein, ml	Titratable acidity, % lactic acid	pH
0.1	0.180	8.59
0.2	0.171	8.50
0.3	0.170	8.49
0.4	0.164	8.40
0.5	0.164	8.41
0.6	0.163	8.36
0.7	0.161	8.36
0.8	0.160	8.32
0.9	0.161	8.34
1.0	0.157	8.33
2.0	0.149	8.14
3.0	0.144	8.12
4.0	0.148	8.16
5.0	0.152	8.22

Colour at the end point of the titration

Most textbooks suggest titrating to a faint pink colour which persists for 15 seconds. Several workers have proposed the use of colour standards. Ling (1937) suggested an 0.2% aqueous solution of rosaniline hydrochloride; Richmond (1920) suggested 1 drop of 0.01% rosaniline acetate in 96% alcohol; and McDowall (1936) recommended the acetate or the hydrochloride. Other workers claim that equally good results can be obtained by comparing the colour at the end point against some of the untitrated milk in a similar shaped vessel and stopping the titration as soon as a distinct pink shade is seen.

It may be seen therefore that whether the titratable acidity test is used in the creamery as a rejection test or in the cheesemaking room to follow the course of acid production, great care must be exercised, more especially when an effort is being made to correlate the quality of a Cheddar cheese with a titratable acidity value at certain stages in the manufacturing process.

Comparison of the different methods for the determination of lactic acid (equivalent) in milk

The following methods may be used to measure the acidity of milk,

1 SOXHLET-HENKEL (SH^{o}) - degrees

ml of N/4 sodium hydroxide/100 ml of milk using 2 ml of 2% alcoholic solution of phenolphthalein indicator

2 THORNER (TH^{o}) - degrees

number of 1/10 ml N/10 sodium hydroxide/10 ml of milk using 5 drops of 5% alcoholic solution of phenolphthalein indicator.

3 DORNIC (D^{o}) - degrees

number of 1/10 ml N/9 sodium hydroxide/10 ml of milk using 1 ml 0.5% alcoholic solution of phenolphthalein indicator.

The following table may be used for conversion purposes.

Table 2

Comparison of the various methods for measurement of milk acidity

SH°	TH°	D°	Lactic acid, %
1	2.5	2.25	0.022
3	7.5	6.75	0.067
5	12.5	11.25	0.112
7	17.5	15.75	0.157
9	22.5	20.25	0.202
11	27.5	24.75	0.247
13	32.5	29.25	0.292
15	37.5	33.75	0.337
17	42.5	38.25	0.382
19	47.5	42.75	0.427
21	52.5	47.25	0.472
23	57.5	51.75	0.517
25	62.5	56.25	0.562
27	67.5	60.75	0.607
29	72.5	65.25	0.652
31	77.5	69.75	0.697
33	82.5	74.25	0.742
36	87.5	78.75	0.787

METHODS FOR THE DETERMINATION OF pH OF CHEESE

Before the different techniques of pH determination are discussed, it is well to consider the British Standard Institution methods (1938) and (1963b).

In 1938, the hydrogen ion concentration was determined potentiometrically, using the quinhydrone technique. No addition of water to the cheese was necessary to form a "paste" of the desired consistency. The procedure required that 5 g of cheese and 0.25 g of quinhydrone were ground to a fine paste in a mortar. A gold electrode was placed in this paste and formed one half-cell which was coupled with a standard half-cell such as a standard quinhydrone half-cell. From the electric potential of this cell the pH of the cheese could be calculated from a given formula. The British Standard Institution method (1963b) is as follows:

"The pH of the cheese is determined potentiometrically with a glass electrode, with a saturated calomel or other suitable reference standard half-cell. If a thick, high resistance glass electrode is used, and the prepared sample of cheese is normally soft, press the electrode directly into the cheese. If sample is unusually hard, or if a fragile low-resistance glass electrode is used, soften the cheese by mixing it with the necessary minimum quantity of distilled water to permit insertion of the electrode".

In this method, the interpretation of "the minimum quantity of distilled water" may give results which are not comparable. Døvle (1938) determined the pH of cheese with varying amounts of water. The pH values of the water-extracts (cheese : water = 1 : 1½) were consistently higher than those found in the cheese mass. Some years later Hackenschmied and Meier (1949) suggested a simple method for determination of pH in cheese. A calomel electrode was inserted in a 2 to 3 cm deep hole situated in the centre of the cheese surface and a glass electrode was placed in an oblique hole bored along the cross axes and 6 cm deep. The holes were of such a diameter as to secure a good contact of the sides with the glass electrode.

Raadsveld (1956) stated that measurements of pH are more easily made on cheese-water mixtures than on the dry cheese. Comparative measurements on 10 cheese of various types and age, alone and in mixture with 20 to 167% water showed no marked variation in pH values unless the percentage of added water was high. The same author was of the opinion that for all practical purposes the pH of cheese could be adequately measured if the cheese was mixed with small quantities (c. 50%) of water. Davies (1964) in an effort to standardise pH measurement of cheese carried out numerous experiments on the effect of varying quantities of water on the pH of the sample. He covered the range from no added water to two parts of water to one of cheese. He found that addition of water caused a fall in pH with small amounts followed by a rise as the amount of water was increased. Finally, he suggested that 10 ml water added to 10 g cheese was sufficient to form a paste thereby eliminating possible errors due to improper contact between electrodes and cheese. Brindley (1954) on experiments on the surface microflora of Stilton cheese determined the pH by taking 1 g cheese and grinding it with 10 ml of cooled, boiled, glass distilled water and using this as the mixture. However, Meyer and Michels (1954) considered that direct measurement of the pH in cheese by the glass electrode the most satisfactory; it gave results 0.15 to 0.40 units lower than measurement in a 1:3 solution of cheese in water.

Brown and Price (1934) used, as well as the quinhydrone electrode, the hydrogen electrode in attempts to measure the pH of the cheese. Samples of the cheese were ground and diluted with distilled water in the proportions of 1 part of cheese to 2, 5, 10 and 20 parts of water. They found that the degree of dilution had a distinct influence on the pH value; the greater the dilution, the higher was the pH. The change in pH caused by dilution is variable and apparently cannot be predicted from a single observation of an unknown sample of cheese. Schulz (1930) and Pasztor (1930) observed the same influence of dilution upon the pH of cheese. Schulz (1930) found no change in pH with the quinhydrone electrode as long as the dilution was kept below the ratio of 1:1. Pasztor (1930) reported an increase of approximately 0.50 pH between a dilution of 1:1 and 1:24. Morris et al. (1963) determined the pH on 40 g of cheese macerated with 20 g distilled water. Although it must be emphasised that the quantity of water used to make the cheese paste is a factor in correct measurement of pH, one must not neglect the effect of temperature on the measurement of pH of dairy products. Dixon (1963) found that over the normal range of room temperatures 10 to 30°C, differences as great as 0.24 for butter and 0.14 for cheese were obtained. It is suggested that in pH determinations in dairy products, the temperature be specified and controlled within 1°C.

The variety of foregoing methods point out the necessity of standardising the method of pH determination in cheese because only then will results obtained be comparable.

METHODS FOR DETERMINING THE TITRATABLE ACIDITY OF CHEESE

The British Standard Institution method (1938) for the determination of titratable acidity in cheese is as follows:

"Two g of a well mixed sample of cheese are weighed into a small porcelain mortar (in the case of hard cheese) or a 250 ml conical flask (in the case of soft cheese). The sample of hard cheese is ground in the mortar to a fine paste with 10 ml of water and 20 ml water are then added and well mixed with the paste. Five drops of 0.5% phenolphthalein solution in 50% alcohol are added and the acidity determined by titrating with N/10 sodium hydroxide until a definite pink colour persists for 15 sec. In the case of soft cheese, 30 ml of distilled water are added to the cheese in the conical flask and warmed to 50^{o}C. After cooling to room temperature, 5 drops of phenolphthalein solution are added and the suspension titrated with N/10 sodium hydroxide as above".

A method suggested by the Association of Official Agricultural Chemists (1960) is that 20 g of cheese are taken and diluted with twice its volume of carbon dioxide-free water. Two ml of 1% phenolphthalein solution are added and N/10 sodium hydroxide is used to titrate the mixture to first persistent pink.

Some methods employ filtration, i.e. where the cheese-water mixture is filtered and aliquot portions of the filtrate titrated. Ling (1956) and Nicholls (1952) stated that 10 g of cheese after addition of water to 105 ml at 40^{o}C are shaken and filtered, and 25 ml of the filtrate titrated with N/10 sodium hydroxide using phenolphthalein as indicator.

Dolby et al. (1940) determined the acidity of cheese by two methods:
(1) The acidity of the water soluble extract ("soluble acidity") was estimated as follows:

12.5 g of cheese were triturated with water at 50°C and the mixture was transferred to a 250 ml measuring flask, sufficient water being added to bring the liquid to the base of the neck. After shaking 2 or 3 times during 10 min the flask was transferred to an incubator at 37°C and after 15 min the contents were made up to the mark. After a further 15 min the flask was removed from the incubator, the fat was drawn off by suction and the cheese suspension was filtered through a fluted filter paper (Whatman No.1). Fifty ml of the filtrate were titrated with N/10 sodium hydroxide using 1 ml of 1% phenolphthalein as indicator. This is a modification of the method of van Slyke and Bosworth (1907).

(2) The total titratable acidity of the cheese ("total acidity") was estimated by the British Standard Institution method (1938) in which 2 g cheese are titrated while being ground in a mortar.

The second method was found to give a much less definite end-point than the first. Further, in the second method, the colour of the cheese had a pronounced effect. Cheese coloured with annatto gave a higher titration than white cheese made under similar conditions. The use of a colour standard did not appear practicable. Comparisons had therefore to be limited to cheese containing the same amount of colouring matter. This, said the authors, constituted a serious disadvantage of the method.

But by the use of filtration, errors may also be introduced depending on how well the cheese and water are mixed and the fineness of the cheese particles. These facts were observed by Lloyd (1899). He estimated the acidity of the curd by at least 2 methods and found that the quantity of acid which appeared to be present in the curd depended very largely upon the way in which the method adopted for its estimation was carried out. The results by any process depended primarily upon the quantity of water with which the curd was diluted before estimating the acidity. This was shown by taking 2 g of finely minced curd and adding 25 ml water. The acidity obtained was 0.75% lactic acid while 2 g of the same finely minced curd with 100 ml added water showed only 0.65% lactic acid. A similar result was obtained when the curd was ground into a paste with water before the estimation of acidity.

To illustrate the effect of the fineness of the curd on the acidity Lloyd (1899) carried out three experiments with the same curd, 2 g being taken in each case. One portion was ground as finely as possible, the second not quite so finely, and the third roughly. The acidities obtained were 1.35, 1.15, and 1.00% respectively, which proved that the action of the sodium hydroxide depended on the fineness of the curd. Brown and Price (1934) made similar observations. They stated that the titratable acidity measurements were not so dependable as were measurements of pH because the very nature of the method of analysis makes the results too variable. The degree of dispersion of the protein material which can be attained during the preparation of the sample for extraction varies decidedly in individual cheese during the first few weeks of curing. Those samples of cheese, which show the greatest tendency to dissolve in the warm water, carry through the filter the greatest amounts of protein material. Brown and Price (1934) showed clearly the unsatisfactory relationship between the titratable acidity and pH measurements during the maturation of cheese.

THE TITRATABLE ACIDITY OF CHEESE

The extent and rate of acid development during the manufacture and maturation of Cheddar cheese will affect its final quality.

There are several methods for the determination of the titratable acidity of cheese all involving the titration with sodium hydroxide (NaOH) of a cheese-water mixture or the filtrate from a cheese-water mixture. Dolby *et al.* (1940) when using the British Standard Institution method (1938) for the determination of acidity of cheese had difficulty in determining the end point more especially when the cheese was coloured with annatto. As the amount of colouring matter added is not always constant, being dependent on the type of cheese made and the time of year, it is not possible to compare results of cheese acidity analyses. Lloyd (1899) pointed out that the quantity of acid which appears to be in the curd depends very largely upon the way in which the method adopted for its estimation was carried out. The result of any method depended primarily upon the quantity of water with which the curd is diluted before estimating the acidity. The conclusion arrived at by Lloyd (1899) was that the action of the sodium hydroxide depended on the fineness of the curd. A similar observation was made by Brown and Price (1934).

EXPERIMENTAL

The following three methods were used to determine the acidity of cheese.

1 Twenty g of sample were weighed in a suitable dish and diluted with 40 ml of distilled water. Two ml of phenolphthalein solution (1% w/v) in alcohol) were added and the mixture titrated with N/9 sodium hydroxide to a persistent pink tint. The number of ml of N/9 sodium hydroxide required divided by 20 equals % acid expressed as lactic acid.

2 Ten g of cheese after addition of water to 105 ml at 40°C were shaken and filtered through a Whatman No.40 filter paper and 25 ml of the filtrate were titrated with N/9 sodium hydroxide using 1 ml of a 0.5% (w/v) of phenolphthalein solution as indicator. The % lactic acid equivalent was calculated as follows,

% lactic acid = ml N/9 NaOH x 0.4

3 Two g of the cheese sample were weighed into a mortar and 10 ml of distilled water added. The mixture was ground to a paste. A further 20 ml of distilled water were added and mixed well, working into the liquid all particles adhering to the pestle or to the upper levels of the mortar. One ml of a 0.05% (w/v) solution of phenolphthalein indicator was added and with constant grinding the mixture was titrated with N/9 sodium hydroxide until the pink colour persisted of 15 sec.

Preliminary investigations into the above methods indicated that a wide range of acidity may be obtained. Typical results for the different methods (using the same Cheddar cheese) were as follows,

Table 3

The titratable acidity of Cheddar cheese using different methods of measurement

Method	Titratable acidity, % lactic acid
1	1.34
2	0.74
3	0.95

Other results were recorded but similar variations between methods were found.

DISCUSSION

The wide variation in the results of titratable acidity tests on Cheddar cheese indicates the necessity for standardisation of the method used and for adherence to the recommended procedure. The apparent discrepancies in the results of the 3 methods investigated in this short preliminary experiment may lead to confusion in their interpretation which can only be avoided by specifying the method and procedure used. One of the methods (Method 2) involved filtration of the cheese-water mixture and the lower titratable acidity obtained using this method was in agreement with the previously mentioned work of Lloyd (1899). Methods 1 and 3 were similar and the variations in the results obtained can possibly be explained by the difficulties in determining the end point and in the adequate mixing of the cheese-water mixture during the titration. Further work was, however, necessary before any of the 3 methods described above could be adopted or rejected and this work is described below.

Method 1 This method was used to determine the acidity of both white and coloured cheese. After a number of tests it was concluded that the method was unsuitable due to non-reproducibility of results. It was also very difficult to detect accurately the end point of the titration due to the presence of the annatto colouring material.

Method 2 and method 3 These were used on the same sample of cheese and the following were typical results. The cheese was white Cheddar.

method	lactic acid, %
2	0.432, 0.472, 0.480
3	0.60, 0.62, 0.90, 0.72

It is apparent from these results that variations within methods were again evident as well as variations between methods. Non-reproducibility in method 3 may be due to difficulty in the detection of the end point - which proved subsequently to be almost impossible with coloured Cheddar - and to incomplete extraction of the lactic acid. In Method 2 differences may be due to different amounts of shaking and/or incomplete extraction of substances contributing to the acidity of the cheese. It was observed, however, that by taking the first 25 ml of filtrate a different result was obtained as compared with the result of the last 25 ml of filtrate to pass through the filter paper. It was decided therefore to allow the cheese-water mixture to filter completely before titrating. Then 25 ml portions were titrated and reproducibility as one might expect was excellent. This in itself proved that standardisation of the end point in Method 2 was correct and easily detectable.

Three samples of cheese were taken and the titratable acidity determined according to Method 2. The first 25 ml through the filter (Whatman No.40) were titrated and the remainder was allowed to filter completely. Then duplicate titrations were made on aliquots of the complete filtrate. The following were the results using N/9 sodium hydroxide and phenolphthalein solution as indicator.

Table 4

The titratable acidity of the filtrate from cheese/water mixtures

Sample	lactic acid, %	
	1st 25 ml	Mixed filtrate
A	1.032	1.232, 1.240
B	0.928	1.120 -
C	0.864	1.088, 1.080

It appears from these results that the longer (within limits) the cheese-water mixture is allowed to stand an increase in titratable acidity will be obtained. It was decided to allow mixtures of cheese and water to stand for certain lengths of time before filtering and then to compare results on the first 25 ml through the filter with the remaining mixed filtrate. Some of the results obtained are recorded below.

Table 5

The effect of length of time of standing on the titratable acidity of the filtrate from cheese/water mixtures

Length of time of standing, min	Titratable acidity, % lactic acid: 1st 25 ml	Titratable acidity, % lactic acid: mixed filtrate
5	1,000	1.208
10	0.816	0.824
15	0.848	0.904
30	0.992	1.032

Summary and conclusion

To determine a suitable length of time that the cheese-water mixture should be allowed to stand before filtering, samples of the same cheese were allowed to stand for periods from 0 to 30 min and the filtrates titrated at intervals of 5 min. The results indicated that the mixture should be left standing for a minimum period of 20 min after which time reproducible results could be obtained due to the complete extraction of the substances contributing to the titratable acidity.

Method adopted

The method finally adopted is to take 10 g of cheese which is grated with a domestic type (Mouli) grater and is made up to 105 ml with distilled water at 40°C. The mixture is shaken and allowed to stand for 20 min when it is filtered through a Whatman No.40 filter paper and the filtrate (25 ml) titrated with N/9 sodium hydroxide using 1 ml of a 0.05% (w/v) solution of phenolphthalein as indicator.

Section two

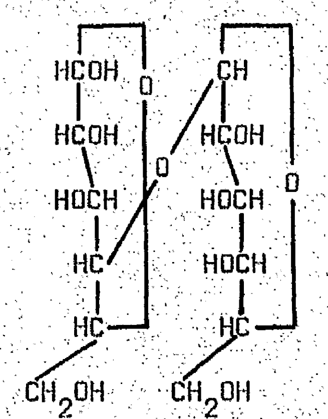
Part II

The determination and identification of lactose in Cheddar cheese

THE DETERMINATION AND IDENTIFICATION OF LACTOSE IN CHEDDAR CHEESE

Chemistry of lactose

Lactose which appears to be formed exclusively in the milk of mammals, is present in cow's milk to the extent of about 4.7%. It is one of the few substances in true solution in milk. Lactose is only faintly sweet, being about one-sixth the sweetness of cane sugar, and it therefore imparts merely a faint sweet taste to milk. It is interesting to note that although containing about the same concentration of lactose, sweet (non-acid) whey is much sweeter than milk, due no doubt to the removal of casein, which masks the flavour (Ling, 1948). Chemically, lactose is a disaccharide composed of a molecule of D-glucose and one molecule of D-galactose. The structural formula is as follows:



Lactose is available in two forms, alpha-lactose and beta-lactose. The alpha form is normally available as the monohydrate containing 5.0% water of crystallisation and is obtained from crystallisation of lactose from solution at temperatures below 93.5°C. The alpha anhydrous lactose can be prepared by dehydrating alpha lactose hydrate in vacuo at temperatures between 65 to 93.5°C and is stable only in the absence of moisture. The beta lactose is obtained from crystallisation of lactose from solution at temperatures above 93.5°C. In solution, the two forms interconvert until an equilibrium is attained, irrespective of the form with which one starts out. In the absence of catalysts and at ordinary temperatures, the rate of approach to equilibrium is fairly slow and can be followed by optical rotation, solubility and rates of crystallisation. When either form of lactose is added to water, the specific rotation changes gradually, due to the interconversion of the sugar from one form to the other, until at equilibrium the specific rotation becomes +55.5°. This phenomenon is referred to as mutarotation and is common to many reducing sugars (Choi, 1958).

The alpha and beta forms of lactose differ in their physical and in some of their chemical behaviours. For example, beta-lactose is sweeter, more soluble and, according to Isbell and Pigman (1937), oxidised at a faster rate by bromine to lactobionic acid than is the alpha form. The specific rotation of alpha-lactose hydrate is +89.4° and of beta-lactose +35°.

Lactic acid bacteria

The lactic acid bacteria represent the most important single group of bacteria utilised by the dairy industry. These bacteria produce lactic acid and other breakdown products from lactose and their presence may be undesirable or desirable depending on the dairy product being made. For example, with raw or pasteurised bottled milk, spoilage sometimes occurs due to the production of lactic acid but in products such as cheese, ripened cream, butter and yogurt, these bacteria are used to produce the desired level of acidity or lactic acid.

The lactic acid bacteria may be classified as follows (Breed, Murray and Smith, 1957).

Streptococcus

Homofermentative

Group I Non pathogenic types saprophytic on animal and plant matter.

Group II Pathogenic and haemolytic types.

Heterofermentative

Group III Types saprophytic on plant matter.

Lactobacillus

Homofermentative

Group I Types saprophytic on plants.

Group II Types saprophytic on plant and animal material.

Heterofermentative

Group III Types saprophytic on plant material.

Utilisation of lactose by bacteria

The rate of transformation of lactose into lactic acid is of very great importance in cheesemaking. van Slyke and Bosworth (1915, 1916) carried out experiments on the souring of milk to which were added B.lactis acidi and B. lactis aerogenes. They found that from 70 to 90% of the lactose fermented was converted to lactic acid. Lempitt and Bogod (1933) experimented with a number of species of bacteria in order to demonstrate the relation between their period of incubation in milk and the resultant titratable acidity and lactic acid contents of the milk. Their results indicated that with Str. lactis, there was considerable production of lactic acid without much corresponding change in titratable acidity. McDowall and Dolby (1935b) have shown that a mixed starter culture, containing both acid and aroma producing organisms, when under conditions of continuous growth in milk gave an almost complete conversion of lactose to lactic acid. van Slyke and Bosworth (1907) estimated the lactose and lactic acid contents of curd at various stages during the cheesemaking process, and of cheese at various times after hooping. They noted a rapid decrease in lactose content of the curd until a few hours after the cheese was hooped, and then a more gradual fall until after 2 weeks the lactose had almost completely been utilised. The lactic acid showed a corresponding rise in concentration reaching a maximum about the time the last of the lactose was decomposed.

Fagen et al. (1952) used a paper chromatographic technique to identify the reducing sugars of Cheddar cheese made from raw and pasteurised milk. These authors noted a difference in the rate of utilisation of lactose in cheese made from raw as compared to pasteurised milk. They found that cheese made from raw milk containing 4.78% lactose had lactose contents of 0.87%. 0.46%, 0.18% and 0.00% at 1, 12, 19 and 25 days respectively. The cheese made from pasteurised milk containing 4.78% lactose had lactose contents of 0.82%, 0.50%, 0.20% and 0.00% at 19, 25, 39 and 53 days respectively. Sjostrom (1956) studied the rate of sugar breakdown in various kinds of cheese made in Sweden. He found that the glucose portion was rapidly fermented. In hard, high-scalded Swedish rennet cheese most of the lactose was utilised before the pressing stage and the chief remaining sugar seemed to be galactose, which was detected up to 22 days. In hard-cheese made with a lower scalding temperature, the sugar breakdown took place much faster, i.e. in about 3 days. In Camembert, the lactose remained in the cheese up to 14 days, the galactose was detected up to the 8th day. Nilsson and Guldstrand (1959) studied the sugar fermentation during the early stages of the maturation of 2 Herrgard cheese. One cheese was made in the normal way and the curd of another cheese was preheated to 48°C before the pressing stage. They found that in the normally made cheese, all sugar had been utilised after 1 day and in the heated cheese after 6 days.

In Cheddar cheesemaking, it is essential to control the amount of lactose remaining in the curd as the typical flavour of mature Cheddar cheese is affected by end products of lactose fermentation. The initial conversion of the lactose to lactic acid in the first few days of maturation affects the final quality of the cheese so that to be able to estimate the amount and rate of removal of lactose during the early stages of cheese maturation is important.

Fermentation of lactose

"Undoubtedly the first step in the breakdown of lactose is hydrolysis to glucose and galactose. Further reactions apparently include phosphorylations, hydrolyses, oxidations and reductions", (Hammer and Babel, 1943). Hucker (1928) reported that Str. lactis does not hydrolyse lactose faster than lactic acid is produced and Tapernaux (1932) stated that the two molecules of hexose formed from one molecule of lactose under the influence of lactase are each split into two portions with formation of methylglyoxal. Lactic acid is then produced by intramolecular oxidation reduction of part of the methylglyoxal. Pien (1937) stated that lactic acid bacteria convert lactose to glucose and galactose, lactic acid then being produced with the intermediate formation of methylglyoxal. According to Werkman (1939) and Werkman and Wood (1942) methylglyoxal was not an important intermediate and played no essential role in the breakdown of lactose. The mechanism suggested by Werkman (1939) and Werkman and Wood (1942) is that glyceraldehyde was changed to phosphoglyceric acid and not methylglyoxal, the phosphoglyceric acid then being converted to pyruvic acid which was reduced to lactic acid. Kandler (1961) stated that the homofermentative lactic streptococci split lactose into its components, glucose and galactose. Glucose then is converted to lactic acid via the Embden-Meyerhof-Parnes (EMP) metabolic pathway.

The final reaction in this pathway involves the reduction of pyruvate to lactic acid with the aid of lactic acid-dehydrogenase (Marth, 1962). Before galactose can be utilised it must be converted to a glucose-form which can enter the EMP metabolic scheme. Heterofermentative starter bacteria differ from homofermentative bacteria in that they do not possess an aldolase and hence are unable to degrade hexoses by means of the EMP system (Kandler, 1961). Two compounds formed in the final stages of carbohydrate metabolism of heterofermentative lactic acid bacteria are acetylphosphate and phosphoglycerinaldehyde. The phosphoglycerinaldehyde is transformed into lactic acid by means of the EMP glycolytic pathway and acetylphosphate is dephosphorylated and forms acetic acid, or is reduced to produce alcohol. If oxygen is present, some of the acetylphosphate is converted to acetic acid and some to alcohol (Marth, 1962).

Theoretically, the homofermentative reaction yields two molecules of lactic acid for each molecule of glucose utilised while the heterofermentative reaction converts one molecule of glucose into one molecule of each of carbon dioxide, lactic acid, and alcohol or acetic acid (Kandler, 1961).

THE DETERMINATION AND IDENTIFICATION OF LACTOSE

Methods of determination

"There are more methods for the measurement of lactose in milk and milk products than for any other milk constituent. This fact, among other things, testifies to the inadequacy of some of the methods". This statement was made by Jenness and Patton (1959) and the situation appears not to have improved in the intervening years. The most common methods of determining lactose in cheese may be classified as follows:

1 Colorimetric

2 Oxidation-reduction methods

3 Chromatographic

1 Colorimetric

Colorimetric tests for reducing sugars and polysaccharides have been known for a considerable time. Phenol in the presence of sulphuric acid may be used for the quantitative microdetermination of sugars and their methyl derivatives, oligosaccharides, and polysaccharides (Dubois, Giles, Hamilton, Rebers and Smith, 1951). This method is particularly useful for the determination of small quantities of sugars separated by paper partition chromatography with the phenol-water solvent. The method is simple and rapid and the colour produced is permenent. Barnett and Tawab (1957) used the phenol-sulphuric acid method to study the removal of lactose in milk during souring and during the ripening or maturation of five different varieties of cheese. They used 6 drops of 80% phenol and stated that the actual amount of phenol added did not matter, within limits, as long as the same quantity was always used. Erickson and Richardson (1957) applied the phenol-sulphuric acid method to the determination of lactose in milk using the clarifying agent of Francis and Smith (1952), in order to obtain a practically pure lactose solution that would be clear, colourless and containing no residual of the clarifying agent. Erickson and Richardson (1957) outlined various sources of errors, the more important being the addition of the sulphuric acid. The colour development takes place when the acid is added and the intensity of the colour is dependent on the temperature attained and since the temperature attained is dependent upon the rate of addition of the acid, this addition must be strictly controlled. Marier and Boulet (1959) stated when using the phenol-sulphuric acid method that the concentrations of the phenol and sulphuric acid were critical. In fact, despite the claims of Barnett and Tawab (1957) that, within limits, the actual amount of phenol did not matter, Marier and Boulet (1959) traced variations which occurred in their replicate analyses of standard lactose solutions to minute differences in the amount of phenol reagent added. As a result of their investigations they recommended the addition of 11 mg of phenol and 0.74 ml of sulphuric acid/ml of the total arithmetic volume.

The use of Anthrone reagent (Dimler, Schaefer, Wise and Rist, 1952; Dreywood, 1946; Koehler, 1952; Morris, 1948; Morse, 1947; Viles and Silverman, 1949) is excellent for standard sugar solutions. However, the Anthrone reagent is expensive and solutions of it in sulphuric acid are not stable (Loewns, 1952; Morris, 1948). The Anthrone method also suffers from the disadvantage that, while it is satisfactory for free sugars and their glycosides, it is of little use for methylated sugars and the pentoses. Thomas (1963) estimated the lactose content of commercial samples of cottage cheese using the Anthrone reagent. He found that he obtained different standard curves depending on whether he used water solutions of lactose or cheese to which was added known amounts of lactose. Thomas (1963) believed that some component of the cheese changes the rate of colour formation and/or degradation and that to obtain reproducible results ~~a~~ chosen time-temperature combination must be closely adhered to.

Fearon's (1948) test for reducing disaccharides is well known. In the presence of lactose a yellow colour forms which slowly changes to carmine when methylamine hydrochloride is added to a mixture containing 4 ml water, 4 drops of milk and 3 to 5 drops of 20% sodium hydroxide. The reaction is specific for reducing disaccharides and glucose, galactose, fructose, starch and many sugar degradation products do not interfere. However, this method is entirely qualitative and is affected by maltose and cellobiose where lactose is being detected.

Mattsson and Jensen (1950) used triphenyl tetrazolium chloride for the detection of lactose. This reagent unites with reducing sugars in alkaline solution to form the reduced triphenyl-formazan, an insoluble red compound. On the addition of pyridine acidified with hydrochloric acid a red solution is produced which may be compared with similarly treated standards. The authors stressed that the method was applicable to milk filtrates provided the time, temperature and alkalinity were strictly controlled.

The picric acid method for the simultaneous determination of lactose and sucrose in dairy products was used by Perry and Doan (1950). This involved the use of a photo-electric colorimeter. Although the method was applicable to the determination of either sugar alone variations in the analysis of replicate samples was wider than expected. Cheronis and Zymaris (1957) developed a colorimetric micro method by which the glucose content of blood was determined by reduction of p-anisyl tetrazolium blue to formazan. Koops (1961) used this method in his investigation on the breakdown of lactose in Dutch cheese. He found the method to be rapid, simple and reliable but indicated that derivatives of proteins formed during cheese maturation contributed to the reduction reaction.

2 Oxidation-reduction methods

The British Standard Institution method (1963a) for the determination of lactose in milk involves the use of chloramine-T and sodium thiosulphate. To the knowledge of the author, it has not been used to determine the lactose content of cheese and the time necessary to complete a test would certainly rule it out as a rapid method for lactose determinations.

The determination of lactose in milk and milk products was carried out in the following manner by Hites and Ackerson (1949). After precipitation with sodium tungstate in a buffered acid solution, the filtrate was heated with excess of standard alkaline ferricyanide. The excess was determined iodometrically by reaction with potassium iodide and titration with sodium thiosulphate.

A number of methods for the determination of lactose in milk products are based on the reduction of some variant of Fehling's solution (McDowell, 1941; A.O.A.C., 1960; Babad and Grunpeter, 1951). Swartling and Mattsson (1953) used a procedure virtually the same as that reported by Babad and Grunpeter (1951) except that the alkaline copper reagent of Somogyi (1945) was preferred. Swartling and Mattsson (1953) found that cheese filtrate itself affected the reduction of the copper reagent and sought to correct this by the preparation of a special standard graph. They stated that the reproducibility of the method was very good as far as determination of lactose in pure solution was concerned and that it was also satisfactory in the case of duplicate analyses on the same cheese filtrate.

3 Chromatographic methods

Paper partition chromatography was first applied to the analysis of reducing sugars by Partridge (1946) and in recent years several workers have used this technique to study sugar fermentation during the early stages of cheese ripening. Fagen et al. (1952) showed that at the beginning of maturation of Cheddar cheese, 3 reducing sugars are present, namely, lactose, glucose and galactose. A qualitative study of the lactose fermentation was also carried out by Sjostrom (1956) who studied the effect of heating the cheese to different temperatures. He found the time necessary to obtain a complete separation of the sugars to be 3 to 4 days. Raadsveld (1957) used paper chromatography for a quantitative study on the breakdown of lactose and the presence of galactose and glucose during the first few days after manufacture of some Dutch cheese. In addition to paper chromatography, ion exchange may be employed in the analysis of a mixture of sugars. Nilsson and Guldstrand (1959) used ion exchange because they were unable to obtain reproducible results using quantitative chromatographic methods. Their procedure was based on ion exchange chromatography of the sugar-borate complexes used by Khym and Zill (1952). The results Nilsson and Guldstrand (1959) obtained were similar to those of other workers (Sjostrom, 1956; Raadsveld, 1957) i.e. that warming cheese to high temperatures during manufacture had a profound influence on the sugar content, in that the high temperatures retarded the fermentation of lactose. However, Nilsson and Gulstrand (1959) reported the presence of another reducing compound, in addition to the sugars, in the cheese extracts. They followed this substance to the 19th day and came to the conclusion that it increased during the ripening of the cheese. Investigations were continued but with little success as to identification of this reducing compound (Nilsson, 1966).

EXPERIMENTAL

The disadvantage of many methods for lactose determination in cheese during ripening is that other reducing sugars and their derivatives are all reported as "lactose". This fact must be borne in mind when a method is being considered to follow the sugar fermentation during cheese maturation.

In an effort to obtain a suitable technique for the estimation of rate of lactose removal in cheese several methods were investigated. These included the British Standard Institution method (1963a) for the determination of lactose in milk, the use of which led to the observation that an amino acid if added to filtrate obtained from a grated cheese sample can greatly increase the apparent lactose concentration.

METHODS

The British Standards Institution method (1963a) for the determination of lactose in milk

The desirable features of any analytical method are that it should be accurate, relatively rapid and simple to perform. The British Standard Institution method (1963a) for the determination of lactose in milk, though not rapid was used on 3 samples of Cheddar cheese to ascertain when all the lactose had been fermented. A sample consisting of 1 g of grated cheese was used. The results indicated that for the first 5 days the lactose content decreased, but thereafter until the cheese was 3 weeks old, when testing was discontinued, the lactose content increased at a steady rate. This observation was disturbing as it is generally accepted (Sjostrom, 1956) that all traces of lactose have disappeared after 12 days.

In order to determine the effect of the age of cheese on the lactose content further experiments were carried out on 8 samples of Cheddar cheese. The ages of the cheese were 3 days, 1, 2 and 3 weeks, 1, 2, 3 and 4 months old. To identify the sugars the paper chromatographic method of Fagen *et al.* (1952) was employed until after running of the chromatogram when the spraying and fixing reagents of Sjostrom (1956) were preferred. Using this method, lactose was clearly identified in the 3 day old cheese, but only with difficulty in the 2 weeks old cheese. Figures obtained for lactose content of the same cheese using the British Standards Institution method (1963a) are shown in Table 6. In general, it can be concluded from these results that as the age of the cheese increases, the apparent concentration of "lactose" increases. This is obviously erroneous and the reason must be attributed to the fact that reducing substances, other than sugars, are produced during the course of cheese ripening and interfere with the accuracy of this quantitative method. This fact warranted further investigation and subsequent experiments showed that by the addition of 0.01 g of l-tyrosine to 10 ml of cheese filtrate the "lactose" content was increased from 1% to almost 20%.

Table 6

Lactose content of Cheddar cheese of different ages using the British Standards Institution method (1963a) for the determination of lactose in milk

Age of cheese, days	Lactose content, %
3	0.76
7	1.10
14	2.13
21	1.52
28	1.41
56	2.05
84	4.55
112	4.44

The phenol-sulphuric acid method (Dubois et al., 1951)

This is a simple straightforward procedure for the determination of lactose in milk and cheese, but reports on the accuracy and reproducibility of the method are not reassuring. There are also conflicting reports on the quantity of reagents that should be used. Barnett and Tawab (1957) stated that the amount of phenol was not critical, provided that the same quantity was used throughout the experiment. Marier and Boulet (1949) however, traced variations in their replicate analyses of standard lactose solutions to minute differences in the amount of phenol reagent added. The rate of addition of sulphuric acid is also important. Erickson and Richardson (1957) stated that the intensity of the colour formed on the addition of sulphuric acid was dependent upon the amount of heat evolved. Since the heat evolved is dependent upon the rate of addition of the acid, the addition must always be at the same rate.

In an attempt to produce a standard curve, the author used the method of Barnett and Tawab (1957) with a Spekker absorptiometer. The plotting of a standard curve proved impossible, due to poor reproducibility. With such disadvantages, this method was considered unsuitable for the determination of lactose in cheese.

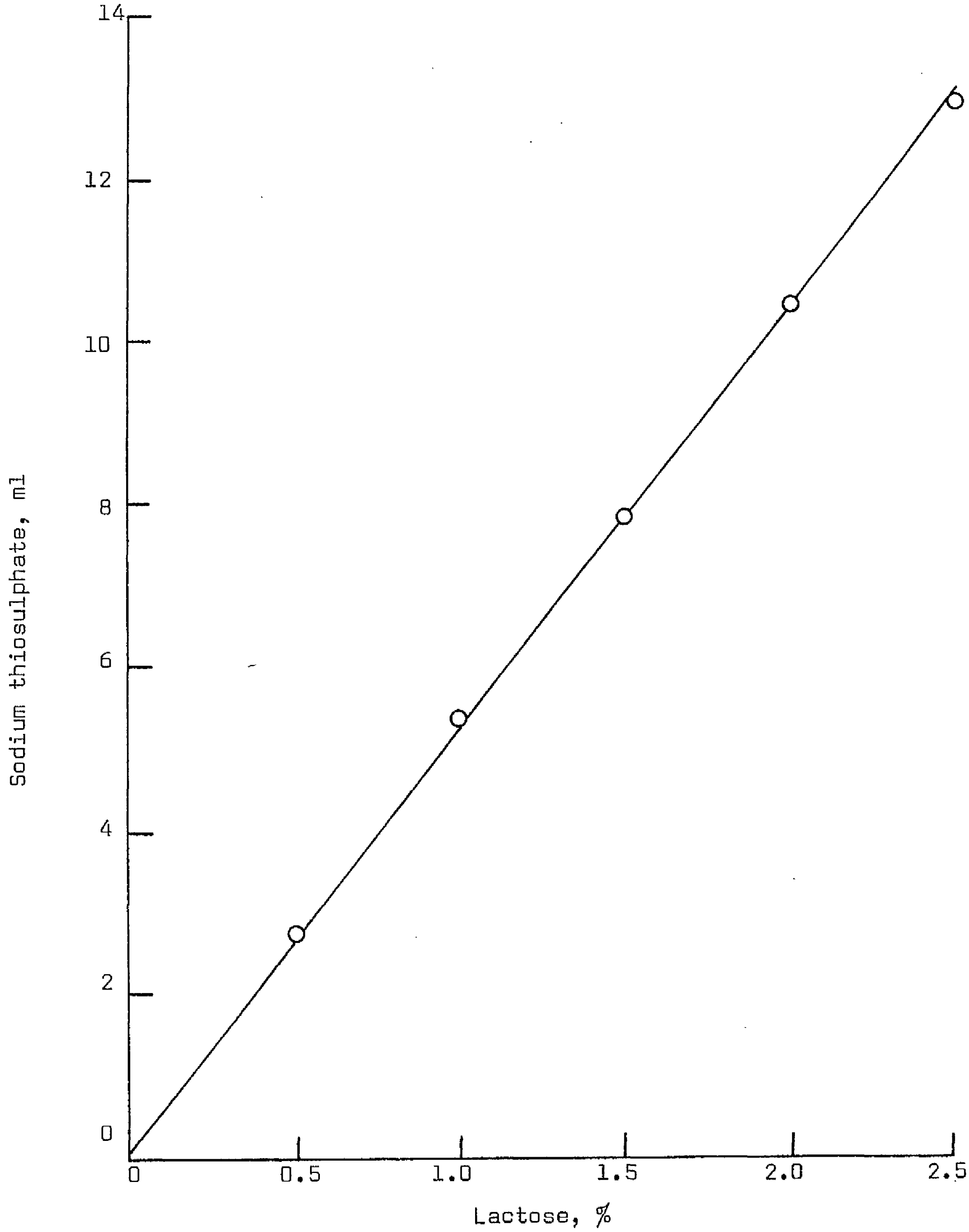
The method of Swartling and Mattsson (1953)

Preliminary observations indicated that this method had certain distinct advantages over those described above. A large quantity (5 g) of cheese is used thus providing a more representative sample and the concentration of the sodium thiosulphate (0.005 N) is so low that errors in the final titration are virtually eliminated.

Before the plotting of a standard curve could be undertaken it was necessary to carry out experiments to decided whether or not to use cheese filtrate or distilled water as the blank because of the possible presence of reducing substances in cheese filtrate. Blanks were prepared in various ways, i.e. the quantity of cheese filtrate was varied and distilled water was added to give a standard test amount of 5 ml. It was found that, in all cases where the quantity of cheese filtrate in the blank varied, the readings also differed. Where 5 ml of water was used as a blank, the thiosulphate reading exceeded the reading obtained using 4 ml cheese filtrate and 1 ml distilled water as a blank, by about 3 ml. It was decided, therefore, that in the preparation of a standard curve, the blank should consist of cheese filtrate.

A sample of cheese, 3 months old, was grated finely by means of a domestic type (Mouli) grater. Lactose powder of Analar quality was then added to the cheese to give 5 lactose concentrations of 0.5 to 2.5% in steps of 0.5%. The same procedure, reagents and reagents strength as suggested by Swartling and Mattsson (1953) was employed, except that a blank consisting of cheese filtrate was used and the filtrate obtained from the cheese containing added lactose was diluted 2 fold. This latter alteration was necessary because, when using 5 ml cheese filtrate, the end point was cloudy, more especially in the higher concentrations of lactose. Each filtrate was examined in triplicate and the average obtained was subtracted from the average of the blank which was also examined in triplicate. Fig. 1 shows the standard curve obtained.

Fig. 1 Standard curve for lactose determination



DISCUSSION

The typical flavour of mature Cheddar cheese is affected by end products of lactose fermentation. The initial conversion of the lactose to lactic acid in the first few days of curing creates a background of character to the cheese flavour so that to estimate the amount and rate of utilisation of lactose during the early period of cheese maturation is of definite importance. Fagen et al. (1952) using paper chromatography showed that at the beginning of maturation of Cheddar cheese, 3 reducing sugars are present, namely, lactose, glucose and galactose. Lactose was absent after 25 days, but traces of galactose were found after 53 days. Glucose could not be detected after 12 days. Nilsson and Gulstrand (1959) found that quantitative paper chromatography methods did not give reproducible results and these workers developed a procedure based on ion exchange chromatography of the sugar-borate complexes. The cheese used for the investigation was Herrgård, a hard rennet cheese with round gas holes. They found that lactose was broken down very rapidly and had almost disappeared after 1 day and that only traces of glucose and galactose were detected.

During the present investigation, it has been shown that cheese filtrate possesses reducing substances which interfere with the accuracy of the British Standards Institution method (1963a) for the determination of lactose in milk and the copper-reduction method of Swartling and Mattsson (1953). The presence of the amino acid, tyrosine, which is produced during the ripening of Cheddar cheese, was found to be one such interfering reducing substance. Because of this inherent reducing power of cheese filtrate it was decided when using the method of Swartling and Mattsson (1953) to draw up a standard curve and for subsequent lactose estimations in cheese, the blank should consist of cheese filtrate. The following method of Swartling and Mattsson (1953), modified by the author was used in the work outlined in this thesis.

Procedure for the determination of lactose in cheese

Five g of grated sample are weighed accurately.

The cheese is dissolved in 5 ml of sodium hydroxide solution and 10 ml water, in a water bath at $50^{\circ}C$. The solution is transferred to a 100 ml volumetric flask, to which 5 ml of zinc solution is added with frequent shaking. Dilute up to the mark.

After 15 min the solution is filtered through a dry filter paper. Two point five ml of the filtrate are transferred together with 2.5 ml of water to a test tube (1 in. x 8 in.). Five ml of alkaline copper reagent are added and the tube is placed in a boiling water bath for 25 min. The tube is then cooled for 30 seconds and 1 ml potassium iodide solution and 1 ml sulphuric acid are added. The liberated iodine is titrated with 0.005 N sodium thiosulphate solution using starch as indicator.

A blank is used which consists of the filtrate obtained from Cheddar cheese not less than 11 weeks old. The difference between the thiosulphate readings obtained for the blank and for the cheese sample is equal to the amount of cuprous oxide and, after reference to the standard curve, will give the lactose content of the sample.

Details of reagents used in the above method for the determination of lactose in cheese.

Sodium hydroxide solution, 0.5 N

Zinc sulphate solution, 10% $ZnSO_4$ $7H_2O$

Alkaline copper solution,

one litre contains 28 g Na_2HPO_4 water free
100 ml N-NaOH solution
40 g potassium-sodium-tartarate
8 g $CuSO_4$, $5H_2O$
180 g Na_2SO_4, water free
100 ml 0.2 N-KIO_3 solution

Potassium iodide solution, 5% KI

Sulphuric acid, 5N-H_2SO_4 solution

Sodium thiosulphate solution 0.005 N,
prepared before use by dilution of 0.1 N solution

Starch solution, 1% soluble starch

Section two

Part III

The determination of lactic acid in Cheddar cheese.

THE DETERMINATION OF LACTIC ACID IN CHEDDAR CHEESE

Chemistry of lactic acid

It was Scheele in 1780 who first discovered in sour milk a substance which he called lactic acid and which was subsequently found to arise as a product of the bacterial fermentation of lactose. Lactic acid is formed by the reduction of pyruvic acid and was recognised as a result of microbiological action in 1847 and subsequently studied extensively by Pasteur. The structure of lactic acid is now known to be that of α - hydroxypropionic acid,

$$CH_3 - \underset{OH}{\overset{H}{\underset{|}{\overset{|}{C}}}} - COOH$$

Lactic acid which has a specific gravity of 1.249 exists in two forms, i.e. the d- and l- forms. Certain bacteria produce the d-form of lactic acid, others the l-form; more usually the acid is optically inactive. Some lactic acid bacteria as well as producing lactic acid also produce ethyl alcohol, glycerol, acetic acid, succinic acid, formic acid and gaseous products.

Lactic acid in milk

The acidity of milk arises from two quite separate and distinct sources. It is due partly to the presence of lactic acid (and possibly other acids, e.g. acetic acid) developed by bacterial fermentation of lactose and partly to the "acidity", which milk fresh from the cow possesses, arising from the presence of carbon dioxide, phosphates, proteins and citrates in the milk. It is generally assumed that fresh milk does not contain lactic acid. The initial titratable acidity of milk from individual cows varies widely. Caulfield and Riddell (1936) found milk with a range of from 0.08% to 0.30% lactic acid equivalent and O'Connor (1964) found individual milk samples varying from 0.098% to 0.206% lactic acid equivalent with corresponding pH values of 7.00 and 6.60.

Methods for the estimation of lactic acid in milk and milk products

Furth and Charnass (1910) determined lactic acid by oxidising it to acetaldehyde after the removal of interfering substances. The acetaldehyde was then determined by use of an excess of sodium bisulphite followed by the iodometric titration of the bisulphite. This method was later improved by Clausen (1922) and Troy and Sharp (1935). Colorimetric determinations of acetaldehyde by use of orthodimethoxybenzene by Mendel and Goldschneider (1925) and hydroquinone after Dische and Lazlo (1927) have also been used. The method advocated by Troy and Sharp (1935) is long and tedious, and Hillig (1937, 1942) later developed a method involving the extraction of lactic adid with ether from a protein-free filtrate, the removal of interfering substances, development of a colour with ferric chloride and comparison with standards. This method was made official by the A.O.A.C. (1945).

Meanwhile, Heinemann (1940) adapted for use with milk the method of Mendel and Goldschneider (1925) for blood, in which lactic acid in a protein and glucose free filtrate was oxidised by sulphuric acid to acetaldehyde. The colour formed between the acetaldehyde and veratrole was compared with colour standards. Barker and Summerson (1941) adopted the p-hydroxydiphenyl reaction of Eegriwe (1933) in preference to the veratrole reaction for the estimation of lactic acid in blood and tissues. Their procedure involved removal of glucose from a protein-free filtrate by the copper hydroxide-calcium hydroxide method of van Slyke (1917), oxidation of lactic acid to acetaldehyde in concentrated sulphuric acid, development of a purple colour between acetaldehyde and p-hydroxydiphenyl reagent and comparison of the colour intensity with that developed from standard lactate solutions.

This convenient and rapid method, which was unaffected by a large number of organic compounds related to lactic acid appeared to provide the type of method needed. However, this method had the disadvantage that one estimation took 1½ to 2 h, although a group of 10 or 12 could be tested at the same time (Davidson, 1949). Ling, (1951) found that by treating milk with barium chloride, sodium hydroxide and zinc sulphate solutions a filtrate free from citric acid was obtained. Then by the addition of a ferric chloride solution to the citric acid-free filtrate a colour developed whose intensity increased with increasing amounts of lactic acid. The same writer also suggested the use of a rapid "sorting" test in order to separate those milk samples in which lactic acid had developed from those which were fresh.

Taylor and Clegg (1958) discussed the need for a test which would measure the developed lactic acid in milk and which was unaffected by the composition of the milk. They examined the method described by Ling (1951) with a view to adopting it as a rejection test for raw milk. They set out to determine the optimum quantity of ferric chloride reagent to add to filtrates containing 0 to 0.1% lactic acid. They found that 2 ml of 1% ferric chloride was sufficient. Pickering and Clegg (1958) thought it desirable to modify the test to give greater sensitivity over a more restricted range of lactic acid, so as to improve the usefulness of the test. They showed that 0.5 ml of 1% ferric chloride reagent was the minimum quantity which would give best results over the range 0 to 0.04% lactic acid. The accuracy and reliability of the method was demonstrated by O'Connor (1966a) using individual cows' milks and bulk milks. As a result of this work a rejection level of 0.02% developed lactic acid was suggested for milk delivered to creameries (O'Connor, 1966b).

Harper and Randolph (1960) made an effort to relate the lactic acid content of Cottage cheese to the flavour. They used the method of Cope and

Choi (1957) which was a modification of the Ling (1951) method. Harper and Randolph (1960) used a Bausch and Lomb Spectronic 20 spectrophotometer in their work but a Spekker absorptiometer was used by the author in the work outlined below.

EXPERIMENTAL

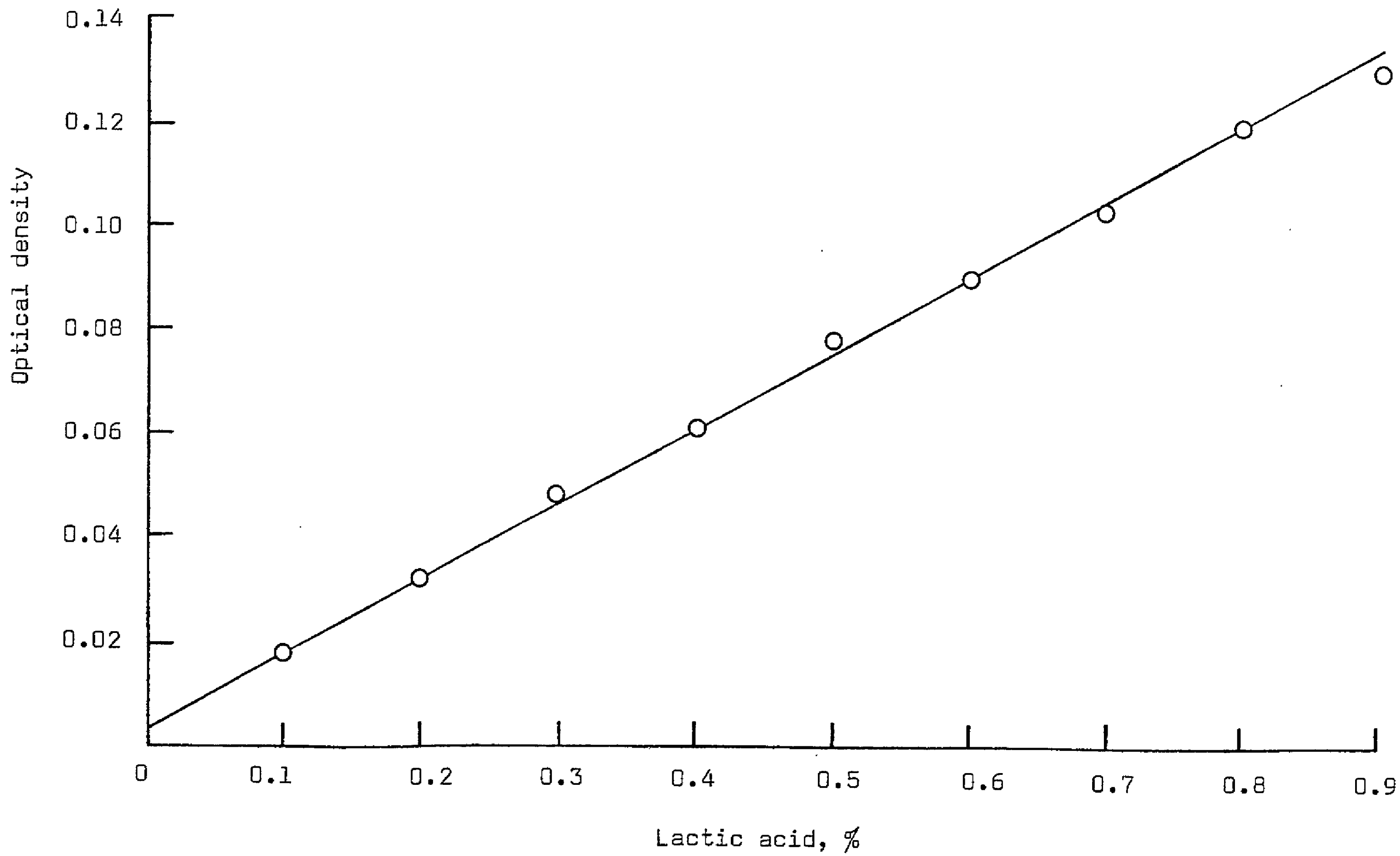
It was necessary first of all to plot a standard curve. Taylor and Clegg (1958) also used a Spekker absorptiometer in their work and suggested adding 2 ml of 1% ferric chloride to 10 ml of clear filtrate and using a 1 cm cell and violet filters. In order to determine which was the most suitable cell to use, ½ cm, 1 cm, 2 cm and 4 cm cells were used with filtrates obtained from lactic acid solutions varying from 0.1% to 1.0% in steps of 0.1% lactic acid to which were added various quantities and concentrations of ferric chloride reagent. The lactic acid solutions were obtained from a 1% lactic acid solution which was prepared by dissolving 1.066 g of lithium lactate in 100 ml of distilled water. Preliminary experiments showed that the quantity of ferric chloride reagent used had a marked influence on the curve obtained, i.e. as the concentration of lactic acid increased the curve obtained by plotting % lactic acid vs optical density tended to level out. The probable reason for this was that insufficient ferric chloride was present to react with the lactic acid. By dilution of the lactic acid solutions a more linear relationship was obtained.

Experiments on the cells showed that the ½ cm and 1 cm were more suitable than the 2 cm and 4 cm, as the latter two cells gave curves which tended to level out with increasing concentrations of lactic acid. The 4 cm cell also had the disadvantage that a large volume of filtrate was required. Work was then concentrated on the ½ cm and 1 cm cells using various quantities and concentrations of ferric chloride. The filtrates and blanks were prepared by the procedure out lined by Harper and Randolph (1960). The quantities of ferric chloride used varied from 0.5 ml to 6 ml and the concentrations varied from 1% (w/v) to 5% (w/v). The best and most consistent results were obtained when ½ cm cell and 2 ml of a 5% (w/v) ferric chloride solution were used. The procedure outlined below was used to plot the standard curve Fig. 2, which was used in work detailed in Section 3, Part IV of this thesis. It is recommended, however, that a new standard curve be plotted with each new lot of reagents.

Method for preparation of the standard curve

A 1% (w/v) solution of lactic acid was prepared by dissolving 1.066 g lithium lactate in 100 ml distilled water. This was designated the stock solution. By taking various quantities of the stock solution, lactic acid solutions from 0.1% to 1.0% in steps of 0.1% lactic acid were obtained. Five ml amounts of these solutions were made up to 100 ml with distilled water. To 25 ml of these solutions were added 10 ml barium chloride solution (197.5 g of $BaCl_2 2H_2O$/litre), 5 ml sodium hydroxide solution (0.66 N-NaOH) and 5 ml of zinc sulphate solution (225 g of $ZnSO_4 7H_2O$/litre). The mixture was shaken thoroughly and allowed to stand for at least 30 secs. The mixture was then filtered through a fluted 12.5 cm Whatman No.40 filter paper and the filtrate collected in a 50 ml conical flask. Two ml of a 5% (w/v) ferric chloride solution were added to 10 ml of the filtrate and the optical density determined on the Spekker absorptiometer using a Kodak filter No.1. A blank of distilled water was treated in a similar fashion and the filtrate obtained therefrom was used in setting the drum of the Spekker instrument. The standard curve used in the work outlined in this thesis is shown in Fig. 2.

Fig. 2 Standard curve for lactic acid determination



Procedure with cheese samples

Five g of grated cheese were mixed with 5 ml distilled water by means of a Silverson mixer and then made up to 100 ml with distilled water. A filtrate was obtained as described above and the optical density determined. From the standard curve the % lactic acid was ascertained.

Section three

EXPERIMENTAL

Part I

The composition and grade scores of commercial Cheddar cheese

THE COMPOSITION AND GRADE SCORES OF COMMERCIAL CHEDDAR CHEESE

INTRODUCTION

The production of Cheddar cheese of uniform composition and quality has been the aim of cheesemakers for many years. Cheese of a uniformly high quality enhances the reputation of a cheesemaker as well as resulting in a greater financial return to the dairy. Because of the variation in compositional and hygienic quality of the milk supply, great demands are made on the skill of the cheesemaker to meet market requirements in respect of both quality and composition of the mature cheese. Since the introduction of legislation (Cheese Regulations, 1966) to control the composition of Cheddar cheese, cheese factory managers have become more aware of the necessity to manufacture cheese which will meet these legal requirements.

Problems arise in the day to day manufacturing procedure which, because of the human element involved, may become unnoticed and unchecked with a consequent detrimental effect on the quality of the cheese. These problems may be of a chemical or a bacteriological nature and even the lack of supervision in the handling of milk may contribute greatly to lack of uniformity in the finished product.

Much has been written on the composition of Cheddar cheese (e.g. Irvine, 1951) but little emphasis has been placed on the variations which might occur in one particular creamery or one particular area and the reason why these variations do occur. Analysis of the cheese has also been limited so that a complete picture is not obtained. Davis and MacDonald (1953) found that the moisture content of 100 samples of British and imported Cheddar cheese ranged from 32 to 42% while for 436 samples of English creamery Cheddar the range was from 29 to 45%. Marquardt and Yale (1941) analysed American

Cheddar cheese for salt and moisture contents. The range of salt content was from 0.96 to 1.73% with an average of 1.40% salt while for moisture the range was 33 to 41% with an average of 37.4% moisture. Zahrndt, Lane and Hammer (1944) found an average of 35.2% moisture from analysis of 52 samples of Cheddar cheese. Hawley, Dwyer and Davis (1960) have outlined the moisture and fat values of cheese made at a creamery in Somerset from 1957 to 1959. In 1959 the range of moisture was from 35.15 to 38.90% and for fat the range was from 31.38 to 34.75% all the cheese being placed in the highest grade.

Some of the more recent work on cheese quality and composition has been done by Irvine, Beach and Burnett, (1962, 1966). Irvine <u>et al</u>.(1962) found ranges for moisture, fat and salt contents of 30.5 to 40.5%, 30.0 to 37.0% and 1.0 to 2.16% respectively from analysis of 364 samples of Cheddar cheese made in Ontario. Irvine (1951) made a comprehensive survey of 386 samples of Ontario Cheddar cheese, estimating the fat, moisture and salt contents and also pH values. A whole range of quality and composition was obtained and an effort was made to relate quality of the cheese to the pH value or salt content. Irvine <u>et al</u>. (1966) examined 326 samples of Cheddar cheese made during the Spring and Summer of 1964. The examination included determinations for moisture, salt and pH value as well as enumeration of the non-acid and acid producing types of bacteria and the results were compared with the flavour and aroma scores of the cheese at time of grading. The moisture content varied from about 31% to 36% and the salt varied from 1.1% to 2.0%.

The above information from the literature indicates the great variations which occur in the composition of Cheddar cheese in several countries. The author, however, feels that there is a lack of information on the composition of cheese manufactured in Scotland and also on the relationship which exists between the chemical analyses and the individual characteristics e.g. flavour, body, texture and grade score of the cheese. In order to obtain such information the following long-term study was made of the quality and composition of commercial Cheddar cheese at the time of grading i.e. at about 8 to 10 weeks old.

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Source of samples

The cheese from which samples were taken were manufactured in commercial cheese factories in the counties of Dumfries, Ayr, Wigtown, Bute and the Stewartry of Kirkcudbright between November 1966 and September 1967.

Grading scheme

All the cheese were examined by the same official of the Company of Scottish Cheesemakers Ltd. and graded on the special points system detailed below. By scoring to the first decimal place it was possible to record very minute differences in the characteristics of the cheese.

Scheme for grading cheese

Date graded								Details of cheese			
Manufacture			Points awarded					Grader's Remarks			
Place	Vat	Date	Flavour & aroma (10)	Body (10)	Texture (10)	Total (30)	Grade	Flavour & aroma	Body	Texture	General

Where possible the remarks of the grader were noted on flavour and aroma, body and texture and the remarks under the heading "General" gave the grader's impression on any aspect of the cheesemaking procedure and composition of the cheese.

Chemical analyses

The cheese were sampled at the time of grading and subjected to salt, fat, moisture and pH determinations.

Salt This was determined by the Volhard method (British Standards Institution, 1963b).

Fat This was determined by the Gerber method, (British Standards Institution, 1955).

Moisture About 3 g of finely grated cheese were weighed accurately in an aluminium foil container (Foilpak, 10335, supplied by R.R. Brodie Ltd, Glasgow) with a diameter of 3.25 in. and a depth of 0.75 in. The container was placed in a hot air oven maintained at 100°C until the container and its contents reached constant weight. The aluminium foil container was then placed in a dessicator and allowed to cool. The moisture content of the cheese sample was then calculated in the usual way.

pH Ten g of cheese were mixed with an equal weight of distilled water by means of a Silverson mixer until a paste was obtained. The hydrogen ion concentration (pH) was then determined using a Radiometer pH meter 25 SE with glass (G 202 C) and calomel (K 401) electrodes.

Sampling

An effort was made to obtain a reasonable variety of cheese with regard to quality as determined by the official grader but the manufacturing procedure was not known by the author or the official cheese grader. The creameries where samples were obtained were selected so as to cover a reasonable area thereby having cheese made from milk from different breeds of cows, and possible different chemical composition.

Samples were obtained from 8 creameries but due to circumstances beyond the author's control the total number of samples were not evenly distributed between the creameries. The number of samples obtained in each creamery are given below together with other details such as size of vat and type of starter culture used.

Creamery	A	B	C	D	E	F	G	H
No of samples	114	58	45	26	23	16	10	8
* Type of starter	M.S.	M.S.	S.S.	M.S.	M.S.	M.S.	M.S.	S.S.
Size of cheese vat, gal	1,000	2,000	2,000	1,000	1,000	1,000	2,200	1,000

Total no of samples 300

* Mixed strain = M.S. Single strain = S.S.

RESULTS

The complete chemical analysis and grade scores obtained by each cheese sample are recorded in Tables 7 to 21. The results are recorded in the order in which the cheese were sampled as the author considers that by regrouping into creameries A, B, C, D, E, F, G and H an unfair comparison might be made between creameries because of the selection of samples. The % moisture in the fat free cheese (MFFC) is also recorded for each individual cheese. Table 23 shows the range and average values recorded for fat, moisture, pH and salt contents.

The total marks awarded varied from 19.5 to 28.5 from a possible maximum of 30.0. These figures (19.5 and 28.5) indicate the wide variation in quality of cheese which was sampled and the scores for the individual characteristics of the cheese indicate the great variation in flavour and aroma, body and texture. The range for the % moisture in fat free cheese (MFFC) was 50.2 to 58.7% and Table 26 shows the distribution of the cheese within this range. It can be seen from Tables 7 to 21 that the composition of the 300 cheese sampled varied greatly, variations which the cheese manufacturer

Table 7

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma (10)	Body (10)	Texture (10)	Total score (30)
1	33.85	36.61	5.19	1.78	55.3	4.9	7.0	8.5	8.0	23.5
2	34.25	36.65	5.17	1.77	55.7	4.8	7.5	8.0	8.0	23.5
3	34.15	35.71	5.43	2.21	54.2	6.2	9.0	9.0	8.5	26.5
4	34.05	37.00	5.20	1.85	56.1	5.0	9.0	9.2	9.0	27.2
5	34.20	35.34	5.45	2.24	53.7	6.3	9.2	8.8	8.5	26.5
6	34.70	36.92	5.26	2.03	56.5	5.5	9.0	7.5	8.0	24.5
7	34.50	36.93	5.13	1.69	56.4	4.6	9.2	8.0	7.5	24.7
8	33.90	37.19	5.14	1.65	56.3	4.4	9.0	8.8	8.0	25.8
9	34.30	36.99	5.17	1.75	56.3	4.7	9.2	8.8	8.4	26.4
10	33.80	37.25	5.13	1.71	56.3	4.6	8.8	8.5	8.1	25.4
11	34.35	36.44	5.11	1.81	55.5	5.0	9.0	8.5	8.5	26.0
12	34.05	36.55	5.04	1.60	55.4	4.4	8.8	8.4	8.5	25.7
13	33.90	37.46	5.28	1.60	56.7	4.3	9.2	8.8	8.8	26.8
14	35.25	35.21	5.07	1.73	54.4	4.9	9.0	8.8	8.0	25.8
15	34.00	36.66	5.31	1.77	55.5	4.8	7.0	8.0	7.5	22.5
16	34.80	36.84	5.08	1.69	56.5	4.6	8.8	8.5	8.5	25.8
17	35.15	35.85	5.04	1.66	55.3	4.6	8.8	8.8	8.0	25.6
18	34.25	36.95	5.06	1.46	56.2	3.9	9.0	9.0	8.8	26.8
19	34.70	37.61	5.04	1.45	57.6	3.8	8.5	8.4	8.6	25.5
20	33.90	36.65	5.19	1.67	55.4	4.5	9.0	8.8	8.6	26.4

Table 8

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
21	29.95	35.18	5.36	2.21	50.2	6.3	8.5	6.0	5.0	19.5
22	37.60	35.84	5.36	2.40	57.4	6.7	8.5	7.0	7.0	22.5
23	34.30	35.98	5.36	2.08	54.8	5.8	9.0	8.8	8.4	26.2
24	34.80	35.49	5.50	2.46	54.4	6.9	7.5	7.5	6.0	21.0
25	35.20	35.08	5.26	1.82	54.1	5.2	8.8	9.0	8.8	26.6
26	34.45	35.61	5.26	1.80	54.3	5.0	9.0	9.0	9.0	27.0
27	34.25	35.95	5.34	2.18	54.7	6.1	9.2	9.0	9.1	27.3
28	34.95	36.95	5.02	1.22	56.8	3.3	9.0	8.4	8.4	25.8
29	35.35	35.15	5.27	2.25	54.4	6.4	8.5	8.6	7.5	24.6
30	35.85	34.86	5.37	2.03	54.3	5.8	9.2	9.0	8.4	26.6
31	35.35	36.98	5.01	1.36	57.2	3.7	8.6	8.5	7.8	24.9
32	35.85	35.35	5.13	1.76	55.1	5.0	8.0	9.0	8.6	25.6
33	33.60	37.85	5.21	1.97	57.0	5.2	8.8	8.4	8.0	25.2
34	33.95	37.41	5.26	2.01	56.6	5.4	9.2	8.8	8.5	26.5
35	34.90	36.33	5.23	1.83	55.8	5.0	9.2	9.0	8.8	27.0
36	34.40	36.07	5.35	1.98	55.0	5.5	9.3	9.1	9.0	27.4
37	35.20	36.54	5.42	1.61	56.4	4.4	8.5	8.5	9.0	26.0
38	33.00	38.59	5.36	2.22	57.6	5.7	8.7	8.4	8.6	25.7
39	35.60	32.94	5.52	2.77	51.1	8.4	8.0	7.5	6.5	22.0
40	34.85	34.95	5.51	2.20	53.6	6.3	9.0	8.8	8.4	26.2

Table 9

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
41	33.80	35.90	5.44	2.12	54.2	5.9	9.2	9.0	9.0	27.2
42	33.50	36.52	5.38	1.95	54.7	5.3	9.0	8.6	9.0	26.6
43	35.00	36.85	5.06	1.47	56.7	4.0	8.5	8.5	8.8	25.8
44	34.70	36.18	5.10	1.43	55.4	3.9	9.4	9.2	9.4	28.0
45	34.40	36.50	5.07	1.63	55.6	4.5	8.8	8.7	9.0	26.5
46	34.15	37.36	5.12	1.54	56.7	4.1	9.4	9.3	9.3	28.0
47	34.80	35.61	5.42	1.97	54.6	5.5	8.6	8.5	8.4	25.5
48	34.30	36.82	5.42	1.81	56.0	4.9	8.4	8.7	8.8	25.9
49	35.55	34.99	5.46	1.76	54.3	5.0	8.0	8.4	8.0	24.4
50	35.00	34.86	5.35	1.97	53.6	5.6	9.0	8.8	8.8	26.6
51	34.35	35.46	5.41	2.06	54.0	5.8	8.8	8.7	8.0	25.5
52	34.90	35.52	5.27	1.86	54.6	5.2	9.0	8.8	8.8	26.6
53	32.25	38.47	5.01	1.59	56.8	4.1	9.0	8.8	7.5	25.3
54	33.30	37.21	5.03	1.73	55.8	4.6	9.2	9.0	8.5	26.7
55	33.40	37.64	5.07	1.82	56.5	4.8	8.8	8.8	8.7	26.3
56	32.45	38.30	5.00	1.69	56.7	4.4	9.0	8.7	8.7	26.4
57	31.70	39.11	5.14	1.37	57.3	3.5	9.2	8.7	8.8	26.7
58	31.95	38.38	5.20	1.49	56.4	3.9	9.0	8.6	8.8	26.4
59	31.50	39.57	5.16	1.33	57.8	3.4	9.2	9.0	9.0	27.2
60	31.95	38.67	5.10	1.45	56.8	3.7	9.1	8.8	9.0	26.9

Table 10

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
61	32.50	39.21	5.20	0.95	58.1	2.4	9.1	9.0	8.8	26.9
62	33.35	37.53	5.05	1.49	56.3	4.0	9.0	8.8	8.8	26.6
63	31.75	38.28	5.17	1.63	56.1	4.2	8.8	8.0	8.4	25.2
64	32.15	38.32	4.97	1.46	56.5	3.8	8.8	8.4	8.4	25.6
65	33.30	37.13	5.08	1.54	55.7	4.1	8.8	8.4	8.2	25.4
66	33.25	35.63	5.32	0.68	53.4	1.9	8.8	8.4	7.5	24.7
67	32.90	38.08	5.05	1.23	56.7	3.2	8.5	8.2	8.4	25.1
68	31.80	39.17	5.03	1.67	57.4	4.3	8.5	8.2	8.4	25.1
69	32.75	37.75	5.05	1.65	56.1	4.4	9.0	8.8	8.5	26.3
70	32.50	38.28	5.06	1.49	56.7	3.9	8.9	8.8	8.7	26.4
71	32.25	37.96	5.08	1.62	56.0	4.3	9.0	9.0	8.9	26.9
72	32.05	38.22	5.15	1.66	56.2	4.3	8.9	8.6	8.6	26.1
73	32.00	38.59	5.05	1.53	56.7	4.0	9.0	8.8	8.6	26.4
74	32.70	37.51	5.16	1.65	55.7	4.4	9.1	9.0	8.8	26.9
75	33.90	36.74	5.07	1.34	55.6	3.6	9.6	9.4	9.5	28.5
76	34.30	37.32	4.90	1.28	56.8	3.4	8.8	8.5	8.0	25.3
77	34.90	35.16	4.97	1.48	54.0	4.2	9.4	9.3	9.2	27.9
78	34.80	35.07	5.08	1.74	53.8	5.0	9.1	9.1	9.0	27.2
79	34.60	36.20	5.07	1.58	55.3	4.4	9.4	8.8	9.0	27.2
80	34.35	35.53	5.07	1.71	54.1	4.8	9.5	9.4	9.0	27.9

Table 11

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
81	34.90	35.49	5.29	1.93	54.5	5.4	8.5	8.4	8.0	24.9
82	35.05	35.73	5.39	2.00	55.0	5.6	9.0	8.5	7.0	24.5
83	34.45	36.12	5.32	1.81	55.1	5.0	8.7	8.5	8.0	25.2
84	35.20	35.03	5.42	2.15	54.0	6.1	8.8	8.5	7.0	24.3
85	33.30	38.45	5.14	1.25	57.6	3.2	9.0	8.6	9.0	26.6
86	32.45	38.53	5.10	1.29	57.0	3.3	9.0	8.9	9.0	26.9
87	32.25	38.38	5.11	1.33	56.6	3.5	9.0	8.6	8.8	26.4
88	32.25	38.78	5.15	1.15	57.2	3.0	9.0	8.8	8.8	26.6
89	32.40	37.74	5.17	1.53	55.8	4.0	8.8	8.6	8.5	25.9
90	32.75	38.06	5.15	1.43	56.6	3.7	9.0	8.8	8.7	26.5
91	32.15	38.22	5.14	1.15	56.3	3.0	8.6	8.5	8.0	25.1
92	31.85	37.83	5.27	1.78	55.5	4.7	8.7	8.2	8.0	24.9
93	31.10	39.02	5.20	1.13	56.6	2.9	8.8	8.4	8.6	25.8
94	32.65	38.10	5.10	1.48	56.6	3.9	9.0	8.8	8.8	26.6
95	32.40	38.47	5.15	1.16	56.9	3.0	8.7	8.6	8.7	26.0
96	32.60	37.65	5.14	1.28	55.9	3.4	8.8	8.5	8.8	26.1
97	36.10	35.87	5.34	1.75	56.1	4.9	8.9	8.9	8.8	26.6
98	35.40	36.27	5.12	1.32	56.1	3.6	9.0	9.0	9.0	27.0
99	35.40	35.37	5.13	1.78	54.7	5.0	9.0	9.0	8.9	26.9
100	35.20	35.80	5.12	1.77	55.2	4.9	8.9	8.8	8.9	26.6

Table 12

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
101	35.35	35.77	5.14	1.84	55.3	5.1	8.8	8.8	8.6	26.2
102	34.90	36.74	5.14	1.40	56.4	3.8	9.0	9.0	8.9	26.9
103	34.80	36.34	5.50	2.10	55.7	5.8	8.5	8.6	8.6	25.7
104	35.50	35.62	5.15	1.36	55.2	3.8	9.1	9.0	8.8	26.9
105	35.05	36.49	5.09	1.27	56.2	3.5	9.3	9.0	9.0	27.3
106	35.75	35.19	5.35	1.66	54.8	4.7	8.9	8.8	8.8	26.5
107	35.95	35.04	5.24	1.44	54.7	4.1	9.3	9.1	9.0	27.4
108	35.90	35.34	5.18	1.42	55.1	4.0	9.2	8.9	9.0	27.1
109	32.95	37.46	5.11	1.60	55.9	4.3	9.0	8.5	8.6	26.1
110	32.95	37.68	5.12	1.50	56.2	4.0	9.0	8.9	8.8	26.7
111	32.90	37.70	5.24	1.70	56.2	4.5	8.8	8.0	8.5	25.3
112	32.55	38.36	5.18	1.59	56.9	4.1	8.3	8.0	8.5	24.8
113	34.75	35.56	5.07	1.51	54.5	4.2	9.2	8.8	8.8	26.8
114	35.20	35.50	4.99	1.66	54.8	4.7	9.3	9.2	8.8	27.3
115	35.65	34.08	5.11	1.94	53.0	5.7	9.0	8.7	8.5	26.2
116	34.85	35.58	5.03	1.67	54.6	4.7	9.2	9.0	8.8	27.0
117	35.25	35.14	5.02	1.59	54.3	4.5	9.0	8.8	8.8	26.6
118	34.50	35.62	5.23	1.84	54.4	5.2	9.0	8.7	8.6	26.3
119	34.90	35.55	5.01	1.81	54.6	5.1	8.4	8.0	7.5	23.9
120	34.50	36.23	5.05	1.44	55.3	4.0	8.2	7.8	8.5	24.5

Table 13

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
121	33.25	38.06	5.22	1.70	57.0	4.5	7.5	8.2	8.8	24.5
122	33.55	37.44	5.33	1.89	56.3	5.0	7.5	8.2	8.8	24.5
123	33.45	37.05	5.31	1.94	55.7	5.2	8.0	8.5	8.8	25.3
124	33.20	37.21	5.21	1.65	55.7	4.4	8.8	8.5	8.5	25.8
125	33.35	38.06	5.14	1.44	57.1	3.8	9.0	8.8	8.8	26.6
126	33.10	37.55	5.16	1.52	56.1	4.0	8.8	8.8	8.8	26.4
127	33.45	37.25	5.18	1.39	56.0	3.7	8.8	8.2	8.8	25.8
128	33.65	37.32	5.15	1.35	56.2	3.6	9.1	8.8	9.0	26.9
129	34.15	34.28	5.11	2.07	52.0	6.0	9.2	8.9	8.9	27.0
130	34.75	33.77	5.13	2.02	51.7	6.0	9.2	8.9	8.8	26.9
131	33.95	34.72	5.09	1.92	52.6	5.5	9.1	8.7	8.8	26.6
132	34.55	34.71	5.05	1.88	53.0	5.4	9.2	9.0	9.0	27.2
133	34.35	34.07	5.09	1.86	51.9	5.5	8.8	8.9	8.8	26.5
134	34.95	33.73	5.11	1.91	51.8	5.7	8.8	8.9	8.9	26.6
135	34.60	35.05	5.02	1.68	53.6	4.8	9.3	9.2	9.2	27.7
136	34.15	35.15	5.08	1.66	53.4	4.7	8.8	8.9	9.0	26.7
137	36.50	32.13	5.43	2.35	50.6	7.3	8.7	8.0	7.5	24.2
138	34.40	34.61	5.08	1.47	52.7	4.2	9.1	8.9	9.0	27.0
139	30.90	40.54	4.98	1.52	58.7	3.7	9.1	8.0	8.8	25.9
140	32.40	37.18	5.12	1.79	55.0	4.8	8.8	8.5	8.7	26.0

Table 14

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
141	32.75	35.81	5.34	2.22	53.2	6.2	9.0	8.8	8.5	26.3
142	32.15	37.84	5.07	1.64	55.8	4.3	9.0	8.8	8.6	26.4
143	32.25	37.08	5.20	2.06	54.7	5.5	9.1	8.6	8.8	26.5
144	32.65	37.39	5.12	1.83	55.5	4.9	8.8	8.6	8.6	26.0
145	32.75	36.67	5.23	2.00	54.5	5.4	8.9	8.8	8.8	26.5
146	32.15	37.71	5.12	1.80	55.6	4.8	9.1	8.9	9.0	27.0
147	31.50	37.80	5.06	1.48	55.2	3.9	8.8	8.7	8.8	26.3
148	32.10	36.97	5.18	1.60	54.4	4.3	8.9	8.9	8.9	26.7
149	32.85	36.50	5.21	1.95	54.3	5.3	8.9	8.9	8.8	26.6
150	32.40	37.05	5.17	1.93	54.8	5.2	8.8	8.7	8.8	26.3
151	32.60	37.01	5.19	1.84	54.9	5.0	8.7	8.7	8.8	26.2
152	32.35	37.13	5.17	1.64	54.9	4.4	9.0	8.9	8.9	26.8
153	32.25	37.43	5.14	1.53	55.2	4.1	8.7	8.7	8.5	25.9
154	32.75	36.56	5.11	1.68	54.4	4.6	8.9	8.6	8.9	26.4
155	32.90	37.66	5.11	1.35	56.1	3.6	8.9	8.8	8.8	26.5
156	32.50	38.42	5.05	1.52	56.9	3.9	9.0	8.8	8.7	26.5
157	32.40	37.95	5.10	1.58	56.1	4.2	8.9	8.9	8.9	26.7
158	32.95	36.41	5.17	1.40	54.3	3.8	9.0	8.8	8.7	26.5
159	31.45	39.44	5.02	1.29	57.5	3.3	8.0	8.5	8.4	24.9
160	31.90	37.30	5.23	1.40	54.8	3.7	8.0	8.6	8.0	24.6

Table 15

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
161	33.50	37.03	5.14	1.39	55.7	3.7	8.2	8.6	8.2	25.0
162	31.35	39.98	5.05	1.35	58.2	3.4	8.8	8.2	8.6	25.6
163	33.95	36.80	5.02	1.55	55.7	4.2	9.1	8.8	9.0	26.9
164	34.85	36.37	4.99	1.62	55.8	4.4	9.0	8.4	8.8	26.2
165	33.75	37.25	5.00	1.49	56.2	4.0	9.2	8.8	8.8	26.8
166	34.85	35.87	4.98	1.64	55.0	4.6	9.1	9.0	9.0	27.1
167	34.40	35.96	5.04	1.90	54.8	5.3	9.2	9.0	9.1	27.3
168	35.25	34.51	5.11	2.04	53.3	5.9	9.2	9.1	8.8	27.1
169	34.85	35.02	5.09	1.79	53.7	5.1	9.0	8.9	8.9	26.8
170	34.35	35.82	4.98	1.60	54.6	4.5	9.4	9.3	9.2	27.9
171	33.95	36.24	5.01	1.91	54.9	5.3	9.1	8.6	8.8	26.5
172	33.85	36.48	5.00	1.58	55.1	4.3	9.3	9.2	8.8	27.3
173	33.50	36.53	5.00	1.76	54.9	4.8	9.0	8.8	9.0	26.8
174	34.90	35.29	5.06	1.91	54.2	5.4	9.2	9.0	8.9	27.1
175	34.30	36.33	5.07	0.96	55.3	2.6	9.4	9.0	9.2	27.6
176	33.95	36.95	5.05	0.90	55.9	2.4	9.2	8.8	9.0	27.0
177	34.95	34.81	5.11	1.34	53.5	3.8	9.2	8.8	8.9	26.9
178	35.40	34.23	5.12	1.41	53.0	4.1	9.0	8.9	8.8	26.7
179	34.40	34.83	5.17	1.49	53.1	4.3	9.4	9.0	9.0	27.4
180	34.35	35.37	5.12	1.37	53.9	3.9	9.2	9.0	9.1	27.3

Table 16

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
181	35.50	33.47	5.17	1.63	51.9	4.9	9.4	9.2	9.0	27.6
182	35.05	34.51	5.09	1.35	53.1	3.9	9.0	8.7	8.5	26.2
183	34.60	36.09	5.12	1.17	55.2	3.2	9.3	9.1	9.2	27.6
184	34.65	36.40	5.05	1.29	55.7	3.5	9.2	9.0	8.8	27.0
185	32.00	38.20	5.04	1.64	56.2	4.3	9.0	8.8	8.9	26.7
186	32.60	37.26	5.15	1.51	55.3	4.0	8.8	8.7	8.8	26.3
187	32.20	38.35	5.05	1.51	56.6	3.9	8.8	8.8	8.9	26.5
188	32.85	37.38	5.12	1.83	55.7	4.9	9.0	8.9	8.9	26.8
189	33.10	37.92	4.99	1.50	56.7	3.9	9.0	8.8	9.0	26.8
190	32.85	36.67	5.13	1.79	54.6	4.9	9.0	8.9	8.6	26.5
191	32.85	36.90	5.20	2.08	54.9	5.6	8.9	8.5	8.0	25.4
192	32.70	38.15	5.09	1.62	56.7	4.2	8.8	8.6	8.8	26.2
193	33.00	36.40	5.28	1.96	54.3	5.4	8.7	8.4	8.0	25.1
194	32.45	36.48	5.35	2.29	54.0	6.3	8.8	8.2	8.0	25.0
195	31.95	37.92	5.11	1.59	55.7	4.2	8.7	8.2	8.2	25.1
196	31.45	38.38	5.08	1.34	56.0	3.5	8.8	8.2	8.0	25.0
197	34.40	35.71	5.01	1.57	5.44	4.4	9.2	8.8	9.0	27.0
198	35.25	33.68	5.05	1.82	52.0	5.4	9.4	9.0	9.0	27.4
199	34.80	35.40	5.03	1.68	54.3	4.7	9.2	8.9	9.0	27.1
200	34.50	35.16	4.99	1.72	53.7	4.9	9.4	8.9	9.0	27.3

Table 17

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
201	34.80	35.62	4.98	1.62	54.6	4.5	9.4	9.1	9.1	27.6
202	34.50	34.80	4.99	1.69	53.1	4.8	9.2	8.9	8.9	27.0
203	34.50	35.89	4.97	1.62	54.8	4.5	9.3	8.9	8.8	27.0
204	34.40	35.73	5.02	1.72	54.5	4.8	9.2	9.0	9.0	27.2
205	35.45	34.43	5.16	1.90	53.3	5.5	9.0	8.8	9.0	26.8
206	34.65	35.73	4.99	1.58	54.7	4.4	9.3	9.2	9.1	27.6
207	35.05	34.81	5.08	1.71	53.6	4.9	9.4	9.2	9.1	27.7
208	35.30	34.53	5.12	1.83	53.4	5.3	9.4	8.8	8.9	27.1
209	33.45	37.28	5.11	1.72	56.0	4.6	9.0	8.9	8.9	26.8
210	32.80	37.54	5.13	1.55	55.9	4.1	9.2	8.9	8.9	27.0
211	33.50	36.69	5.15	1.85	55.2	5.0	9.0	8.9	8.8	26.7
212	32.70	37.39	5.12	1.66	55.5	4.4	9.2	9.1	9.0	27.3
213	33.30	36.91	5.09	1.63	55.3	4.4	9.0	8.9	8.9	26.8
214	33.45	36.94	5.13	1.79	55.5	4.8	9.2	9.0	9.0	27.2
215	33.10	37.59	5.07	1.70	56.2	4.5	9.1	8.0	8.7	25.8
216	33.90	36.48	5.22	2.04	55.2	5.6	8.8	8.2	8.4	25.4
217	32.95	38.44	5.05	1.41	57.3	3.7	9.1	8.0	8.4	25.5
218	32.25	38.14	5.13	1.42	56.3	3.7	9.1	8.2	8.8	26.1
219	31.95	39.72	5.08	1.12	58.4	2.8	8.5	8.2	8.6	25.3
220	33.30	38.06	5.08	1.64	57.1	4.3	9.0	8.0	8.2	25.2

[illegible]

Table 18

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
221	33.80	35.14	5.21	1.72	53.1	4.9	7.0	8.5	8.2	23.7
222	34.10	36.02	5.11	1.54	54.6	4.3	9.4	9.0	9.2	27.6
223	34.40	34.75	5.14	1.64	53.0	4.7	9.3	9.2	9.1	27.6
224	32.90	36.62	5.11	1.54	54.6	4.2	9.2	8.8	9.0	27.0
225	33.55	35.58	5.28	1.92	53.5	5.4	9.2	9.0	8.8	27.0
226	34.25	36.36	5.05	1.39	55.3	3.8	8.8	8.9	8.8	26.5
227	33.70	36.37	5.06	1.38	54.8	3.8	8.5	8.7	8.8	26.0
228	33.25	36.89	5.04	1.38	55.3	3.7	8.9	8.8	8.8	26.5
229	34.40	35.96	4.96	1.68	54.8	4.7	8.8	8.0	8.0	24.8
230	34.65	34.44	5.11	2.03	52.7	5.9	8.0	8.2	8.0	24.2
231	34.45	36.26	4.96	1.50	55.3	4.1	8.8	8.0	7.5	24.3
232	33.00	37.77	5.04	1.25	56.4	3.3	9.0	7.8	7.7	24.5
233	32.90	37.55	4.93	1.65	56.0	4.4	8.8	7.8	7.3	23.9
234	36.10	32.28	5.35	2.29	50.5	7.1	7.5	8.0	7.0	22.5
235	35.75	33.37	5.24	2.18	51.9	6.5	7.8	8.0	7.5	23.3
236	33.65	35.35	5.06	1.76	53.3	5.0	9.0	8.8	8.8	26.6
237	34.15	34.55	5.14	1.92	52.5	5.5	8.8	8.7	8.7	26.2
238	34.35	35.36	5.13	2.09	53.9	5.9	8.8	8.6	8.6	26.0
239	33.55	36.82	4.99	1.45	55.4	3.9	9.0	8.8	8.8	26.6
240	33.20	36.25	5.02	1.59	54.3	4.4	9.1	8.9	8.9	26.9

[illegible]

Table 19

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
241	32.65	37.11	5.19	1.63	55.1	4.4	8.3	8.0	8.0	24.3
242	33.10	36.54	5.15	1.81	54.6	4.9	8.6	7.8	8.1	24.5
243	33.15	37.55	5.13	1.73	56.2	4.6	8.8	7.9	8.4	25.1
244	33.30	36.38	5.12	1.71	54.5	4.7	8.6	8.0	8.4	25.0
245	33.10	38.38	5.04	1.56	57.4	4.1	8.8	7.8	8.8	25.4
246	33.30	36.54	5.10	1.80	54.8	4.9	9.0	7.8	8.2	25.0
247	33.55	36.10	5.20	1.91	54.3	5.3	8.8	8.0	8.2	25.0
248	33.20	37.04	5.20	1.93	55.4	5.2	7.5	8.0	8.0	23.5
249	32.60	38.09	5.01	1.60	56.5	4.2	9.0	7.8	7.8	24.6
250	32.90	35.88	5.50	2.95	53.5	8.2	8.0	8.0	7.0	23.0
251	31.05	37.11	5.27	1.96	53.8	5.3	9.0	8.0	7.5	24.5
252	32.60	37.68	5.11	1.83	55.9	4.8	8.9	7.8	8.6	25.3
253	34.55	36.07	5.05	1.55	55.1	4.3	9.2	8.0	8.0	25.2
254	33.75	36.28	4.97	1.58	54.8	4.3	9.1	7.8	7.5	24.4
255	32.95	36.09	5.03	1.65	53.8	4.6	9.0	7.8	8.2	25.0
256	35.35	32.80	5.19	2.04	50.7	6.2	8.9	8.2	8.0	25.1
257	35.75	32.77	5.21	1.94	51.0	5.9	8.8	8.0	7.8	24.6
258	33.85	35.11	5.06	1.87	53.1	5.3	9.3	9.0	9.0	27.3
259	34.80	33.81	5.13	1.81	51.8	5.3	9.2	8.8	8.8	26.8
260	34.70	33.94	5.14	1.94	52.0	5.7	9.3	8.8	8.8	26.9

[illegible]

Table 20

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
261	33.65	35.93	5.07	1.65	54.1	4.6	9.4	8.6	9.0	27.0
262	33.85	36.77	5.11	1.51	55.6	4.1	9.4	9.2	9.2	27.8
263	33.90	36.09	5.10	1.78	54.6	4.9	9.4	9.3	9.3	28.0
264	34.15	33.97	5.09	2.21	51.6	6.5	9.2	8.8	8.8	26.8
265	32.65	36.56	5.16	2.06	54.3	5.6	8.5	8.6	8.8	25.9
266	32.50	37.56	5.01	1.79	55.6	4.8	8.8	8.4	9.0	26.2
267	31.40	38.48	5.03	1.63	56.1	4.2	9.1	8.8	8.5	26.4
268	31.70	38.52	5.06	1.25	56.4	3.2	8.8	8.0	9.0	25.8
269	32.20	36.88	5.11	1.74	54.4	4.7	9.1	9.0	9.2	27.3
270	31.95	37.40	5.09	1.61	54.9	4.3	8.9	8.8	8.8	26.5
271	32.45	35.93	5.24	2.10	53.2	5.8	8.9	9.0	8.9	26.8
272	32.15	38.82	5.08	1.33	57.2	3.4	9.1	8.6	9.2	26.9
273	31.50	38.30	5.11	1.64	55.9	4.3	8.8	8.5	8.6	25.9
274	31.15	37.85	5.10	1.50	55.0	4.0	8.9	9.2	9.2	27.3
275	31.85	37.71	5.09	1.68	55.3	4.4	8.9	9.0	9.0	26.9
276	31.80	37.64	5.11	1.82	55.2	4.8	8.9	8.8	8.8	26.5
277	32.00	37.40	5.19	1.79	55.0	4.8	7.0	8.0	9.0	24.0
278	32.60	37.63	5.16	1.49	55.8	3.9	6.8	8.0	8.8	23.6
279	32.35	37.54	5.16	1.47	55.5	3.9	6.8	8.0	8.8	23.6
280	32.25	37.84	5.18	1.54	55.8	4.1	6.5	8.5	8.5	23.5

Table 21

The analysis of and points scored by commercial Cheddar cheese at time of grading

Sample no.	Analysis						Grading			
	Fat, %	Moisture, %	pH	Salt, %	MFFC, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
281	31.90	38.67	5.08	1.88	56.8	4.9	8.0	7.5	8.0	23.5
282	32.55	37.67	5.08	1.79	55.8	4.7	8.8	7.8	8.0	24.6
283	32.55	38.24	5.09	1.51	56.7	3.9	9.0	8.8	9.0	26.8
284	32.65	36.21	5.24	2.01	53.8	5.5	9.0	8.9	8.5	26.4
285	32.40	37.63	5.22	1.56	55.7	4.1	9.0	8.8	8.8	26.6
286	32.25	38.20	5.14	1.67	56.4	4.4	9.1	8.5	9.0	26.6
287	32.05	37.89	5.03	1.92	55.8	5.1	9.0	8.5	8.6	26.1
288	32.20	38.40	5.00	1.81	56.6	4.7	8.8	8.5	8.5	25.8
289	32.85	36.04	5.08	1.76	53.7	4.9	8.8	7.4	8.8	25.0
290	32.00	38.36	5.08	1.72	56.4	4.5	8.5	7.5	8.8	24.8
291	33.20	37.38	5.10	1.43	55.9	3.8	8.5	7.6	8.5	24.6
292	33.00	36.28	5.12	1.72	54.1	4.7	8.2	7.8	8.5	24.5
293	33.20	36.86	5.13	1.75	55.2	4.7	7.4	8.0	8.7	24.1
294	32.25	37.27	5.13	1.59	55.0	4.3	8.0	8.1	8.6	24.7
295	32.25	36.54	5.13	1.66	53.9	4.5	8.5	8.0	8.5	25.0
296	31.95	37.81	5.19	1.41	55.6	3.7	8.5	7.6	8.5	24.6
297	31.75	36.44	5.11	1.86	53.4	5.1	8.6	7.8	8.8	25.2
298	32.55	34.97	5.30	2.12	51.8	6.1	8.0	7.8	7.5	23.3
299	30.70	38.68	5.09	1.51	55.8	3.9	7.5	7.5	8.0	23.0
300	32.05	36.92	5.15	1.76	54.3	4.8	7.5	7.8	7.5	22.8

[illegible]

would not normally find acceptable. As the remarks of the official cheese grader agreed so closely with the chemical analyses of the cheese e.g. where the grader considered that a cheese had a high moisture content this was usually verified by the chemical procedures, they are not recorded.

Correlation coefficients for each of the 10 variates are recorded in Table 22. It is apparent from these figures that quite definite relationships do exist between the chemical analyses and the subjective measurements for (a) flavour and aroma, (b) body and (c) texture.

The partial correlation coefficients were calculated in order to compare the simple correlation coefficients (Table 22) with the net effect of each one of the 6 factors (fat, moisture and salt contents, salt concentration, moisture in fat free cheese and pH values) on the flavour and aroma, body, texture and total scores, after the full effect of the other 5 factors was considered. In Table 27 the partial correlation coefficients are recorded.

Table 22

Correlation coefficients of the various characteristics of commercial Cheddar cheese

Fat, %									
-0.768***	Moisture, %								
0.166	-0.250*	pH							
0.243*	-0.475***	0.544***	Salt, %						
0.163	-0.101	-0.280**	-0.157	Flavour & aroma					
0.260**	-0.160	-0.156	-0.183	0.545***	Body				
-0.009	0.120	-0.353***	-0.373***	0.432***	0.695***	Texture			
0.369***	-0.625***	0.539***	0.982***	-0.124	-0.139	-0.367***	Salt concentration		
-0.397***	0.892***	-0.240*	-0.508***	-0.030	-0.050	0.163	-0.635***	MFFC	
0.155	-0.046	-0.320**	-0.290**	0.780***	0.881***	0.857***	-0.258**	0.040	Total score

*** $P < 0.001$, ** $P < 0.01$. * $P < 0.05$.

[illegible]

Table 23

The mean, minimum and maximum values and standard deviations of various characteristics of commercial Cheddar cheese

	Mean	Minimum	Maximum	Standard deviation
Fat, %	33.60	29.95	37.60	1.26
Moisture, %	36.61	32.13	40.54	1.41
pH	5.14	4.90	5.52	0.12
Salt, %	1.68	0.68	2.95	0.29
Flavour and aroma, (10)	8.8	6.5	9.6	0.50
Body, (10)	8.6	6.0	9.4	0.46
Texture, (10)	8.6	5.0	9.5	0.55
Salt concentration, %	4.6	1.9	8.4	0.89
MFFC, %	55.1	50.2	58.7	1.49
Total score	26.0	19.5	28.5	1.27

Table 24

Frequency distribution of the fat, moisture and pH values of 300 commercial Cheddar cheese

Fat, %	No. of samples	% of total no. of samples	Moisture, %	No. of samples	% of total no. of samples	pH	No. of samples	% of total no. of samples
29.50-30.45	1	0.3	31.50-32.45	2	0.7	4.85-4.94	2	0.7
30.50-31.45	9	3.0	32.50-33.45	5	1.7	4.95-5.04	51	17.0
31.50-32.45	58	19.3	33.50-34.45	12	4.0	5.05-5.14	136	45.3
32.50-33.45	77	25.7	34.50-35.45	45	15.0	5.15-5.24	63	21.0
33.50-34.45	71	23.7	35.50-36.45	70	23.3	5.25-5.34	21	7.0
34.50-35.45	68	22.7	36.50-37.45	78	26.0	5.35-5.44	20	6.7
35.50-36.45	14	4.7	37.50-38.45	70	23.3	5.45-5.54	7	2.3
36.50-37.45	1	0.3	38.50-39.45	14	4.7			
37.50-38.45	11	0.3	39.50-40.45	3	1.0			
			40.50-41.45	1	0.3			

Table 25

Frequency distribution of (a) flavour, (b) body and (c) texture scores of 300 commercial Cheddar cheese

Flavour & aroma (10)	No. of samples	% of total no. of samples	Body (10)	No. of samples	% of total no. of samples	Texture (10)	No. of samples	% of total no. of samples
6.5-7.1	7	2.3	6.0-6.6	1	0.3	5.0-5.6	1	0.3
7.2-7.8	10	3.3	6.7-7.3	1	0.3	5.7-6.3	1	0.3
7.9-8.5	35	11.7	7.4-8.0	55	18.3	6.4-7.0	6	2.0
8.6-9.2	217	72.3	8.1-8.7	92	30.7	7.1-7.7	15	5.0
9.3-9.6	31	10.3	8.8-9.4	151	50.3	7.8-8.4	56	18.7
						8.5-9.1	207	69.0
						9.2-9.5	14	4.7

Table 26

Frequency distribution of the salt, salt concentration and moisture in fat free cheese percentages of 300 commercial Cheddar cheese

Salt, %	No. of samples	% of total no. of samples	Salt concentration,%	No. of samples	% of total no.of samples	MFFC, %	No. of samples	% of total no. of samples
0.65-0.84	1	0.3	1.0-1.9	1	0.3	50.0-50.9	4	1.3
0.85-1.04	3	1.0	2.0-2.9	5	1.7	51.0-51.9	10	3.3
1.05-1.24	8	2.7	3.0-3.9	62	20.7	52.0-52.9	7	2.3
1.25-1.44	43	14.3	4.0-4.9	141	47.0	53.0-53.9	36	12.0
1.45-1.64	81	27.0	5.0-5.9	70	23.3	54.0-54.9	70	23.3
1.65-1.84	90	30.0	6.0-6.9	17	5.7	55.0-55.9	81	27.0
1.85-2.04	45	15.0	7.0-7.9	2	0.7	56.0-56.9	70	23.3
2.05-2.24	21	7.0	8.0-8.9	2	0.7	57.0-57.9	18	6.0
2.25-2.44	5	1.7				58.0-58.9	4	1.3
2.45-2.64	1	0.3						
2.65-2.84	1	0.3						
2.85-3.04	1	0.3						

Table 27

The partial correlation coefficients of the various characteristics of commercial Cheddar cheese at 8 to 10 weeks old

	Flavour[5] and aroma	Body[6]	Texture[7]	Total score[10]
Fat, [1]%	0.045	0.282**	0.336***	0.269**
Moisture, [2]%	0.034	0.265**	0.322**	0.252*
pH[3]	-0.222*	-0.005	-0.111	-0.145
Salt, [4]%	0.091	0.295**	0.372***	0.308**
Salt concentration, [8]%	-0.095	-0.306**	-0.384***	-0.318**
MFFC [9]	-0.041	-0.276**	-0.335***	-0.265**

*** $P < 0.001$. ** $P < 0.01$, * $P < 0.05$

In Table 27 the variates are numbered 1 to 10 for ease in designating the partial correlation coefficient to which one might be referring e.g. the partial correlation coefficient between the fat content of the cheese and the flavour and aroma score is designated r 15.23489. By comparison of Tables 22 and 27 one may observe that there is a similarity in certain cases between the partial and simple correlation coefficients. However, in some instances the partial correlation coefficient is significant e.g. fat content and texture score, whereas the simple correlation coefficient is not significant, where r 17.23489 = 0.336 and r = 0.009. The reverse situation occurs between pH value and texture score. When the single influence of pH on texture was considered, the correlation coefficient was -0.353 ($P < 0.001$). The apparent effect of the pH is then

markedly reduced ($r_{37.12489} = -0.111$) when the influence of the fat and moisture content, salt, salt concentration and MFFC (moisture in fat free cheese) are considered.

Since a number of the correlation coefficients (Table 22) were significant ($P<0.001$, $P<0.01$ or $P<0.05$) or almost significant, regression equations were calculated which might be utilised in the prediction of flavour and aroma, body, texture or total scores of Cheddar cheese. A number of these regression equations are recorded below and for each equation are recorded (a) a multiple correlation coefficient (R) i.e. the degree of correlation between the actual and predicted value and (b) a "% explained" figure which indicates the % variability with which the dependent variate is associated with the independent variates used in the particular regression equation.

The following abbreviations are used in the equations recorded below.

M = Moisture, %

F = Fat, %

S = Salt, %

SC = Salt concentration, %

MFFC = Moisture in fat free cheese, %

(1) Flavour and aroma = 16.3-0.15M-1.36pH+0.09 MFFC
R = 0.35 12.4% explained

(2) Body = -93.4+3.64F+5.94M+10.22S-3.86SC-4.30 MFFC
R = 0.48 23.0% explained

(3) Texture =-127.7+4.94F+8.22M-0.53pH+14.81S-5.57SC-5.94MFFC
R = 0.56 30.9% explained

(4) Texture =-137.8+5.22F+8.69M+15.66S-5.92SC-6.28MFFC
R = 0.55 30.0% explained

(5) Total score = -219.7+9.20F+14.97M-1.65pH+28.45S-10.73SC-10.91MFFC
R = 0.52 26.8% explained

The above equations would require numerous and lengthy calculations and

it was considered that equations utilising less variables may be of more practical value and also sufficiently accurate for prediction purposes. These are recorded below.

(6) Flavour and aroma = 12.8+0.08F-1.33 pH
R = 0.35   12.3% explained

(7) Flavour and aroma = 6.6 + 0.08F - 0.36S
R = 0.26   6.7% explained

(8) Flavour and aroma = 14.8-1.17pH-0.02S
R = 0.28   7.8% explained

(9) Body = 5.3 + 0.12F - 0.42S
R = 0.36   13.2% explained

(10) Body = 13.3 - 0.10M - 0.54S
R = 0.34   11.3% explained

(11) Texture = 14.5 - 0.99pH - 0.49S
R = 0.41   17.1% explained

(12) Texture = 14.5 - 1.02pH - 0.15SC
R = 0.41   16.9% explained

(13) Texture = 9.8 - 0.72S + 0.001Sc
R = 0.37   13.9% explained

(14) Texture = 9.8 - 0.71S
R = 0.37   13.9% explained

(15) Total score = 38.4 + 0.21F - 3.82pH
R = 0.38   14.7% explained

(16) Total score = 20.5 + 0.24F - 1.54S
R = 0.37   13.8% explained

(17) Total score = 49.9 - 0.12M - 3.80pH
R = 0.35   12.0% explained

(18) Total score = 40.3 - 0.30M - 0.66SC
R = 0.37   13.7% explained

It is obvious from the foregoing regression equations that where more values of independent variates are used the greater is the accuracy of prediction. In the case of equations (13) and (14) however, there does not appear to be an improvement in accuracy of prediction by using the value for salt concentration, the multiple correlation coefficient in both cases being 0.37.

DISCUSSION

Irvine et al. in Ontario (1962) found a range of fat content of 30.0% to 37.0%. This agrees closely with the results (29.95% to 37.60%) recorded above while a much narrower range was obtained by Hawley et al. (1960) i.e. 31.38% to 34.75%. This latter set of figures are not really comparable to those of the author or Irvine et al. (1962) as they were obtained from cheese made at the same creamery.

The reason for such variations in fat content might range from composition of the milk due to the breed or feed of the cow and season of the year to the inadequate mixing of milk where it is stored in large quantities. Without standardization of the fat content of the milk the cheesemaker might find difficulty where milk of widely varying composition is used but the inadequate mixing of large quantities of milk prior to dispensing to the cheese vat is due to direct lack of supervision. As a result of the variation in fat content of milk throughout the year, the cheesemaker finds it necessary to alter his make procedure so as to obtain a cheese with a suitable moisture content both from the quality aspect and legal standards which may be in operation. The moisture contents of Cheddar cheese manufactured in South West Scotland varied from 32.13% to 40.54% with an average of 36.61%. The lower moisture content could mean a drastic reduction in yield while the higher moisture values although giving a greater yield are above the legal limit of 39.0% in force in Britain for Cheddar cheese (Cheese (Scotland) Regulations, 1966). Irvine et al. (1966) found on examination of 326 samples of Cheddar cheese a range of 31.5% to 36.4% i.e. a spread of just less than 5.0%. The same authors, (Irvine et al. 1962) had previously found a range of 30.5% to 40.5% moisture with a mean of 35.55%, these figures being slightly lower than those found by the writer and

DISCUSSION

[illegible] (1929) [illegible] to 27.0%. [illegible] (1960) [illegible] comparable to those of the [illegible] obtained from cheese made [illegible]

[illegible]

Nicholls (1941) who obtained an average of 36.69% moisture on examination of 363 samples of cheese.

Excess moisture in cheese curd may be removed by the addition of extra quantities of salt. If salting rates are selected judiciously the cheese quality may be improved by the removal of this extra moisture. It seems quite certain in some cases that the salt is added in some cheese factories without taking into consideration the condition of the curd. There are additional causes for variation in salt content of Cheddar cheese e.g. uneven or careless distribution of salt if carried out by hand or aggregations of salt in corners or crevices of equipment more especially where the later stages of the cheesemaking process are mechanised. The range of salt content recorded above is 0.68 to 2.95% with a mean value of 1.68%. The higher salt content of 2.95% is interesting in the light of work recorded in Section 3, Part V of this thesis. It was found by the author that with a salting rate of 6% the maximum % salt recovered in the cheese was about 2.6%. Cheesemakers endeavour to obtain a salt content in the mature cheese of between 1.4 to 1.8% and in order to obtain such a level salt is added to the milled curd at the rate of from 2 to 2½% of the weight of curd. The rate of salt addition should be varied depending on the moisture content of the curd after milling. It could be stated therefore that the figure of 2.95% salt is due to careless salt distribution whether salting is a mechanical or manual operation. Where salt contents of over 2.0% are obtained it is suggested that together with poor salt distribution the proper salting rate was not selected for the particular type of curd which might have been drier than normal due to a slow rate of acid production during the make procedure.

In the opinion of the author it is regrettable that at the present time in Britain there is no legal requirement governing the salt content of

Coimbra (1967) [illegible]

[illegible] of examples are given.

[illegible]

Cheddar cheese but for Australian cheese exported to Japan the salt content must be within the range 1.5 to 1.7% (Gunnis, 1966).

The results recorded above show a greater variation than that cited in the literature, Marquardt and Yale (1941) obtained a range of 0.70 to 1.86%, Irvine et al. (1966) obtained a range of 1.00 to 2.16% salt. As has been stated the addition of extra quantities of salt provide an effective means of removing moisture but where excessive amounts are used the resultant cheese will be dry, and lacking the typical flavour of Cheddar cheese. Because of the higher salt content bacterial activity is suppressed or retarded resulting in non-fermentation of the lactose and complete lack of acid production. The cheese is termed "sweet" by the official grader and subsequent analysis invariably shows that the cheese has a high pH value.

The pH range obtained in this experiment was from 4.90 to 5.52 with a mean of 5.14 and it can be said that where a cheese has a high salt content, i.e. greater than 2.0%, the cheese is usually termed "sweet" and has a higher than normal pH value. It has been suggested by the author that a particular starter culture may be blamed unfairly for its inability to produce acid during maturation of the cheese because its environment e.g. the concentration of salt in the aqueous phase, is completely unsuited for its growth. It does not follow, however, that a low salt content, less than 1.0%, will result in a low pH value because the amount of acid produced is also limited by the amount of lactose remaining in the curd at time of milling. In any case cheese with low salt content may be of inferior quality due to off flavours or weak body.

From the statistical analyses of the results there are some interesting observations to be made. Fat content is related to the body of the cheese but the moisture content, pH value and salt content are not significantly related to the body. These facts may be disturbing as it is generally [illegible] (Figure 3.19b).

In reality [illegible]

[illegible] (1977) [illegible] a range of [illegible]

[illegible] et al. (1980) [illegible]

[illegible]

accepted in the cheese industry that moisture content and the body of the cheese as assessed by the cheese grader are closely related. Fat and moisture content are not related to the total grade score but pH and salt content are significantly related ($P<0.01$). It may be suggested here that from the results recorded in Table 22 that the two more important chemical tests i.e. those tests which will be a better indication of overall cheese quality are pH and salt content. One will observe that there is a very definite relationship between the pH and the salt content ($r = 0.544$, $P<0.001$) and from the complete analyses of the cheese (Tables 7 to 21) one may observe that where one has a high salt content in a cheese the pH value is invariably high. Although moisture determinations may be made with the legal requirements in mind, the usefulness of fat determinations which are time consuming and possibly dangerous to the operator as sulphuric acid is used, is questionable except to ascertain if the cheese conforms to legal requirements for % fat in dry matter.

A parameter which is rarely mentioned in the literature and seldom if ever calculated in the cheese quality control programmes is that of salt concentration in the aqueous phase. The salt concentration in the aqueous phase which is calculated from the moisture and salt contents, is significantly related to the texture ($P<0.001$) and total grade ($P<0.01$) scores and also to the pH ($P<0.001$) and fat ($P<0.001$) contents.

The practical application of the results of experimental work is a very important consideration. It has been stated above that when the simple correlation coefficients were studied it appeared that there was a non significant relationship between the moisture content of Cheddar cheese and the score for body as assessed by the official cheese grader. From the partial correlation coefficient (Table 27) it appears that the body of the cheese is affected by the moisture content although not to a very high degree.

absorption in the cheese industry, that moisture content and the body of the cheese as assessed by the cheese grader are closely related. It is also [illegible] content are not related to the total score, but the fat content are significantly related (r = 0.02). It may be concluded then that from the results obtained in Table 26 this [illegible] most important [illegible]

[illegible] (r = 0.86) [illegible] (Tables 7 to 13) [illegible]

[illegible] legal requirements [illegible] in any manner.

[illegible]

As it is generally accepted in industry that moisture content and body of Cheddar cheese are closely related it was decided to plot a scatter diagram of moisture values and body scores of the 300 cheese examined. This indicated for example that for a range of moisture contents from 35% to 37% the scores for body ranged from 6.0 to 9.4. Where a score for body of 8.0 (maximum 10) was recorded the range of moisture contents was from approximately 32% to 40%. Similarly for a body score of 9.0 (which indicated a cheese of good commercial quality) the moisture values ranged from about 33.7% to 39.7%. This indicates in the opinion of the author that notwithstanding a statistically significant partial correlation coefficient the belief that the moisture content of a Cheddar cheese and its body as judged by the cheese grader are closely related is not substantiated by this study.

It is interesting to observe that the simple and partial correlation coefficients between salt content and texture score are of similar magnitude (0.373, 0.372) and statistically sifnificant ($P<0.001$) but the simple correlation coefficient between pH value and texture score although statistically significant ($P<0.001$) results in a non-significant partial correlation coefficient. There are other similar apparent anomalies between the simple and partial correlation coefficients in Tables 22 and 27 but care must be exercised in their interpretation.

The relationships between the independent variates (Table 22) are very important and although verifying beliefs in certain instances, e.g. the relationship between the fat and moisture contents, Table 22 points out the relationships existing between less often considered variates or properties e.g. the highly significant relationship($P<0.001$) between the pH value and the salt content of the cheese.

The prediction of scores for flavour and aroma, body, texture and total score might be possible with a reasonable degree of accuracy by the calculation of regression equations. A limited number of these equations are recorded above which demonstrate the practical possibility of estimating scores for certain properties or overall quality of commercial Cheddar cheese. Equation (1) indicates that 12.3% of the variations in Cheddar cheese flavour are accounted for by the moisture content, pH value and the % moisture in the fat free cheese but the accuracy of prediction of flavour and aroma score is only slightly reduced by the use of equation (6) where values for fat and pH are utilised i.e. R = 0.35 in both equations (1) and (6). Equations (7) and (8) are considered not sufficiently accurate for predicting the score for flavour and aroma of Cheddar cheese. A greater accuracy of prediction for a score of a certain property is obtained generally when all values of independent variates are used in the regression equation. Equations (3) and (4) may be used in the prediction of texture score. The elimination of pH value in equation (4) results only in a very slight reduction in accuracy of prediction as compared with equations (3) the multiple correlation coefficients for equations (3) and (4) being 0.56 and 0.55 respectively. In an effort to reduce computation and calculations, equations (11), (12), (13) and (14) may be used for the prediction of texture score. Only one independent variate is used in equation (14) without suffering any reduction in accuracy of prediction when compared with equation (13) which uses a salt concentration value as well as a value for salt content. The estimation of total score (i.e. overall grade score) may be made using equation (5) which involves the use of the results of all chemical tests employed in this study. Again by reducing the number of variates e.g. in equations (15), (16), (17) and (18) the accuracy of prediction of total grade is also reduced.

[illegible]

[illegible]

Equations (7) and (8) are [illegible]

[illegible]

(6) and [illegible]

of [illegible] in equation (4) [illegible]

[illegible] equation (2) [illegible]

[illegible] (7) and (8) [illegible]

[illegible] (10) and (11) [illegible] equation (16) [illegible]

[illegible] equation (3) [illegible]

[illegible] equations (10), (10), (11) and (14), the [illegible]

is also reduced.

While it is realised that regression equations provide only estimates of a particular property it is considered that the above equations will be of value in the prediction of flavour and aroma, body, texture and total grade scores of commercial Cheddar cheese.

In the interpretation of results recorded as frequency distributions it must be borne in mind that the selection of class boundaries is very important i.e. the selection of the class interval is important if gross misinterpretation is to be avoided. Frequency distributions of the various characteristics of Cheddar cheese are indicated in Tables 24, 25 and 26 and an effort was made to select a practical and realistic class interval for each of the characteristics recorded. As stated above the salt content and salt concentration are significantly related to the total grade score and from Table 26 one can see the wide distribution in salt contents obtained. This wide distribution in salt content reflects, in the opinion of the writer, the inability of the cheesemaker to assess the quality and composition of the cheese curd at the time of salting and consequently the selection of the proper salting rate. In view of the relationship between moisture content and total grade score the distribution of the moisture contents is satisfactory in the opinion of the writer but it must be emphasized that there is a legal maximum of 39% moisture for Cheddar cheese (Cheese (Scotland) Regulations, 1966) and that a low moisture content can result in reduced yields.

CONCLUSIONS

The relationships between the various parameters are recorded in Table 22 and one may observe that there is very little or no relationship between fat content and texture score, between moisture content and score for flavour and aroma and body and the % moisture in fat free cheese or between

the % moisture in fat free cheese and the total grade score. There are relationships between the remaining parameters to varying degrees, the more important being the highly significant ($P < 0.001$) relationship between fat and moisture contents and between the pH and salt content ($P < 0.001$) and pH and salt concentration ($P < 0.001$). There are also significant relationships between the salt concentration and the % moisture in fat free cheese ($P < 0.001$) and between the salt content and moisture content ($P < 0.001$). It is concluded that the determination of the hydrogen ion concentration (pH) and the salt content give a better estimation of the overall cheese quality than either the fat or moisture contents although it is appreciated that the latter estimations may be necessary in relation to conformance to legal standards.

An observation made during the above investigation was that the official cheese grader may have difficulty in assigning a border line cheese to a particular grade category. It is suggested, therefore, that where it is practically feasible, to have at hand values for the pH and salt contents. The writer is of the opinion that where this information is available to the official grader there would be no hesitation in most cases as to what grade category these border line cheese would be assigned.

SUMMARY

A total of 300 commercial Cheddar cheese were analysed for fat, moisture and salt contents and pH. Each cheese was scored by an official cheese grader of the Company of Scottish Cheesemakers on a points system based on a maximum of 10 points each for (a) body, (b) texture and (c) flavour and aroma thereby giving a maximum possible total grade score of 30 points. The salt concentration in the aqueous phase and the % moisture in fat free cheese were also calculated. The results of the chemical and subjective tests were subjected to statistical analysis which was composed mainly of

simple and partial correlation coefficients. These are recorded in Tables 22 and 27. The correlation coefficients are discussed and the more important chemical analyses stressed. Regression equations are recorded which may be used to predict a grade score of a particular property of Cheddar cheese.

It is suggested that the results of chemical tests e.g. pH and salt content be made available if possible to the official cheese grader when the cheese is being graded at the cheese store.

Section three

Part II

The effect of variations in the manufacturing process on the quality and composition of Cheddar cheese.

THE EFFECT OF VARIATIONS IN THE MANUFACTURING PROCESS ON THE QUALITY AND COMPOSITION OF CHEDDAR CHEESE

INTRODUCTION

Much has been written on the relationship between the acidity at certain stages in the manufacture of Cheddar cheese and the final quality of the cheese. Milk with a highly developed acidity gives a cheese difficult to control in the vat and a mature cheese of inferior quality. In commercial practice milk is usually stored overnight and pumped to the vats the following morning after heat treatment to reduce numbers of spoilage bacteria. The quality and composition of bulked milk supplies varies little, with the result that the cheesemaker does not alter the length of time the starter bacteria are allowed to ripen the milk in the vat. It is necessary, however, where difficulty is being experienced with starter activity or where there is a risk of an attack by bacteriophage to extend or shorten the ripening period.

The interval from adding the rennet to the cutting of the coagulum varies within very narrow limits but nevertheless great care is exercised by the cheesemaker in determining the optimum time. After cooking or scalding the next stage in Cheddar cheese manufacture is the pitching or settling of the curd and is usually carried out in a definite period following the reaching of maximum scald by the curds and whey mixture. More work has probably been carried out on the effect of acidity at running of the whey and the acidity at the milling stage than the acidities at the preliminary stages. Dolby (1941) stated that a change in whey running acidity, expressed as % lactic acid or pH value produced a definite change in the pH and quality of the mature cheese. Pimblett (1962) varied the period of time from running of the whey to the milling of the curd from 1 to 3 h

THE EFFECT OF VARIATIONS IN THE [illegible] PROCESS ON THE [illegible] QUALITY AND COMPOSITION OF [illegible]

INTRODUCTION

Much has been written on the relationship between the [illegible] [illegible]

[illegible]

[illegible]

[illegible] (1962) [illegible]

[illegible]

and stated that such variations had little influence on the final grade score of the cheese. Baron (1947) on the other hand stated that the acidity at milling time affected the properties of the mature cheese.

As far as is known to the author, no work has been undertaken which would indicate simultaneously the effect of varying the acidities (or time intervals) at certain stages in the manufacturing process on the acidities at other stages and on chemical analysis and properties of the mature cheese. The work outlined below describes the planning and the carrying out of such an experiment.

EXPERIMENTAL

Planning and design of the experiment

The various stages in the manufacture of Cheddar cheese have been mentioned above and so will not be described further. In an effort to ascertain the effect of varying the time intervals between each individual stage on the composition and quality of the mature cheese an experiment would be theoretically possible but from the practical point of view be very difficult. To reduce the number of stages at which acidities (or time intervals) would be varied simplifies matters sufficiently to make the experiment a practical proposition. In eliminating or choosing a number of factors there is obviously a risk of criticism as to the wisdom of such a choice but in this experiment the following stages were chosen in the light of previous work and experience which had indicated that they were important stages in Cheddar cheese manufacture. The experiment was designed to give information on the behaviour of the cheese in the vat and on the subsequent course of maturation or curing.

The 4 stages were; cutting the coagulum, settling the curd, running the whey and milling of the curd.

Having decided on the stages of most importance the next problem was to bring about acidity changes at these particular stages. The manufacture

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

of a number of cheese with various levels of acidity at each selected stage would be difficult and as statistical analysis of all data concerning manufacture, chemical analysis and grading of the cheese would be necessary to obtain clear cut and valuable information it was decided to manufacture all cheese on a time basis. To vary any time interval for any of the stages it was necessary to prepare a 'standard' or normal make procedure. The following time sheet based on commercial practice was adopted as a normal procedure and from this were calculated the schedules for the remaining cheese.

Stage	h	min		
Starter addition - Renneting	0	45		
Renneting - Cutting the coagulum	0	40	A	± 10 min
Cutting the coagulum - Maximum scald	1	00		
Maximum scald - Settling the curd	0	40	B	± 20 min
Settling the curd - Running the whey	0	30	C	± 15 min
Running the whey - Milling the curd	1	40	D	± 30 min

A, B, C and D refer to the 4 stages in the manufacturing process at which the timings were varied. It was then necessary to select a suitable time by which to vary each of the stages A, B, C and D, and such times as were considered suitable are shown above. This means for example that the renneting to the cutting stage varied from 30 min to 50 min and so on with the other stages. If one examines the above time schedule it will be seen that there are 4 stages (or factors) whose timings are to be altered and that there are 3 time variations (or levels) i.e. normal time, specified time less than normal and specified time greater than normal, for each of the 4 stages. The design for the experiment is outlined below and includes all possible combinations giving a total of 81 cheese i.e. 3^4 factorial experiment.

Table 28

<u>The design for Cheddar cheesemaking experiment</u>

Day no.	Vat 1				Vat 2				Vat 3			
	A	B	C	D	A	B	C	D	A	B	C	D
1	2	0	0	1	1	1	2	2	0	2	1	0
2	0	0	0	2	2	1	2	0	1	2	1	1
3	1	0	1	1	0	1	0	2	2	2	2	0
4	2	1	2	1	1	2	1	2	0	0	0	0
5	2	2	2	2	1	0	1	0	0	1	0	1
6	0	2	2	0	2	0	1	1	1	1	0	2
7	1	1	1	2	0	2	0	0	2	0	2	1
8	1	0	2	2	0	1	1	0	2	2	0	1
9	1	2	0	2	0	0	2	0	2	1	1	1
10	0	2	1	2	2	0	0	0	1	1	2	1
11	2	1	1	0	1	2	0	1	0	0	2	2
12	2	0	1	2	1	1	0	0	0	2	2	1
13	2	2	1	1	1	0	0	2	0	1	2	0
14	0	1	2	2	2	2	1	0	1	0	0	1
15	1	2	2	1	0	0	1	2	2	1	0	0
16	1	1	2	0	0	2	1	1	2	0	0	2
17	0	0	2	1	2	1	1	2	1	2	0	0
18	1	0	0	0	0	1	2	1	2	2	1	2
19	0	2	0	1	2	0	2	2	1	1	1	0
20	2	2	0	0	1	0	2	1	0	1	1	2
21	2	0	2	0	1	1	1	1	0	2	0	2
22	1	1	0	1	0	2	2	2	2	0	1	0
23	2	1	0	2	1	2	2	0	0	0	1	1
24	0	1	1	1	2	2	0	2	1	0	2	0
25	1	2	1	0	0	0	0	1	2	1	2	2
26	0	0	1	0	2	1	0	1	1	2	2	2
27	0	1	0	0	2	2	2	1	1	0	1	2

Timings are denoted as,

0 $\equiv$ specified time less than normal

1 $\equiv$ standard time space for the stage concerned

2 $\equiv$ specified time longer than normal

Since in the standard procedure the process or manufacturing time from renneting the milk to the time of milling the curd is 4 h 30 min this means that the shortest and longest make times for the above design are 3 h 15 min and 5 h 45 min respectively from renneting to the milling of the curd.

Materials and methods

In the planning of the experiment it was decided to restrict the number of vats used/day to 3 for ease of manipulation, each vat having a working capacity of 40 gal. The rate of starter addition was $1\frac{1}{2}$% and the milk was ripened for 45 min after which rennet was added at the rate of 4.4 oz/100 gal of milk. The milk after addition of the rennet was stirred for 3 min. All subsequent stages were carried out according to the day and vat number as shown in the design (Table 28). The temperature of maximum scald was 102°F in all cases.

Starters

An effort was made to have the 5 pairs of single strain starters used with equal frequency over the 27 experimental days but due to external factors, e.g. non delivery of milk, this was not possible. The following starters were used and are shown along with their corresponding experimental day numbers.

Starter	Day no.
C_3, 865	1, 5, 10, 15, 20, 24
EB_2, HP	2, 6, 11, 16, 21, 25
EB_7, ML_3	3, 7, 12, 17
Z_8, R_1	4, 8, 13, 18, 22, 27
BR_4, 818	9, 14, 19, 23, 26

(Starters 818 and ML_3 are Str. lactis, the remainder are Str. cremoris).

Analysis during manufacture

Titratable acidity determinations were carried out on the milk and on the whey at all stages except at the milling stage when there was no free whey available. The determinations were carried out by titrating 10 ml of milk or whey with N/9 sodium hydroxide to a faint pink tint using 1 ml of 0.5% phenolphthalein solution as indicator.

The pH values of the milk, whey and curd were determined using a Radiometer pH meter 25 SE with glass and calomel electrodes. The pH of the curd at milling time was obtained by piercing the curd with the glass electrode with the calomel electrode resting on the curd surface.

Cheese storage

After pressing, the cheese were wrapped in waxed cellulose laminate and heat sealed. They were then placed in a store at a temperature of 48 to 50^{o}F.

Cheese analysis

Each cheese was analysed for fat, moisture and salt content and pH value by the methods outlined in Section 3, Part I of this thesis. The analyses were carried out at 1 day, 3 weeks, 8 weeks and 16 weeks old and at 10 months old the pH value alone was determined.

Grading of the cheese

At 8 weeks and 16 weeks old each cheese was graded and scored on a points system by an official of the Company of Scottish Cheesemakers Ltd. A maximum each of 10 points was available for (a) body, (b) texture and (c) flavour and aroma, points being awarded to the first decimal place. Together with scoring on a points system each cheese was placed in a particular grade according to commercial cheese grading practice i.e. first second or third grade cheese. Comments made by the official cheese grader

on the characteristics of each cheese were noted.

When the cheese were 10 months old the cheese grader examined and commented on certain characteristics of the cheese i.e. flavour and aroma, and these were also noted but in this case the cheese were not scored but placed in one of three commercial grades as mentioned above.

RESULTS

Complete details of each individual cheese from manufacture to grading at 16 weeks were given in Tables 29 to 55 in Appendix A. Table 29 is shown overleaf.

Table 56 summarises the titratable acidities and pH values obtained during manufacture, Table 57 outlines the chemical composition of the cheese during maturation and Table 58 gives details of the grade scores for flavour and aroma, body and texture at 2 and 4 months old.

The best cheese i.e. the cheese with the highest total score, obtained 29.2 points from a maximum possible of 30.0 and the details of the manufacturing process and chemical analysis are recorded in Table 36, vat number 2. The total manufacturing time from the starter addition to the milling of the curd was 4 h 35 min. The time from the removal of the whey to the time the curd was milled was 1 h and 10 min and the pH value of the curd at milling was 5.54. When this cheese was examined at 16 weeks by the official cheese grader, it obtained 28.8 points and the remarks of the grader indicated that the cheese was "very good" both at 8 and 16 weeks old. The cheese obtaining the lowest overall grade score at 8 weeks was made on day 25 in vat 3. The score obtained by this cheese was 22.5 points at this stage but the score increased to 25.4 points at 16 weeks old. The total time from starter addition to the milling of the curd was 6 h 10 min which was 20 min shorter than the longest make time used during this study. From Table 53 it may be seen that the flavour and aroma score of this cheese receiving the lowest overall grade score at 8 weeks old was good but scores

Table 29

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 1

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.142	0.142	0.146	6.69	6.69	6.69
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.160	0.158	0.158	6.57	6.57	6.56
Curd cut	1.35	1.25	1.15	0.108	0.110	0.108	6.49	6.53	6.53
Maximum scald, °F	2.35	2.25	2.15	0.126	0.122	0.120	6.39	6.44	6.47
Curd settled	2.55	3.05	3.15	0.144	0.148	0.156	6.31	6.27	6.20
Whey run	3.10	3.50	3.45	0.170	0.274	0.264	6.10	5.75	5.79
Curd milled	4.50	6.00	4.55	-	-	-	5.29	5.17	5.25

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	4.88	4.90	4.89	4.96	4.95	5.01	4.92	4.94	4.95	4.92	4.89	4.94
Moisture, %	40.01	37.63	37.25	40.07	37.74	37.76	39.91	37.79	37.61	39.48	37.39	37.58
Salt, %	1.28	1.45	1.30	1.37	1.49	1.27	1.29	1.49	1.20	1.31	1.53	1.36
Fat, %	31.30	32.20	33.10	32.10	33.50	33.10	31.95	32.75	33.00	31.95	33.00	33.00

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Fair	7.5	Fair	8.0	Good	9.0	Fair	8.0	Fair	8.0	Fair	8.5
Flavour and aroma, (max. 10)	Good	9.0	Good	9.2	Good	9.6	Fair	9.0	Poor	8.0	Poor	7.5
Texture, (max. 10)	Short	7.0	Short	7.0	Slightly rough	8.5	Very rough	6.0	Very short	6.5	Slightly rough	7.0
Total points scored, (max. 30)		23.5		24.2		27.1		23.0		22.5		23.0

for body and texture were low and the score for texture indicated that the cheese was one of the poorest textured Cheddar cheese encountered by the official cheese grader either under experimental or commercial conditions.

The titratable acidities and pH values during manufacture (Table 56) show the wide range at the different stages which resulted from the variations in time intervals betweeen these particular stages. The differences between the minimum and maximum values for titratable acidity at (a) cutting the curd, (b) maximum scald, (c) settling of the curd, and (d) removing the whey from the vat were 0.022%, 0.032%, 0.048% and 0.18% lactic acid respectively. The corresponding pH values were 0.15, 0.23, 0.33 and 0.70 respectively. The difference between the maximum and minimum value for pH at the curd milling stage was 0.53 pH. Because of the lack of free whey at the curd milling stage it was not possible to make a titratable acidity estimation.

The chemical analyses during maturation of the cheese are summarised in Table 57. The differences between the minimum and maximum values at 1day old for pH, moisture, salt and fat contents were 0.51 pH, 4.91% moisture, 0.55% salt and 4.50% fat. The corresponding values at 8 weeks old were 0.26 pH, 4.53% moisture, 0.56% salt and 3.75% fat. The range for moisture content at 1 day old was 35.5% to 40.4%, this latter figure being above the legal limit permissible for Cheddar cheese (Cheese (Scotland) Regulations, 1966). It is interesting to note that this cheese containing the highest amount of moisture at 1 day old, had the shortest possible manufacturing time i.e. the total time from starter addition to the curd milling stage was exactly 4 h. This cheese although obtaining a high overall grade score was weak in body, as judged by the official cheese grader.

Table 58 indicates the variation in scores for flavour and aroma, body and texture obtained by the 81 cheese at both 2 and 4 months old. The

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scores at 2 months ranged as follows; (a) flavour and aroma, 8.0 to 9.8, (b) body, 7.5 to 9.6, (c) texture, 5.5 to 9.8, (d) total score, 22.5 to 29.2. Similar ranges in score points were obtained when the cheese were examined at 4 months.

Statistical analysis

As stated earlier this study was designed and planned so that the results could be subjected to statistical examination. The statistical examination would, it was hoped, provide precise and clear cut information. A total of 35 analysis of variance tests were carried out. (The analysis of variance test is a very useful technique "by which the total variation in a set of data may be reduced to components associated with possible sources of variability whose relative importance we wish to assess" (Moroney, 1963). In Tables 59 to 71 are recorded details of 15 analysis of variance tests while Table 72 summarises the significance levels of the 4 main effects i.e. A, B, C and D on the titratable acidities and pH values during manufacture, on the composition of the cheese during maturation and on the flavour and aroma, body, texture and total scores at 2 and 4 months old. Two and 3-factor interactions are not included in Table 72 because the number of such interactions that were significant was approximately the number that one would expect on the basis of chance alone. There were only two 2-factor interactions significant at the 1% level. These were (a) the AC interaction having an effect on the moisture content of cheese at 1 day old and (b) the AD interaction having an effect on the pH value of cheese at 2 months old. These 2-factor interactions which are significant at the 1% level are indicated in Tables 63 and 64.

However, it was the purpose of this study to examine the 4 main effects i.e. to ascertain the effect of varying the length of time between stages of Cheddar cheese manufacture on the composition and quality of the maturing cheese.

One would expect that by varying the time interval between the addition of rennet and the cutting of the coagulum it would have a significant effect on the titratable acidity and pH value at the cutting stage. This in fact is so (Table 72), the effect being significant at the 5% level ($P < 0.05$) for titratable acidity but for the pH value the effect was highly significant ($P < 0.001$). The effect of the treatment A is highly significant on the titratable acidities and pH values at the stages of maximum scald, settling of the curd and removal of the whey from the vat and also on the pH value at the time of milling the curd. Similarly the effects of the treatments B, C and D were highly significant ($P < 0.001$) on the titratable acidities and pH values at each of its own and subsequent stages of the manufacturing process. Treatments A and D seem to have little or no effect on the fat content of the cheese during maturation but the effects of B and C (the maximum scald to curd settling and the curd settling to the whey removal stages) on the fat content at 1 day and 21 days and at 2 and 4 months are highly significant ($P < 0.001$). The effects of treatments B and C on the moisture content of the cheese during maturation are highly significant ($P < 0.001$), treatment A is significant ($P < 0.05$) at 1 day old only while the effect of treatment D is not significant at any stage during maturation.

It is of interest to note that the treatments A, B, C and D did not affect the salt content of the cheese during maturation except for the significant effect ($P < 0.05$) of treatment B at 4 months old. The effects of A, B, C and D on the pH value during the maturing of the cheese are significant at varying levels being highly significant ($P < 0.001$) both at 2 and 4 months.

The scores obtained for body and flavour and aroma were not affected by either of the treatments A, B, C or D. The effects of treatments A and B

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on the scores for texture at 2 and 4 months were significant ($P < 0.01$) while the effect of treatment C was significant ($P < 0.05$) and the effect of treatment D was significant ($P < 0.05$ and $P < 0.01$) at 2 and 4 months respectively. The effect of the 4 treatments A, B, C and D on the overall grade score of cheese may be considered the most important result of this study. It may be seen from Table 72 that the total score is affected by the treatment A ($P < 0.01$) at 4 months by treatment B ($P < 0.05$) and treatment D at 2 months ($P < 0.05$) and at 4 months ($P < 0.01$). Treatment C does not appear to have any affect on the total grade score either at 2 months or 4 months.

Values for titratable acidity and pH during the manufacturing process as affected by the 4 treatments A, B, C and D are shown in Table 73. It is not surprising to see that neither the titratable acidity nor the pH value at the time of rennet addition is affected by the variations in timings of treatment A but it is reassuring to see such uniformity in these values. It appears that there is little difference in the titratable acidity at cutting of the coagulum when the 'standard' time interval of 40 min from the rennet addition to the cutting stage is reduced to 30 min. By increasing this time interval to 50 min there is a slight increase in titratable acidity. There is a decrease in pH value of the whey at cutting from 6.539 to 6.516 as the time from rennet addition to cutting the coagulum increased from 30 min to 50 min and there is an increase in titratable acidity and a decrease in pH values at maximum scald as the timings of treatment A were increased. There is a similar but more pronounced trend in the effect of the various treatments on the titratable acidity and pH values at the stages of settling the curd, removal of whey from the vat and the milling of the curd. (As pointed out earlier the titratable acidity test was not made at the milling stage because of the

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unavailability of sufficient whey). Substantial increases in the titratable acidity when the whey was removed or run from the vat were obtained as the timings within treatments A, B and C were increased. An increase of about 0.03% lactic acid was obtained when the time from settling the curd to the removal of the whey was increased by 15 min from 15 to 30 min and an increase of just more than 0.03% lactic acid was obtained when the time was increased from 30 min to 45 min. When the time from removal of the whey to the milling stage was increased from 1 h 10 min to 1 h 40 min there was a decrease in pH of just under 0.09 pH while there was a decrease of about 0.05 pH when the time was increased from 1 h 40 min to 2 h 10 min.

Tables 74 to 81 show the actual values for fat, moisture and salt contents and pH values at 1 and 21 days and 2 and 4 months old along with scores for flavour and aroma, body, texture and total points when the cheese were 2 and 4 months old.

There is little difference in the fat content at any age as the timings of treatment A were increased but at 1 day old there was an increase of about 0.7% fat as timings of treatment B were increased i.e. when the time interval between the stages of maximum scald and settling of curd was increased from 20 min to 60 min. As the timings of treatment C were increased from 15 to 45 min there was an increase of almost 0.7% fat at 1 day old but when the time between removal of whey and the milling of the curd was increased from 1 h 10 min to 2 h 10 min the fat contents at 1 day old were identical i.e. D_0, D_1 and D_2 had fat contents of 33.31%, and the values at 21 days, 2 months and 4 months were also very similar.

Table 75 shows that only treatments B and C had a significant effect on the moisture content of the cheese during maturation. Taking the moisture values at 1 day old it may be seen that as the timings of treatment

A increase so also does the moisture in the cheese, however slightly; as treatment B goes from B_0 to B_2 there is a decrease in the moisture of the cheese by about 0.8%; as treatment C goes from C_0 to C_2 there is almost a 1% decrease in moisture and for treatment D there is no difference between the D_0 and D_1 levels, i.e. 37.47% moisture but for the D_2 level there is a slight increase to 37.62% moisture.

The effects of treatments A, B, C and D on the salt content of the cheese are shown in Table 76. Not only are the salt contents at each level for all treatments very similar but there appears to be a very high degree of uniformity in the salt contents in general. The fact that very little variation was obtained in the salt contents of the cheese as a result of the treatments applied is a very important and possibly unexpected observation.

The pH values at 1 day old were affected by each of the treatments A, B, C and D. As each treatment increased (in terms of time) from the lowest to the highest level so did the pH value decrease. The differences in pH at 1 day old between A_0 and A_2, B_0 and B_2, C_0 and C_2 and D_0 and D_2 were 0.024, 0.034, 0.027 and 0.037 pH respectively. The corresponding differences at 2 months old were 0.046, 0.048, 0.030 and 0.031 pH.

As Cheddar cheese is examined in commercial practice at about 2 months old the cheese in this study were examined at this age and also at 4 months. The scores for flavour and aroma at 2 and 4 months for the different levels of each treatment are shown in Table 78. There appears to be a slight decrease in the scores at 2 and 4 months as treatment A increases from A_0 to A_2 there being little or no difference between the A_0 and the A_1 level. The trend is somewhat similar for the treatments B, C and D. The effects of the treatments A, B, C and D on the scores obtained for the body of the cheese are shown in Table 79. As is the case with the scores for flavour

and aroma neither of the treatments A, B, C or D have a significant effect on the scores for body either at 2 or 4 months. There is a slight decrease both at 2 and 4 months as treatment A increase from the A_1 to the A_2 level. There is also a slight decrease in body score at 2 months when treatment D is increased from the D_1 to the D_2 level. One may also see from Table 79 that for each level of the 4 treatments the score obtained for body at 4 months is higher than the corresponding figure at 2 months. The 4 treatments, A, B, C and D have an effect on the scores obtained for the texture of the cheese at 2 and 4 months old. In general there appears to be a decrease in the texture score as the level of each treatment increases from the lowest to the highest level except for treatment D at 2 months when the level D_1 gave the highest score and treatment C at 4 months when C_1 gave the highest score.

The maximum possible total score obtainable by each cheese was 30 points so that small differences, e.g. 1 point, between total score of two cheese could mean very different quality cheese. The effects of each of the treatments A, B, C and D on the total grade score of the cheese at 2 and 4 months are recorded in Table 81. At 2 months there appears to be no difference between A_0 and A_1 but there is a decrease of 1.2 points from 26.93 to 25.73 as treatment A increases from A_0 to A_2. As treatments B and C increase from B_0 to B_2 and C_0 to C_2 there are decreases from 26.90 to 26.06 and from 26.76 to 26.07 points in the total score at 2 months. The total scores for levels D_0 and D_1 of treatment D are somewhat similar at 2 months (26.68 and 27.01 points respectively) but the level D_2 resulted in a total score of 25.90 i.e. a decrease of 1.11 from the total score obtained at the D_1 level. At 4 months a score of 27.26 was obtained for the lowest level of treatment A decreasing to 26.16 at the highest level (A_2). Treatments B, C and D at the levels B_0 and B_2, C_0 and C_2 and D_0 and D_2

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resulted in total scores of 27.03, 26.15, 26.85, 26.38, 27.16 and 26.16 points respectively there being little difference between the lowest i.e. the '0' level and the standard or '1' level. In general there appeats to be higher total scores at 4 months for the various levels of the treatments A, B, C and D.

Calculation of linear correlation coefficients and the plotting of scatter diagrams for certain parameters of the manufacturing and maturing process

To examine possible associations between the variables, correlation coefficients for a number of pairs of variables were calculated after eliminating the main effects of treatments A, B, C and D. These correlations, therefore, are correlations between the random variations occurring under standard timings in the manufacturing process. In the few instances showing evidence of interactions among A, B, C and D variation would be in part due to such interaction as well as to random causes but since interactions were generally negligible it was decided because of the additional computation involved, not to eliminate interactions. The 80 correlation coefficients so calculated are shown in Table 82. Since a correlation coefficient is an approximate measure of association between two variables only if the relationship between the variables is approximately linear, scatter diagrams were also plotted (by computer) for each of the 80 pairs. Correlation coefficients were mostly very small and none of the diagrams appeared to contradict the linearity assumption.

It may be seen that 16 correlation coefficients are highly significant ($P<0.001$), 3 are significant ($P<0.01$) and 7 are significant at the 5% level ($P<0.05$). Some of the more interesting results are that the fat and moisture contents at 1 day old are correlated ($P<0.001$) and that the

moisture and pH values at 1 day are correlated ($P<0.001$). The fat and moisture contents at 8 weeks are also correlated ($P<0.001$) as are the moisture contents and pH values at 8 weeks ($P<0.001$). A number of the non-significant correlation coefficients are also of interest. There appears to be no correlation between the fat and salt contents ($r = -0.083$) and the moisture and salt contents ($r = 0.080$) at 1 day. The corresponding correlation coefficients at 8 weeks are -0.098 and -0.020 respectively, the latter figure changing from a positive correlation at 1 day. There is a correlation between the moisture at 8 weeks and the pH value ($P<0.001$) and the pH value appears to be the only chemical test to be significantly ($P<0.01$) related to the total score at 8 weeks.

The correlation between the titratable acidity at maximum scald and at the stage of removal of whey from the vat is highly significant ($P<0.001$) while both are correlated ($P<0.001$) with the total score at 8 weeks. Although there is a correlation ($P<0.001$) between the fat and moisture contents at 8 weeks and between the moisture and pH value at 8 weeks, the correlation coefficient between the fat content and pH value at 8 weeks is virtually negligible i.e. $r = 0.083$.

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Table 56

The mean, minimum and maximum values for titratable acidity and pH of Cheddar cheese made with variations in the manufacturing process

Operation	Titratable acidity, % lactic acid			pH		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Renneting	0.160	0.148	0.170	6.58	6.54	6.63
Curd cut	0.115	0.104	0.126	6.53	6.44	6.59
Maximum scald	0.127	0.114	0.146	6.45	6.30	6.53
Curd settled	0.146	0.122	0.170	6.31	6.12	6.45
Whey run	0.210	0.140	0.320	6.02	5.65	6.35
Curd milled	-	-	-	5.36	5.16	5.69

Table 57

The mean, minimum and maximum values for pH, moisture, salt and fat contents during maturation of Cheddar cheese made with variations in the manufacturing process

1 day			21 days			8 weeks			16 weeks		
Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
pH											
5.02	4.76	5.27	5.01	4.91	5.17	5.01	4.87	5.13	5.02	4.87	5.16
Moisture, %											
37.52	35.52	40.43	37.47	35.15	40.07	37.49	35.38	39.91	37.23	35.13	39.48
Salt, %											
1.45	1.18	1.73	1.43	1.17	1.66	1.39	1.16	1.72	1.41	1.11	1.69
Fat, %											
33.30	31.30	35.80	33.30	31.60	35.35	33.45	31.55	35.30	33.90	31.90	36.50

Table 36

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Table 58

The mean, minimum and maximum scores for (a) flavour and aroma, (b) body, (c) texture and (d) total score of Cheddar cheese made with variations in the manufacturing process

2 months			4 months		
Mean	Minimum	Maximum	Mean	Minimum	Maximum
Flavour and aroma, (max. 10)					
9.2	8.0	9.8	9.2	7.5	9.7
Body, (max. 10)					
8.7	7.5	9.6	8.9	8.0	9.6
Texture, (max.10)					
8.6	5.5	9.8	8.6	5.5	9.7
Total, (max. 30)					
26.5	22.5	29.2	26.7	22.5	28.9

Table 59

Analysis of variance

(a) Titratable acidity when the curd was settled

Treatment	D.F.	Sum of squares	Mean square	F
A	2	0.00149452	0.00074726	60.8 ***
B	2	0.00561274	0.00280637	228.3 ***
AB	2	0.00001452	0.00000726	
Error	46	0.00056533	0.00001229	
Total	80	0.01042400	0.00013030	

(b) pH value when the curd was settled

Treatment	D.F.	Sum of squares	Mean square	F
A	2	0.055417	0.027709	55.6 ***
B	2	0.312010	0.156005	313.3 ***
AB	2	0.003751	0.001875	3.76 *
Error	46	0.022909	0.000498	
Total	80	0.574454	0.007181	

*** Significant, $P < 0.001$

* Significant, $P < 0.05$

Table 60

Analysis of variance

(a) Titratable acidity when the whey was removed from the vat

Treatment	D.F.	Sum of squares	Mean square	F
A	2	0.01070410	0.00535205	31.45 ***
B	2	0.03653965	0.01826983	107.37 ***
C	2	0.05177165	0.02588583	152.12 ***
AB	2	0.00032425	0.00016212	
AC	2	0.00149047	0.00074523	4.38 *
BC	2	0.00151002	0.00075501	4.44 *
ABC	6	0.00113985	0.00018998	
Error	34	0.00578509	0.00017015	
Total	80	0.13626706	0.00170334	

(b) pH value when the whey was removed from the vat

Treatment	D.F.	Sum of squares	Mean square	F
A	2	0.206165	0.103083	61.43 ***
B	2	0.629647	0.314823	187.61 ***
C	2	0.814862	0.407431	242.81 ***
AB	2	0.003410	0.001705	
AC	2	0.005202	0.002601	
BC	2	0.005617	0.002809	
ABC	6	0.023941	0.003990	2.38
Error	34	0.057049	0.001678	
Total	80	2.239565	0.027995	

*** Significant, $P < 0.001$

* Significant, $P < 0.05$

Table 61

Analysis of variance: pH at milling the curd

Treatment	D.F.	Sum of squares	Mean of square	F
A	2	0.075267	0.037633	32.61 ***
B	2	0.266052	0.133026	115.27 ***
C	2	0.123919	0.061959	53.66 ***
D	2	0.269600	0.134800	116.81 ***
AB	2	0.00585	0.000293	
AC	2	0.001830	0.000915	
AD	2	0.004289	0.002144	
BC	2	0.000741	0.000370	
BD	2	0.009096	0.004548	3.94 *
CD	2	0.001430	0.000715	
ABC	6	0.016030	0.002672	2.28
BCD	6	0.009519	0.001586	
Error	20	0.023089	0.001154	
Total	80	1.135600	0.014195	

*** Significant, $P < 0.001$

* Significant, $P < 0.05$

Table 62

Analysis of variance; pH at 1 day old

Treatment	D.F.	Sum of squares	Mean of square	F
A	2	0.007963	0.003981	3.80 *
B	2	0.017096	0.008548	8.16 **
C	2	0.010941	0.005470	5.22 *
D	2	0.019074	0.009537	9.11 **
AB	2	0.000289	0.000144	
AC	2	0.002807	0.001404	
AD	2	0.001807	0.000904	
BC	2	0.002067	0.001033	
BD	2	0.004067	0.002033	
CD	2	0.000919	0.000459	
ABC	6	0.011326	0.001888	
BCD	6	0.002593	0.000432	
Error	20	0.020933	0.001047	
Total	80	1.200800	0.015010	

** Significant, $P < 0.01$

* Significant, $P < 0.05$

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Table 63

Analysis of variance; pH at 2 months old

Treatment	D.F.	Sum of squares	Mean of square	F
A	2	0.028240	0.014120	25.81 ***
B	2	0.033669	0.016835	30.78 ***
C	2	0.013521	0.006760	12.35 ***
D	2	0.012751	0.006375	11.65 ***
AB	2	0.000988	0.000494	
AC	2	0.000551	0.000275	
AD	2	0.006521	0.003260	5.96 **
BC	2	0.004521	0.002260	4.13 *
BD	2	0.000121	0.000060	
CD	2	0.000388	0.000194	
ABC	6	0.012067	0.002011	3.68 *
BCD	6	0.005074	0.000846	
Error	20	0.010936	0.000547	
Total	80	0.262728	0.003284	

*** Significant, $P < 0.001$

** Significant, $P < 0.01$

* Significant, $P < 0.05$

Table 64

Analysis of variance; moisture at 1 day old

Treatment	D.F.	Sum of squares	Mean of square	F
A	2	3.144165	1.572083	5.59 *
B	2	9.324002	4.662001	16.59 ***
C	2	11.501106	5.750553	20.47 ***
D	2	0.379602	0.189810	
AB	2	0.465514	0.232757	
AC	2	3.605262	1.802631	6.42 **
AD	2	0.110151	0.055075	
BC	2	0.774921	0.387460	
BD	2	0.640491	0.320246	
CD	2	0.154121	0.077060	
ABC	6	5.426474	0.904412	3.22 *
BCD	6	1.943889	0.323981	
Error	20	5.618714	0.280936	
Total	80	84.223699	1.052796	

*** Significant, $P<0.001$

** Significant, $P<0.01$

* Significant, $P<0.05$

Table 65

Analysis of variance: salt at 1 day old

Treatment	D.F.	Sum of squares	Mean of square	F
A	2	0.043022	0.021511	
B	2	0.072267	0.036133	1.28
C	2	0.016807	0.008404	
D	2	0.053541	0.026770	
AB	2	0.018489	0.009244	
AC	2	0.004052	0.002026	
AD	2	0.013563	0.006781	
BC	2	0.008674	0.004337	
BD	2	0.056452	0.028226	
CD	2	0.010341	0.005170	
ABC	6	0.040644	0.006774	
BCD	6	0.070230	0.011705	
Error	20	0.563267	0.028163	
Total	80	1.385222	0.017315	

Table 66

<u>Analysis of variance; fat content at 1 day old</u>

Treatment	D.F.	Sum of squares	Mean of square	F
A	2	2.057222	1.028611	4.03 *
B	2	6.792407	3.396204	13.31 ***
C	2	5.985741	2.992870	11.73 ***
D	2	0.001296	0.000648	
AB	2	0.394630	0.197315	
AC	2	0.911296	0.455648	
AD	2	0.177963	0.088981	
BC	2	0.011296	0.005648	
BD	2	0.587963	0.293981	
CD	2	0.485741	0.242870	
ABC	6	0.905741	0.150957	
BCD	6	3.159444	0.526574	2.06
Error	20	5.101852	0.255093	
Total	80	66.125000	0.826563	

*** Significant, $P < 0.001$

* Significant, $P < 0.05$

Table 67

Analysis of variance, flavour and aroma score at 2 months

Treatment	D.F.	Sum of squares	Mean of squares	F
A	2	0.4477	0.2238	2.19
B	2	0.2773	0.1386	
C	2	0.0640	0.0320	
D	2	0.2402	0.1201	
AB	2	0.3751	0.1875	
AC	2	0.1454	0.0727	
AD	2	0.0536	0.0268	
BC	2	0.0151	0.0075	
BD	2	0.0365	0.0183	
CD	2	0.0277	0.0138	
ABC	6	0.4156	0.0693	
BCD	6	0.4926	0.0821	
Error	20	2.0365	0.1018	
Total	80	8.4454	0.1056	

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Table 68

Analysis of variance; body score at 2 months old

Treatment	D.F.	Sum of squares	Mean of square	F
A	2	1.3188	0.6594	2.69
B	2	0.0536	0.0268	
C	2	0.4640	0.2320	
D	2	1.1454	0.5727	
AB	2	0.4477	0.2238	
AC	2	1.1928	0.5964	
AD	2	0.2373	0.1186	
BC	2	0.4551	0.2275	
BD	2	0.3528	0.1764	
CD	2	0.8165	0.4083	
ABC	6	2.2393	0.3732	
BCD	6	3.8126	0.6354	2.59
Error	20	4.9040	0.2452	
Total	80	26.7832	0.3348	

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Table 69

Analysis of variance; texture score at 2 months old

Treatment	D.F.	Sum of squares	Mean of square	F
A	2	11.5662	5.7831	9.09 **
B	2	7.5810	3.7905	5.95 **
C	2	4.6002	2,3001	3.61 *
D	2	7.0802	3.5401	5.56 *
AB	2	1.7958	0.8979	
AC	2	1.8417	0.9209	
AD	2	0.2491	0.1246	
BC	2	0.3143	0.1572	
BD	2	0.7928	0.3964	
CD	2	2.4188	1.2094	
ABC	6	8.1163	1.3527	2.12
BCD	6	6.4970	1.0828	
Error	20	12.7299	0.6365	
Total	80	104.1647	1.3021	

** Significant, $P<0.01$

* Significant, $P<0.05$

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Table 70

Analysis of variance; total grade score at 2 months old

Treatment	D.F.	Sum of squares	Mean of square	F
A	2	25.6822	12.8411	5.88 **
B	2	9.9474	4.9737	2.28
C	2	8.5430	4.2715	
D	2	17.7119	8.8559	4.05 *
AB	2	6.5274	3.2637	
AC	2	7.7563	3.8781	
AD	2	1.4785	0.7393	
BC	2	1.7489	0.8744	
BD	2	2.4941	1.2470	
CD	2	6.1267	3.0633	
ABC	6	22.1281	3.6880	
BCD	6	23.6881	3.9480	1.81
Error	20	43.6756	2.1838	
Total	80	276.6289	3.4579	

** Significant, $P < 0.01$

* Significant, $P < 0.05$

Table 71

Analysis of variance: total grade score at 4 months old

Treatment	D.F.	Sum of squares	Mean of squares	F
A	2	16.3573	8.1786	7.09 **
B	2	13.1410	6.5705	5.70 *
C	2	4.7499	2.3749	2.06
D	2	14.1936	7.0968	6.15 **
AB	2	2.5402	1.2701	
AC	2	2.4595	1.2298	
AD	2	3.3699	1.6849	
BC	2	0.0432	0.0216	
BD	2	0.9158	0.4579	
CD	2	5.6417	2.8209	2.45
ABC	6	14.8333	2.4722	2.14
BCD	6	13.0437	2.1740	
Error	20	23.0625	1.1531	
Total	80	239.7743	2.9972	

** Significant, $P < 0.01$

* Significant, $P < 0.05$

Table 72

The significance levels of the main effects (A,B,C,D) on (a) the titratable acidities and pH values during manufacture, (b) the composition during maturation, and (c) the flavour and aroma, body, texture and total scores of Cheddar cheese

		Significance level of			
Manufacture		A	B	C	D
Curd cut:	Titratable acidity, % lactic acid	*	-	-	-
	pH	***	-	-	-
Maximum scald:	Titratable acidity, % lactic acid	***	-	-	-
	pH	***	-	-	-
Curd settled:	Titratable acidity, % lactic acid	***	***	-	-
	pH	***	***	-	-
Whey run:	Titratable acidity, % lactic acid	***	***	***	-
	pH	***	***	***	-
Curd milled:	pH	***	***	***	***
Composition					
Fat:	1 day	*	***	***	
	21 days		***	***	
	2 months		***	***	
	4 months		***	***	
Moisture:	1 day	*	***	***	
	21 days		***	***	
	2 months		***	***	
	4 months		***	***	
Salt:	1 day				
	21 days				
	2 months				
	4 months		*		
pH:	1 day	*	**	*	**
	21 days	***	***	**	**
	2 months	***	***	***	***
	4 months	***	***	***	***
Grade scores:					
Flavour and aroma:	2 months				
	4 months				
Body:	2 months				
	4 months				
Texture:	2 months	**	**	*	*
	4 months	**	**	*	**
Total score:	2 months	**			*
	4 months	**	*		**

A,B,C,D refer to the cutting, settling, running and milling stages respectively.

*** Significant, $P < 0.001$

** Significant, $P < 0.01$

* Significant, $P < 0.05$

Table 73

The effect of variations in the cheese manufacturing process on the titratable acidities and pH values during manufacture

		A_0	A_1	A_2	Mean
Rennet added:	Titratable acidity, % lactic acid	0.1599	0.1605	0.1600	0.1601
	pH	6.586	6.584	6.584	6.585
Curd cut:	Titratable acidity, % lactic acid	0.1147	0.1141	0.1160	0.1149
	pH	6.539	6.528	6.516	6.528
Maximum scald:	Titratable acidity, % lactic acid	0.1252	0.1264	0.1304	0.1274
	pH	6.477	6.456	6.433	6.455

Treatment	Curd settled		Whey run		Curd milled	
	Titratable acidity, % lactic acid	pH	Titratable acidity, % lactic acid	pH	Titratable acidity, % lactic acid	pH
A_0	0.1411	6.342	0.1944	6.084		5.402
A_1	0.1466	6.304	0.2129	6.004		5.360
A_2	0.1516	6.278	0.2220	5.963		5.328
B_0	0.1365	6.381	0.1842	6.126		5.433
B_1	0.1459	6.312	0.2088	6.014		5.364
B_2	0.1569	6.230	0.2362	5.910		5.293
C_0	-	-	0.1789	6.142		5.414
C_1	-	-	0.2096	6.012		5.357
C_2	-	-	0.2408	5.896		5.319
D_0	-	-	-	-		5.439
D_1	-	-	-	-		5.352
D_2	-	-	-	-		5.299

A, B, C, D refer to the cutting, settling, running and milling stages respectively.

Subscripts 0, 1 and 2 refer to a decreased, normal or increased time interval.

Table 74

The effect of variations in the manufacturing process on the fat content of Cheddar cheese during maturation

Treatment	Fat, %			
	Age of cheese			
	1 day	21 days	2 months	4 months
A_0	33.40	33.36	33.46	33.81
A_1	33.35	33.30	33.44	33.92
A_2	33.10	33.31	33.47	33.95
B_0	33.02	33.02	33.11	33.46
B_1	33.21	33.31	33.49	33.94
B_2	33.71	33.63	33.76	34.29
C_0	32.95	33.02	33.15	33.60
C_1	33.37	33.30	33.54	33.95
C_2	33.61	33.64	33.67	34.14
D_0	33.31	33.30	33.50	33.89
D_1	33.31	33.36	33.38	33.88
D_2	33.31	33.30	33.50	33.91

A, B, C, D, refer to the cutting, settling, running and milling stages respectively.

Subscripts 0, 1 and 2 refer to a decreased, normal or increased time interval.

Table 75

The effect of variations in the manufacturing process on the moisture content of Cheddar cheese during maturation

	Moisture, %			
	Age of cheese			
Treatment	1 day	21 days	2 months	4 months
A_0	37.33	37.46	37.43	37.27
A_1	37.43	37.43	37.40	37.14
A_2	37.79	37.53	37.63	37.27
B_0	37.96	38.00	38.04	37.77
B_1	37.46	37.38	37.42	37.15
B_2	37.14	37.03	36.99	36.76
C_0	37.98	37.94	37.87	37.60
C_1	37.52	37.45	37.50	37.21
C_2	37.06	37.02	37.09	36.87
D_0	37.47	37.41	37.42	37.19
D_1	37.47	37.46	37.50	37.18
D_2	37.62	37.55	37.54	37.31

A, B, C, D refer to the cutting, settling, running and milling stages respectively.

Subscripts 0, 1 and 2 refer to a decreased, normal and increased time interval.

Table 76

The effect of variations in the manufacturing process on the salt content of Cheddar cheese during maturation

Treatment	Salt, %			
	Age of cheese			
	1 day	21 days	2 months	4 months
A_0	1.46	1.44	1.40	1.43
A_1	1.46	1.44	1.40	1.42
A_2	1.42	1.41	1.36	1.38
B_0	1.41	1.40	1.36	1.38
B_1	1.47	1.44	1.40	1.42
B_2	1.47	1.45	1.40	1.44
C_0	1.44	1.43	1.38	1.40
C_1	1.44	1.41	1.37	1.40
C_2	1.47	1.45	1.41	1.43
D_0	1.48	1.45	1.40	1.42
D_1	1.42	1.42	1.38	1.39
D_2	1.45	1.41	1.38	1.41

A, B, C, D refer to the cutting, settling, running and milling stages respectively.

Subscripts 0, 1 and 2 refer to a decreased, normal or increased time interval.

Table 77

The effect of variations in the manufacturing process on the pH value of Cheddar cheese during maturation

Treatment	pH Age of cheese 1 day	21 days	2 months	4 months
A_0	5.033	5.033	5.037	5.047
A_1	5.024	5.004	5.011	5.019
A_2	5.009	4.989	4.991	4.992
B_0	5.036	5.030	5.033	5.036
B_1	5.028	5.009	5.021	5.030
B_2	5.002	4.987	4.985	4.993
C_0	5.039	5.021	5.031	5.042
C_1	5.016	5.011	5.007	5.014
C_2	5.012	4.994	5.001	5.002
D_0	5.043	5.024	5.030	5.031
D_1	5.019	5.009	5.010	5.026
D_2	5.006	4.994	4.999	5.001

A,B,C,D refer to the cutting, settling, running and milling stages respectively.

Subscripts 0, 1 and 2 refer to a decreased, normal or increased time interval.

Table 78

The effect of variations in the manufacturing process on the flavour and aroma scores obtained by Cheddar cheese at 2 and 4 months old

Treatment	Flavour and aroma scores(max.10) Age of cheese 2 months	4 months
A_0	9.27	9.26
A_1	9.28	9.21
A_2	9.12	9.14
B_0	9.26	9.25
B_1	9.27	9.25
B_2	9.14	9.10
C_0	9.23	9.24
C_1	9.25	9.19
C_2	9.19	9.17
D_0	9.23	9.27
D_1	9.29	9.21
D_2	9.16	9.12

A, B, C, D refer to the cutting, settling, running and milling stages respectively.

Subscripts, 0,1 and 2 refer to a decreased, normal or increased time interval.

Table 79

The effect of variations in the manufacturing process on the body scores obtained by Cheddar cheese at 2 and 4 months old

Treatment	Body scores (max. 10) Age of cheese 2 months	4 months
A_0	8.75	9.02
A_1	8.88	8.89
A_2	8.57	8.79
B_0	8.70	8.88
B_1	8.77	8.99
B_2	8.73	8.84
C_0	8.73	8.90
C_1	8.83	8.94
C_2	8.64	8.86
D_0	8.79	9.01
D_1	8.85	8.90
D_2	8.57	8.80

A, B, C, D refer to the cutting, settling, running and milling stages respectively.

Subscripts 0, 1 and 2 refer to a decreased, normal or increased time interval.

Table 80

The effect of variations in the manufacturing process on the texture scores obtained by Cheddar cheese at 2 and 4 months old

Treatment	Texture scores (max.10) Age of cheese 2 months	4 months
A_0	8.91	8.99
A_1	8.76	8.64
A_2	8.04	8.23
B_0	8.93	8.89
B_1	8.60	8.75
B_2	8.19	8.21
C_0	8.79	8.71
C_1	8.68	8.80
C_2	8.24	8.34
D_0	8.67	8.88
D_1	8.87	8.74
D_2	8.17	8.24

A, B, C, D refer to the cutting, settling, running and milling stages respectively.

Subscripts 0, 1 and 2 refer to a decreased, normal or increased time interval.

Table 81

The effect of variations in the manufacturing process on the total scores obtained by Cheddar cheese at 2 and 4 months old

	Total scores (max. 30)	
	Age of cheese	
Treatment	2 months	4 months
A_0	26.93	27.26
A_1	26.92	26.74
A_2	25.73	26.16
B_0	26.90	27.03
B_1	26.63	26.99
B_2	26.06	26.15
C_0	26.76	26.85
C_1	26.76	26.93
C_2	26.07	26.38
D_0	26.68	27.16
D_1	27.01	26.85
D_2	25.90	26.16

A, B, C, D refer to the cutting, settling, running and milling stages respectively.

Subscripts 0, 1 and 2 refer to a decreased, normal or increased time interval.

Table 82

Linear correlation coefficients between certain parameters of Cheddar cheese made with variations in the manufacturing process

	Rennet added, T.A.	Maximum scald, T.A.	Whey run, T.A.	Rennet added, pH	Maximum scald, pH	Whey run, pH	Fat, % 1 day	Moisture, % 1 day	Salt, % 1 day	pH, 1 day	Fat, % 8 weeks	Moisture, % 8 weeks	Salt, % 8 weeks	pH, 8 weeks
Rennet added, T.A.														
Maximum scald, T.A.	0.560***													
Whey run, T.A.	0.154	0.386***												
Rennet added, pH	-	-	0.274*											
Maximum scald, pH	-	-	0.664***	0.529***										
Whey run, pH	-	-	-	-	-									
Fat, % 1 day	0.081	0.059	0.067	0.122	0.014	0.048								
Moisture, % 1 day	-0.129	-0.030	0.063	0.087	0.037	-0.068	-0.686***							
Salt, % 1 day	0.208	0.124	-0.056	-0.063	-0.137	0.016	-0.083	0.080						
pH, 1 day	0.056	0.014	-0.376***	0.207	0.351**	0.523***	0.288***	-0.396***	-0.007					
Fat, % 8 weeks	0.126	0.246*	0.154	-0.038	-0.145	-0.118	-	-	-	-				
Moisture, % 8 weeks	-0.093	-0.064	0.035	0.096	0.004	-0.017	-	-	-	-	-0.699***			
Salt, % 8 weeks	0.229*	0.119	-0.074	-0.282*	-0.164	-0.072	-	-	-	-	-0.098	-0.020		
pH, 8 weeks	-0.108	-0.184	-0.557***	0.216	0.462***	0.597***	-	-	-	-	0.083	-0.495***	-0.007	
Total score 8 weeks	-0.236*	-0.388***	-0.412***	0.066	0.335**	0.241	0.098	-0.233*	-0.017	-0.087	-0.109	-0.251*	-0.078	0.324**

T.A. = Titratable acidity, % lactic acid

*** $P < 0.001$ ** $P < 0.01$ * $P < 0.05$

DISCUSSION

Many experiments reported in the literature that were made on Cheddar cheese either on a chemical, bacteriological or rheological aspect have been made using one cheese from a vat in which several cheese were manufactured. Baron (1949) in her investigations on the rheological properties of Cheddar used cheese that were manufactured in 750 gal vats while Franklin and Sharpe (1963) as well as using cheese manufactured in vats ranging from 750 to 1100 gal capacity also used cheese of different size and shape, i.e. 60 lb cylindrical traditional cheese and 40 lb film-wrapped rindless blocks. Errors may be introduced due to the lack of uniformity existing between different cheese made in the same vat and conclusions drawn from the results of such experimental cheese may be erroneous and misleading. It was considered desirable therefore that in an effort to eliminate such experimental error in this study that only one cheese was made in each vat and each cheese was of similar size and shape.

It is well known that proper starter quality control is necessary if uniform acid production is to be obtained during the cheese manufacturing process. Starter bacteria play very important roles in the cheese vat including major contributions to flavour development and control of harmful micro-organisms. Certain starter bacteria have been shown to produce flavour and texture defects (Vedamuthu, Sandine and Elliker, 1966; Dawson and Feagan, 1960b) and so the identification and elimination of such starters is a first consideration in the manufacture of top quality Cheddar cheese.

Because of the variations in the manufacturing process it is almost impossible to attribute any of the lower scores for flavour and aroma to any pair of starters used in this work. It may be suggested that little difference would be obtained in flavour and aroma scores at 8 weeks or 4 months if all

Discussion

Many experiments reported in the literature that was made on [illegible]

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cheese were made to exactly the same time schedules. Because of the variations in composition of the cheese as a result of the experimental variations the starter bacteria were subjected to different environments which no doubt resulted in different growth patterns of the cheese bacterial flora and in kinds and amounts of degradation products during maturation. Where similar treatments were applied in the manufacturing process of a number of cheese up to certain stages i.e. the settling of the curd or the removal of whey from the vat, one may expect similar increases in acid production for each cheese as estimated from the titratable acidity or pH tests. This in general appears to be the case with the starters used throughout this work and certain deviations may in part be accounted for by the heat sensitivity of some of the starter bacteria.

In commercial practice the cheesemaker is able to make adjustments in the cheesemaking process to compensate for any variations in the rate of acid production but strict time schedules were adhered to in this study together with the same temperature of maximum scald of 102°F.

The first experimental variation was made at the stage of cutting the coagulum. A variation of ± 10 min was made on the 'standard' time interval of 40 min from the addition of rennet. This variation in renneting to cutting time could occur in large scale commercial factories where many of the workers may have little knowledge of the cheesemaking process or of the importance of certain operations and where the control of several large size vats are entrusted to one or maybe two individuals. The use of such a small vat in this work meant that cutting of the coagulum was capable of being carried out at exactly the stated time and the cutting operation could be completed in about 1 min.

That the effect of variations in cutting times have an effect on the

composition and quality of the cheese may be seen from Tables 72, 74, 75, 80 and 81. It is likely that in commercial practice errors will lie in the lengthening of the period from rennet addition to cutting and it appears that it is the increasing rather than the decreasing of this time interval that has the greater effect on the quality of the cheese as judged by the total grade scores of the cheese at 2 and 4 months old. When the time interval from rennet addition to cutting of the coagulum was increased there was a slight increase in the moisture content of the cheese at 1 day old. There was a decrease in the pH value at 1 day with increase in cutting time and as there was a similar trend in pH values at 2 months and 4 months i.e. when the cheese were examined and scored, this may possibly explain the lower scores obtained for texture and therefore the lower overall grade score when the interval between rennet addition and cutting the coagulum was increased. It might be suggested that by varying the renneting to cutting interval by more than 10 min a clearer picture might emerge but a variation of 20 min which Pimblett (1962) used on a 'standard' 50 min interval is not likely to occur under commercial conditions. The results of this study on the variation in the renneting to cutting interval are in agreement with the conclusions of Pimblett (1962) who found that when the time from renneting to cutting was reduced from 50 min to 30 min a relatively low acid coagulum was produced which gave better than average body and texture in the final cheese.

It appears that as the starters used by the writer produced acid at a uniform rate as judged from cheese manufactured with similar time schedules up to certain stages it may be assumed that the curd at these stages showed similar characteristics. The 'standard' time of 40 min from maximum scald to the settling of the curd was varied by ± 20 min. It was observed by the composition and quality of the diets may be also [illegible] (… 19,

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author that in commercial practice the stages up to and including settling of the curd are carried out almost entirely on a time basis with little attention being paid to acidity determinations. This apparent lack of attention stems from the fact that the cheesemaker is aware from experience of the performance of the starter being used and possibly from the idea that Cheddar cheese quality is influenced to a greater extent by changes and adjustments made after the curd has been settled.

Baron (1949) made rheological measurements on the curd during manufacture and during the maturing of the cheese and found that the firmness of the curd at settling had a highly significant effect upon the firmness of the cheese at 7, 14 and 28 days and at 4½ months old - a firm curd at pitching resulting in a firm dry cheese on maturity. The results obtained by the author appear to be in agreement with the work of Baron (1949) as the effect of increasing the time from maximum scald to settling of the curd from 20 min to 60 min was a decrease of about 1% moisture in the cheese. Baron (1949) indicated that the rheological test on the curd at settling was correlated with the moisture content of the cheese. However, it did not appear in this study that the variations in the interval maximum scald to settling of the curd had any significant effect on the scores for body awarded by the official cheese grader at 2 and 4 months old. Scott Blair _et al._ (1942) also found that the consistency of the curd at settling was closely correlated with moisture content and the firmness of the cheese as measured by the ball compressor. The fact that there is a correlation between the firmness of the curd and the moisture content of the cheese (Baron, 1949) and that there is an apparent lack of correlation between variations in the time interval from maximum scald to settling of the curd and the body scores of the mature cheese obtained by the writer is not understood. This may be explained partly

by the sensitivity of the rheological intruments used by Baron (1949) and the probability that the official cheese grader assessed the body score from a slightly different physical property.

It is a widely held belief in commercial practice that one of the most important if not the most important stage in Cheddar cheesemaking is the stage of removing the whey from the vat. It has been stated by Dolby (1941) that the acidity at removal of whey from the vat had a definite influence on the rate of acid production in the later stages and on the acidity of the cheese. Dolby _et al._ (1937) had already shown that the acidity at which the whey was removed from the curd had an important effect on the mineral content of the cheese. Dolby (1941) also found that by varying the acidity at removal of the whey the lactose content of the curd at hooping varied and that these differences persisted in the cheese during the first few days of maturation thus explaining to a great extent the differences in pH values of the cheese at 14 days. That the amount of lactose present in the curd at time of hooping had an effect on the quality of the mature cheese has been demonstrated by the author (Section 3, Part III of this thesis) when the addition of small amounts (0.78%) of lactose resulted in pronounced flavour and texture defects in the cheese. As acid production during manufacture throughout this present experiment proceeded at a uniform rate variations in the time interval betweensettling the curd to the removal of the whey produced a considerable change in acidity of this latter stage. The 'standard' time from settling the curd to the whey removal was 30 min and the lower and higher levels were 15 and 45 min respectively. These times could be adhered to very closely and the actual operation of whey removal took place in about 1 min which emphasises again the advantage of using small vats for experimental work. Where larger vats are used in commercial practice there may be difficulty in estimating

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the rate of removal of whey from the vat so that unobserved acidity increases may take place with a consequent effect on the quality of the mature cheese. The titratable acidity and pH changes brought about by variations in the settling to the removal of whey times are striking and easily detectable. The titratable acidity at the 'standard' level was about 0.03% lactic acid above the lower level and there was a similar increase at the higher level. The corresponding pH values were 0.13 pH, i.e. $C_0 - C_1$ and 0.12 pH i.e. $C_2 - C_1$. The variations in acidity at the time of removal of the whey had an affect on acidity (as measured by pH) at the curd milling stage this being in agreement with the findings of Dolby (1941).

From work recorded in Section 3, Part I of this thesis on the composition and quality of commercial Cheddar cheese there appeared to be a highly significant correlation ($r = -0.768$, $P < 0.001$) between the fat and the moisture content at about 8 weeks old. In the present experiment it may be observed (Tables 74 and 75) that the effect of increasing the time intervals between settling the curd and removal of the whey was to increase the fat content and to decrease the moisture content of the cheese. In fact the effects of variations in the time intervals from maximum scald to settling and from settling of the curd to the removal of the whey on the fat and moisture contents at 1 and 21 days and at 2 and 4 months were highly significant ($P < 0.001$). The decrease in moisture at 1 day (c 1%) does not appear to have a great affect on the scores for flavour and aroma or body scores at 2 or 4 months. This seems to be in agreement with the work of Section 3, Part I of this thesis where the correlation coefficient ($r = -0.16$) between the moisture content and the body scores of commercial Cheddar cheese was not significant.

Variations in the time interval from settling the curd to the removal of the whey did not have an affect on the scores for flavour and aroma and body at 2 and 4 months but the texture of the cheese was affected by these

variations. This effect on the texture score ($P<0.05$) might be expected to be reflected in the significance of these variations on the total grade score but one may see (Tables 72 and 81) that this does not appear so, although there was a slight decrease in total score from the lower level (i.e. 15 min from settling to whey removal) to the higher level (i.e. 45 min from settling to whey removal) of about 0.7 points. This small difference of 0.7 points could be the difference between grade 1 and grade 2 cheese in commercial practice. However, the variations in timings used in this work from settling the curd to the removal of the whey did not have a significant effect on the overall grade score of the cheese either at 2 months or 4 months old. This is partially substantiated by the work of Brown and Price (1934) on the relationship between hydrogen ion concentration, titratable acidity and the quality of Cheddar cheese. These workers obtained total grade scores of 90.8 and 87.0 (maximum 100) points for cheese made with titratable acidities at removal of the whey of 0.15% and 0.20% lactic acid respectively and total grade scores of 87.3 and 84.2 where the titratable acidities when the whey was removed from the vat were 0.145% and 0.160% lactic acid respectively.

The distinctive stage of Cheddar cheesemaking takes place between the removal of the whey and the milling of the curd. This cheddaring stage may be altered considerably or the actual technique of cheddaring e.g. depth to which blocks of curd may be piled, may be varied in an effort to influence the quality of the mature cheese. In the work described above the 'standard' adopted for the time from the removal of whey to milling of the curd was 1 h 40 min and variations of ± 30 min were made. Although variations in the time allowed for cheddaring had a significant effect ($P<0.001$) on the pH values obtained from the curd at that stage they did not affect the fat or

moisture content of the cheese at any stage during maturation up to 4 months old. Variations in the milling time did have an affect on the pH values at 1 and 21 days ($P<0.01$) and at 2 and 4 months old ($P<0.001$).

The work of Baron (1947) on the rheological properties of Cheddar cheese during manufacture and maturation indicated that the milling acidity affected the properties of the mature cheese in so much as the higher the acidity the firmer was the body of the cheese when measured by the ball compressor. It would have been interesting if Baron (1947) had awarded scores to her experimental cheese because as was the case when variations in curd settling time were correlated with the composition of the cheese it was not possible to compare body scores awarded by a cheese expert with the results of a rheological instrument or test. In later work Baron (1949) found that the higher the milling acidity the softer the cheese and that the higher the milling acidity the higher the percentage fat in the cheese. This latter fact is in complete opposition to the findings of the writer (Table 74) when variations in the milling time although producing a significant decrease in pH at milling and during maturation, resulted in almost identical fat contents in the young (1 day) and mature cheese. Pimblett (1962) varied the milling time from 1 h to 3 h having adopted a 'standard' of 1 h 45 min. Pimblett (1962) stated that "contrary to the accepted view the milling acidity did not directly affect the quality of the finished product" and she went on to say that "the curd could be milled at almost any stage during cheddaring without apparent influence on the quality of the cheese at grading". When Pimblett (1962) was scoring her experimental cheese the properties body and texture were scored as one property and this may account in part for the results of the writer who scored body and texture separately and found that the milling acidity had a non significant effect on the body scores but had a significant effect on the scores for texture at 2 months ($P<0.05$) and at

4 months ($P<0.01$). However, the writer's results do not correspond with the effect of milling acidity on the total grade score as reported by Pimblett (1962). It may be observed from Table 81 that the total grade scores (maximum 30.0) at 2 months for the lower, 'standard' and higher level of milling times were 26.68, 27.01 and 25.90 while the corresponding figures at 4 months were 27.16, 26.85 and 26.16. It is possible in the opinion of the writer that if the variations in milling time as used by Pimblett (1962) were used in the above experiment a more significant result might be obtained for the effect of variations in milling time on the total grade score of the cheese.

It was to be expected that wide variations both in the quality and composition of the cheese would result from manufacturing times varying from 3 h 15 min to 5 h 45 min from rennet addition to milling of the curd. There was a wide variation in total scores, ranging from 22.5 to 29.2 (maximum 30.0) points but it is interesting to look at the moisture, fat and salt contents in the light of work on the composition of commercial Cheddar cheese recorded in Section 3, Part I of this thesis. From the results recorded below one can directly compare the composition of the cheese from the present experiment with the commercial cheese.

	Commercial cheese		Experimental cheese	
	Minimum	Maximum	Minimum	Maximum
Fat, %	29.95	37.60	31.55	35.30
Moisture, %	32.13	40.54	35.38	39.91
Salt, %	0.68	2.95	1.16	1.72

The results of the commercial cheese are disturbing and they appear even more disturbing when compared with the results of the experimental cheese. In the present experiment salt was added to the curd each day at the rate of 2 lb/ 100 lb curd irrespective of the manufacturing schedules used.

The resultant spread figure of 0.56% salt for the entire 81 cheese seems to indicate that commercial cheese factories are extremely careless in the manufacture and especially in the salting rates and techniques used. The effect of salt content on the quality of Cheddar cheese has been demonstrated in Section 3, Part V of this thesis and the above spread figure of 0.56% salt for the experimental cheese is considered reasonable in the light of the wide variations in manufacturing procedures used.

There are many other variations which one might make in the Cheddar cheese making process but the results of the experiment recorded above may be of value in throwing new light on Cheddar cheese manufacture and maturing and may also form the basis of further experimental work.

CONCLUSIONS

The main conclusions are as follows:

1 Variations of $\pm$ 10 min in the 'standard' time interval of 40 min from the addition of rennet to the cutting of the coaculum had a significant effect on,

(a) the titratable acidities at cutting ($P < 0.05$), maximum scald, settling the curd and at removal of whey from the vat ($P < 0.001$)

(b) the pH values at cutting, maximum scald, settling the curd, removal of the whey from the vat and at the milling of the curd ($P < 0.001$).

(c) the fat content of the cheese at 1 day old ($P < 0.05$) and on the pH of the cheese at 1 day old ($P < 0.05$) at 21 days, 2 months and 4 months old ($P < 0.001$).

(d) the score for texture at 2 and 4 months old ($P < 0.01$) and on the total grade score at 2 and 4 months old ($P < 0.01$).

2 Variations of $\pm$ 20 min in the 'standard' time interval of 40 min from the stage of maximum scald to the settling of the curd had a significant

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SUMMARY

The main [illegible] are as follows:

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(a) [illegible]

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(b) [illegible]

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(c) [illegible] 1 day [illegible]

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(d) [illegible]

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2. [illegible]

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effect on,

(a) the titratable acidities and pH values at the time of settling the curd, removing the whey from the vat and at the milling of the curd ($P<0.001$)

(b) the fat and moisture contents at 1 day, 21 days, 2 months and 4 months ($P<0.001$), the salt content at 4 months ($P<0.05$), and the pH of the cheese at 1 day ($P<0.01$), 21 days, 2 months and 4 months ($P<0.001$)

(c) the score for texture at 2 and 4 months old ($P<0.01$) and the total grade score at 4 months old ($P<0.05$).

3 Variations of $\pm$ 15 min in the 'standard' time interval of 30 min from the settling of the curd to the removal of whey from the vat had a significant effect on,

(a) the titratable acidity and pH values at the removal of whey from the vat and the milling of the curd ($P<0.001$)

(b) the fat and moisture contents of the cheese at 1 day, 21 days, 2 months and 4 months ($P<0.001$), the pH of the cheese at 1 day ($P<0.05$), 21 days ($P<0.01$) and at 2 months and 4 months old ($P<0.001$).

(c) the texture score at 2 and 4 months old ($P<0.05$).

4 Variations of $\pm$ 30 min in the 'standard' time interval of 1 h 40 min from the removal of whey from the vat to the curd milling stage had a significant effect on,

(a) the pH value of the curd at milling time ($P<0.001$)

(b) the pH of the cheese at 1 day and 21 days ($P<0.01$) and at 2 and 4 months ($P<0.001$)

(c) the texture score at 2 months ($P<0.05$) and 4 months ($P<0.01$) and the total grade score at 2 months ($P<0.05$) and 4 months ($P<0.01$).

SUMMARY

In order to study the effect of variations in the Cheddar cheese-making process on the quality and on the composition of the cheese a 3^4 (factorial) experiment was carried out. A 'standard' time schedule was drawn up and the time intervals of the 4 operations, the rennet addition to cutting the coagulum, maximum scald to settling the curd, settling the curd to whey removal and whey removal to the milling of the curd were varied by ± 10 min, ± 20 min, ± 15 min and ± 30 min respectively from the 'standard' time intervals.

Titratable acidity and pH determinations were made during the manufacturing process and fat, moisture and salt contents and pH values were determined when the cheese were 1 day, 21 days, 2 months and 4 months old.

At 2 and 4 months old the cheese were examined by an official cheese grader who awarded a maximum of 10 points each for (a) flavour and aroma, (b) body and (c) texture of the cheese.

To assess the effects if any, of the variations in timings of the above stages on the quality and composition of the cheese during the maturation process the results of the chemical analyses and the scores obtained by the cheese were subjected to statistical analysis.

None of the 4 treatments where the time intervals were varied had a significant effect on the flavour and aroma or body scores. The variations in the timings of the 4 treatments had a significant effect on the titratable acidities and pH values during manufacture, on the fat and moisture contents of the cheese (except treatment D) and on the pH values during maturation. All the 4 treatments except the variation in the time interval between the settling of the curd and the removal of whey from the vat had a significant effect on the texture and total grade score obtained by the cheese.

THE EFFECT OF VARIATIONS IN THE MANUFACTURING PROCESS ON THE QUALITY OF CHEDDAR CHEESE AT 10 MONTHS OLD

INTRODUCTION

As there was a wide variation in the quality of the cheese made during the above experiment and described in Section 3, Part II of this thesis it was decided to retain the entire 81 cheese for quality assessment at about 10 months old. Cheddar cheese is not generally held in store for long periods e.g. up to 1 year, in the United Kingdom because of the cost of providing suitable storage and also because of the market requirements. However, as all details of the make procedure and analysis and grade scores of each cheese up to 4 months old were known, it was decided that in order to obtain a more complete picture the cheese should be examined for overall quality at about 10 months old.

Grading of the cheese

The same official grader as carried out the grading at 2 and 4 months old examined the cheese. At the 2 and 4 months gradings, points were awarded for flavour and aroma, body and texture of each cheese but in this case no points were awarded but remarks were recorded for the flavour and aroma and texture of the cheese. In addition each cheese was placed by the grader in grades 1, 2 or 3 corresponding to a grade 1, graded and a no-stamp cheese as used in commercial practice.

Analysis of the cheese

Only the pH of the cheese was determined on this occasion. Each cheese sample was prepared by mixing 10 g of cheese with 10 ml of distilled water by means of a Silverson blender and the pH was determined using a Radiometer pH meter 25 SE with glass and calomel electrodes.

RESULTS

In Tables 83, 84 and 85 are recorded the pH values, overall grade and remarks for flavour and aroma and texture awarded by the official cheese grader. One can see that of the 81 cheese 10 were grade 1, 12 were grade 2 and 59 were grade 3. The pH values ranged from 4.85 to 5.24 with almost equal numbers falling at either side of pH 5.00. About 25% of the cheese had a good and acceptable flavour and aroma; the most common off flavour and aroma being described as fruity. The texture in most cases, apparently regardless of pH value, was described as short or grainy.

DISCUSSION

Due to the poor appearance of the cheese and the fact that the grader was aware of the age of the cheese seemed to make the grading more difficult than a usual commercial grading. The task of the official cheese grader was to place the cheese in one of 3 grades as in the normal commercial procedure. However, the difficulty was that although the majority of the cheese were unfit for the market due to off flavour or poor cutting properties as judged from the texture, there were some cheese which were placed in a higher grade than they merited because of their age.

Any effort to relate the quality of the cheese to the starter used is complicated by the fact that each cheese had a different make procedure and therefore in this particular experiment one cannot attribute defects outlined in Tables 83, 84 and 85 to the starter used for a particular cheese.

As stated above 10 cheese were placed in grade 1 category and all but one of these cheese scored very good marks at the 8 weeks and 16 weeks old gradings. The one exception was made on day 27, Vat 1 (Table 55, Appendix A). A comparison of the scores of this cheese at the earlier gradings indicates that this cheese scored a total of 2.8 points more at 16 weeks than at 8 weeks old. One would expect a decrease or at most a very slight increase

in certain cases in the score obtained at 16 weeks as compared with the score at 0 weeks old. One can only assume that discrepancies (or at least getting results which one would not expect) arising in the correlation of a grade at one particular age and another may not alone be due to the complexity of cheese manufacture and the cheese maturation process but also to the fact mentioned above, i.e. the grader may be less critical when the age of the cheese is known to him.

It is interesting to note that the pH at milling of 7 of the 10 grade 1 cheese is greater than 5.40 but it must be added that about an equal number of cheese having a pH greater than 5.40 at milling were grade 3 at 10 months old. Therefore, before one could predict cheese quality from a pH or acidity value at a particular stage during the manufacturing process one would have to consider acidity development during manufacture together with the final composition of the cheese.

The majority of the cheese had poor flavour and aroma and texture, the latter being described as short or very short in the majority of cases. A wide variety of flavour and aromas were encountered, a fruity defect being possibly the most common. The fruity defect seemed in most cases to be accompanied by a pH of over 5.00 and although one associates a short crumbly texture with a low pH, cheese made on day 19, vat 2 (Table 47, Appendix A) had a "slightly fruity flavour and aroma, a "very short" texture but had a pH of 5.24. This again points to the difficulty of predicting quality from a limited amount of information.

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Table 83

The pH value, overall grade and remarks for flavour and aroma and texture of Cheddar cheese 10 months old

Day no.	Vat no.	Flavour	Texture	pH	Grade
1	1	Good	Very short	4.90	3
	2	Good	Very short	4.91	3
	3	Good	Short	4.93	3
2	1	Very bad	Very short	4.97	3
	2	Good	Very short	4.89	3
	3	Slightly off	Very short	5.08	3
3	1	Fruity	Short	5.15	3
	2	Fruity	Good	5.07	3
	3	Slightly fruity	Good	4.93	3
4	1	Slightly off	Very short	4.97	3
	2	Good	Very short	4.95	3
	3	Good	Short	5.12	3
5	1	Good	Short	4.90	3
	2	Good	Fair	5.06	3
	3	Slightly off	Fair	5.05	3
6	1	Good	Short	4.95	3
	2	Good	Short	4.92	3
	3	Garlic	Very short	4.86	3
7	1	Good	Very short	5.01	3
	2	Slightly fruity	Short	5.06	3
	3	Good	Very short	5.00	3
8	1	Slightly fruity	Short	5.05	3
	2	Good	Good	5.04	1
	3	Slightly off	Short	4.99	3
9	1	Slightly fruity	Short	4.94	3
	2	Garlic	Short	5.00	3
	3	Slightly off	Very short	4.86	3

Table 84

The pH value, overall grade and remarks for flavour and aroma and texture of Cheddar cheese 10 months old

Day no.	Vat no.	Flavour	Texture	pH	Grade
10	1	Fair	Fair	4.94	3
	2	Good	Slightly short	4.95	1
	3	Good	Short	4.95	3
11	1	Very slightly off	Short	4.87	3
	2	Off	Short	4.95	3
	3	Buttery	Very short	4.98	3
12	1	Fruity	Slightly short	5.04	3
	2	Slightly fruity	Fair	5.06	3
	3	Slightly fruity	Very short	5.02	3
13	1	Very bad	Short	4.96	3
	2	Very slightly off	Fair	5.00	2
	3	Very slightly off	Fair	5.08	2
14	1	Very bad	Very short	5.02	3
	2	Bad	Good	4.95	3
	3	Bad	Good	5.09	3
15	1	Good	Short	4.85	3
	2	Good	Good	4.94	2
	3	Good	Good	4.99	1
16	1	Slightly off	Short	4.96	3
	2	Slightly off	Very short	4.97	3
	3	Slightly off	Very short	4.95	3
17	1	Fruity		5.10	3
	2	Fruity	Short	5.06	3
	3	Bad	Short	4.98	3
18	1	Good	Good	5.00	1
	2	Good	Slightly grainy	5.02	1
	3	Sour	Very short	4.88	3

Table 85

The pH value, overall grade and remarks for flavour and aroma and texture of Cheddar cheese at 10 months old

Day no.	Vat no.	Flavour	Texture	pH	Grade
19	1	Slightly fruity	Short	5.12	3
	2	Slightly fruity	Very short	5.24	3
	3	Off	Very short	5.03	3
20	1	Good	Good	5.06	1
	2	Fair	Short	5.05	2
	3	Fair	Short	4.99	2
21	1	Very slightly off	Short	4.96	2
	2	Fair	Short	4.95	2
	3	Bad	Very short	5.07	3
22	1	Very slightly fruity	Short	5.04	2
	2	Sour	Very short	4.89	3
	3	Off	Very short	4.95	3
23	1	Fruity	Short	5.12	3
	2	Slightly fruity	Very short	4.89	3
	3	Slightly fruity	Short	5.02	3
24	1	Yeasty	Short	5.03	3
	2	Slightly yeasty	Very short	4.86	3
	3	Good	Fair	4.94	2
25	1	Good	Good	4.95	1
	2	Good	Good	5.07	1
	3	Fair	Very short	4.90	3
26	1	Slightly fruity	Fair	5.13	2
	2	Slightly fruity	Slightly grainy	5.08	2
	3	Fair	Very short	4.92	3
27	1	Good	Good	5.03	1
	2	Good	Grainy	4.97	2
	3	Good	Fair	4.98	1

SUMMARY

The cheese made in the preceding 3^4 (factorial) experiment were examined at about 10 months. The official cheese grader placed each cheese in grade 1, 2 or 3 and his remarks on flavour and aroma and texture were recorded. Of the 81 cheese made 10 cheese were grade 1 and 12 cheese were grade 2 the high number of inferior cheese being associated with a wide variety of make procedures used. The range of pH was from 4.85 to 5.24. The texture of the cheese was generally short or very short, the more common flavour and aroma defect being fruitiness.

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Section three

Part III

The rate of utilisation of lactose during maturation and the effect of various rates of lactose addition to the curd on the quality and composition of Cheddar cheese

THE RATE OF UTILISATION OF LACTOSE DURING MATURATION AND THE EFFECT OF VARIOUS RATES OF LACTOSE ADDITION TO THE CURD ON THE QUALITY AND COMPOSITION OF CHEDDAR CHEESE

INTRODUCTION

The principal carbohydrate present in cows' milk is lactose. The lactose content of cows' milk varies widely, from breed to breed as well as within breeds. Richmond (1920) found a mean of 4.75% lactose in cows' milk, Overman, Sanmann and Wright (1929) found 4.8%, Golding, Mackintosh and Mattick (1932) 4.80%, Cornalba (1934) 4.80% and Tocher (1925) 4.64% lactose, the range being from 0.68% to 6.11%.

Overman *et al.* (1929) recorded the following figures for the lactose content of the milk of cows of different breeds together with the range obtained within each breed.

Breed	Average lactose, %	Range, %
Ayrshire	4.69	2.41 - 6.11
Guernsey	4.91	3.57 - 5.78
Holstein	4.86	3.96 - 5.71
Jersey	4.94	2.73 - 5.66
Guernsey-Holstein	4.86	2.98 - 6.05

These figures show the wide variation in the lactose content of cows' milk. It is likely, however, that the above data contain figures obtained from the milk of cows suffering from mastitis which causes a reduction in the lactose content of milk.

The rate of conversion of lactose into lactic acid is of very great importance in cheesemaking and its utilisation by the lactic acid bacteria has been studied by several workers. van Slyke and Bosworth (1915) carried out experiments on the souring of milk to which were added *B. lactis* and *B. lactis aerogenes*. They found that only from 70 to 93% of the lactose

fermented was converted to lactic acid. van Slyke and Bosworth (1907) estimated the lactose and lactic acid contents of curd at various stages during the cheesemaking process, and the cheese at various times during pressing and maturation. They noted a rapid decrease in lactose content of the curd until a few hours after the cheese was hooped and then a more gradual fall until after 2 weeks the lactose had almost completely disappeared.

In Cheddar cheesemaking it is essential to control the amount of lactose remaining in the curd since the typical flavour of mature Cheddar cheese is directly affected by end products of lactose fermentation. The initial conversion of the lactose to lactic acid in the first few days of curing can affect the quality of the mature cheese. This being so the quantity of lactose remaining in the curd at hooping and its rate of utilisation during the subsequent curing of the cheese is of commercial as well as of academic interest.

To demonstrate the effect of the addition of lactose to cheese curd on the quality of the mature cheese and also to estimate the rate of utilisation of the lactose in the cheese the experiments detailed below were carried out.

EXPERIMENTAL

Materials and methods

A total of 39 cheese were made i.e. 3 controls to which no lactose was added, the remainder containing various amounts of added lactose. This involved 3 separate experiments.

In preliminary trials lactose was added to the milk in the vat and to the curd after milling. However, most of the lactose added to the milk was lost in the whey. It was decided, therefore, that if substantial increases in the lactose content of the cheese were to be brought about the lactose must be added to the cheese curd.

Cheddar cheese was made in the usual manner up to and including the salting stage. When the salt was thoroughly mixed with the curd about 130 pounds of curd was removed from the vat which contained about 500 pounds of curd. Then, thirteen, 10 pound quantities of curd were weighed accurately. One 10 lb portion of the curd was used as a control. The remaining 12 quantities of curd were divided into 6 pairs, the individual cheese of each pair containing the same amount of lactose. The rates of addition of lactose ranged from 0.78% to 4.68% in steps of 0.78% lactose. The lactose was distributed evenly over the cheese curd which was at a temperature of 85^{o}F. The cheese were pressed in wooden cheese moulds overnight and sampled the following day. After sampling the cheese were returned to press for a further period of 24 h. After removal from the press the cheese were allowed to stand for 4 days and then waxed to prevent surface mould growth. The cheese were then stored at a temperature of 45 to 47^{o}F and 85% relative humidity.

<u>Analysis</u>

All cheese were sampled at 1 day old and analysed for fat, moisture, salt (Section 3, Part I of this thesis) and lactose contents, (Section 2, Part II of this thesis), pH determinations were also carried out. Lactose determinations were also carried out during the maturing of each cheese giving a total of 5 lactose estimations. The following quantities of filtrate were used in order to bring the lactose content within the scale of the standard curve; control, 5 ml; blank and sample numbers 1, 2 and 3, 2.5 ml; sample numbers 4, 5 and 6, 1 ml. As the standard curve was plotted using 2.5 ml of filtrate, the appropriate conversion factors of 0.5, 1.0 and 2.5 were used. When the cheese were about 9 weeks old they were examined by an official of the Company of Scottish Cheesemakers Ltd, who scored the

cheese on the points system described in Section 3, Part I of this thesis. The fat, moisture and salt content and pH values were also determined at about 9 weeks old.

RESULTS

The rate of lactose utilisation in the cheese in each of the 3 experiments is shown in Tables 86, 87 and 88. The results of the analyses for fat, moisture, salt and pH are recorded in Tables 89, 90 and 91. In Tables 92, 93 and 94 are shown the grade scores obtained by each cheese at about 9 weeks old. The results recorded in Tables 86, 87 and 88 indicate that almost all of the lactose in the control cheese was removed within 21 days depending on the initial concentration of lactose in the cheese at 1 day old. It may be seen that in samples 1A and 1B - to which lactose was added at the rate of 0.78% - only some of the added lactose was utilised.

On examination of Tables 86, 87 and 88 some discrepancies in the amount of lactose present in the cheese at certain ages are apparent. This may be explained by the fact that it was extremely difficult to distribute the lactose powder uniformly throughout the cheese curd. Sample 2B, Table 86 had an abnormally high lactose content at 50 days old. It must be added, however, that in the case of sample 2B, Table 86, when the grated cheese sample was weighed out, a tiny speck of lactose was noticed in it which would account in part at least for the high lactose concentration. Nevertheless, Tables 86, 87 and 88 do give a general picture concerning lactose utilisation in cheese, the control cheese having almost all its lactose removed within 21 days and additions of even small quantities of lactose powder to cheese curd are not completely utilised.

The composition of the cheese is altered greatly by lactose addition to cheese curd. The fat content shows a slight upward trend with increase in the amount of added lactose. This holds for the analysis both at 1 day old [illegible] Section 3 [illegible] of this chapter.

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Results

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and at time of grading, about 9 weeks old. The decrease in moisture with increase in amounts of added lactose is quite dramatic, differences of more than 5% moisture being obtained between the control cheese and cheese having the greatest amounts of added lactose.

The pH values obtained at 1 day old and 9 weeks old seem to follow somewhat different patterns. At 1 day old the pH values of cheese containing added lactose are similar or slightly higher than the pH values of the control cheese. At grading time, about 9 weeks old, the pH values of cheese containing added lactose are lower than that of the corresponding control cheese.

From previous work reported in Section 3, Part V of this thesis, the spread figure for salt content within a vat i.e. the difference between the highest and the lowest salt content could be expected to be of the order of 0.40% salt and possibly 0.80% where hand salting is practised (O'Connor, 1968). In the light of these figures the salt content figures both at 1 day and 8 weeks old are acceptable and do not appear to be related to the moisture content of the cheese.

Tables 92, 93 and 94 show that the control cheese in each of the 3 experiments obtained higher scores than all but one of the cheese to which lactose had been added. Although there was some improvement in the body of the cheese containing added lactose, the aroma and texture of these cheese were defective. In the cheese with the higher lactose concentrations very low points were awarded for flavour and aroma, body and texture.

Table 86

The rate of utilisation of lactose during maturation of Cheddar cheese containing various amounts of added lactose

Experiment 1

Cheese no.	Rate of lactose addition, %	Age, days				
		1	4	10	21	50
		Lactose, %				
Control	0.00	0.21	Trace	0.08	0	0
1A	0.78	0.86	0.71	0.94	0.82	0.33
1B	0.78	0.76	0.60	1.02	0.93	0.29
2A	1.56	0.91	1.32	1.79	0.87	1.08
2B	1.56	1.28	2.33	1.87	-	2.46
3A	2.24	1.03	1.50	1.89	1.81	1.28
3B	2.24	1.57	1.25	2.42	1.76	1.43
4A	3.12	3.52	2.07	2.63	2.55	1.30
4B	3.12	2.62	1.50	1.90	2.60	1.22
5A	3.90	1.45	0.70	1.70	2.58	0.85
5B	3.90	2.05	2.45	3.25	2.75	1.70
6A	4.68	2.12	3.75	3.30	3.42	2.07
6B	4.68	2.20	4.35	3.95	3.12	2.55

Table 87

The rate of utilisation of lactose during maturation of Cheddar cheese containing various amounts of added lactose

Experiment 2

Cheese no.	Rate of lactose addition, %	Age, days				
		1	4	10	21	50
		Lactose, %				
Control	0.00	0.50	0.20	0.41	0.02	0.03
1A	0.78	0.92	0.79	0.82	0.62	0.44
1B	0.78	1.02	0.99	1.08	0.57	0.51
2A	1.56	1.19	1.32	1.13	1.00	0.53
2B	1.56	1.12	1.47	1.31	1.31	0.73
3A	2.24	1.61	1.72	1.54	1.72	1.26
3B	2.24	1.93	1.68	1.54	1.61	0.97
4A	3.12	1.52	2.15	1.30	0.75	1.32
4B	3.12	1.00	2.02	2.85	0.85	1.30
5A	3.90	3.00	3.15	3.05	1.85	2.07
5B	3.90	2.30	3.12	3.42	2.52	1.70
6A	4.68	2.85	3.02	2.87	3.77	3.33
6B	4.68	3.12	3.35	2.85	2.87	3.15

Table 88

The rate of utilisation of lactose during maturation of Cheddar cheese containing various amounts of added lactose

Experiment 3

Cheese no.	Rate of lactose addition, %	Age, days				
		1	3	8	21	45
		Lactose, %				
Control	0.00	0.75	0.60	0.18	0.25	-
1A	0.78	1.37	1.56	0.87	0.56	0.54
1B	0.78	1.52	1.37	0.71	0.46	1.02
2A	1.56	1.68	1.61	1.21	1.30	1.47
2B	1.56	1.75	1.73	1.55	1.20	0.97
3A	2.24	1.95	1.58	1.72	1.85	1.40
3B	2.24	2.06	1.84	1.87	1.75	1.34
4A	3.12	2.47	2.52	2.37	2.00	1.65
4B	3.12	2.87	2.92	2.67	2.47	1.87
5A	3.90	3.55	3.30	2.65	2.45	2.60
5B	3.90	3.97	3.35	3.15	2.55	2.20
6A	4.68	4.72	3.72	3.72	4.10	2.47
6B	4.68	4.27	3.67	3.67	3.82	2.45

Table 89

The effect of lactose added to cheese curd on the composition of Cheddar cheese at 1 day and 9 weeks old

Experiment 1

Cheese no.	pH		Moisture, %		Salt, %		Fat, %	
	Age of cheese							
	1 day	9 weeks	1 day	9 weeks	1 day	9 weeks	1 day	9 weeks
Control	5.26	5.16	38.42	37.35	1.58	1.67	31.40	32.20
1A	5.33	4.95	37.65	37.82	1.69	1.64	31.20	31.10
1B	5.36	4.98	37.28	37.38	1.74	1.65	31.40	32.30
2A	5.32	4.90	37.21	36.39	1.50	1.55	31.50	32.00
2B	5.31	4.99	36.96	33.10	1.52	1.29	31.40	33.30
3A	5.32	4.89	36.15	35.53	1.41	1.45	32.40	32.40
3B	5.33	4.94	35.91	35.74	1.47	1.49	32.20	31.80
4A	5.34	4.94	35.39	34.44	1.37	1.38	31.70	32.70
4B	5.32	4.88	35.71	34.82	1.37	1.31	31.70	32.60
5A	5.31	4.93	34.19	35.86	1.27	1.50	32.90	32.40
5B	5.30	5.02	34.54	33.62	1.30	1.40	32.30	32.50
6A	5.33	4.88	33.01	32.10	1.32	1.31	33.40	33.80
6B	5.35	5.00	34.23	32.91	1.70	1.35	32.30	32.40

Table 90

The effect of lactose added to cheese curd on the composition of Cheddar cheese at 1 day and 9 weeks old

Experiment 2

Cheese no.	pH		Moisture, %		Salt, %		Fat, %	
	Age of cheese							
	1 day	9 weeks	1 day	9 weeks	1 day	9 weeks	1 day	9 weeks
Control	5.36	5.18	37.99	37.63	1.74	1.54	32.40	32.50
1A	5.36	4.94	37.29	37.27	1.58	1.53	34.00	33.20
1B	5.39	4.95	38.14	37.28	1.72	1.56	32.50	32.80
2A	5.39	4.90	36.99	36.24	1.32	1.52	32.00	33.20
2B	5.40	4.90	36.82	36.29	1.58	1.61	33.00	32.80
3A	5.42	4.92	36.28	35.86	1.60	1.61	32.50	32.10
3B	5.41	4.86	35.94	34.47	1.59	1.43	32.60	33.30
4A	5.38	4.88	35.38	34.11	1.41	1.33	33.00	33.80
4B	5.40	4.99	35.93	34.87	1.61	1.63	32.40	33.50
5A	5.37	4.88	34.21	32.64	1.31	1.31	32.20	34.40
5B	5.42	4.86	34.56	33.09	1.39	1.30	33.20	34.40
6A	5.40	4.99	33.76	32.04	1.36	1.35	33.20	34.40
6B	5.40	4.97	34.72	32.71	1.47	1.45	32.10	33.80

Table 91

The effect of lactose added to cheese curd on the composition of Cheddar cheese at 1 day and 9 weeks old

Experiment 3

Cheese no.	pH		Moisture, %		Salt, %		Fat, %	
	Age of cheese							
	1 day	9 weeks	1 day	9 weeks	1 day	9 weeks	1 day	9 weeks
Control	5.27	5.04	38.94	37.90	1.78	1.75	31.50	32.80
1A	5.26	4.91	37.72	37.14	1.47	1.62	31.90	32.40
1B	5.28	4.92	38.01	37.12	1.69	1.73	32.00	32.70
2A	5.21	4.85	36.87	35.90	1.25	1.56	32.30	33.80
2B	5.28	4.85	36.57	36.36	1.62	1.67	32.40	33.30
3A	5.29	4.84	36.18	34.58	1.48	1.47	32.60	33.90
3B	5.30	4.82	35.08	34.97	1.57	1.49	33.10	33.50
4A	5.31	4.86	34.92	33.97	1.50	1.49	32.70	34.30
4B	5.32	4.89	34.44	33.88	1.53	1.55	33.00	34.30
5A	5.30	4.81	33.94	32.60	1.48	1.32	33.10	34.60
5B	5.28	4.85	33.12	31.41	1.35	1.34	33.20	35.40
6A	5.28	4.82	33.15	30.94	1.37	1.31	33.60	35.70
6B	5.25	4.83	34.04	30.92	1.22	1.30	33.20	35.20

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Table 92

The effect of lactose added to cheese curd on the quality and grade score of Cheddar cheese at 9 weeks old

Experiment 1

Cheese no.	Rate of lactose addition, %	Flavour & aroma (10)	Body (10)	Texture (10)	Total (30)
Control	0.00	8.8	8.5	8.6	25.9
1A	0.78	8.8	8.8	8.5	26.1
1B	0.78	8.5	8.6	8.6	25.7
2A	1.56	8.0	8.2	8.0	24.2
2B	1.56	7.0	7.5	7.5	22.0
3A	2.24	8.0	8.0	7.8	23.8
3B	2.24	7.8	8.0	7.9	23.7
4A	3.12	8.2	7.8	7.8	23.8
4B	3.12	8.0	7.4	7.0	22.4
5A	3.90	7.8	8.6	8.5	24.9
5B	3.90	7.6	7.8	7.5	22.9
6A	4.68	6.5	6.0	6.0	18.5
6B	4.68	7.0	7.5	7.0	21.5

Table 93

The effect of lactose added to cheese curd on the quality and grade score of Cheddar cheese at 9 weeks old

Experiment 2

Cheese no.	Rate of lactose addition, %	Flavour & aroma (10)	Body (10)	Texture (10)	Total (30)
Control	0.00	8.8	8.5	8.6	25.9
1A	0.78	7.0	8.2	8.4	23.6
1B	0.78	7.0	7.5	7.8	22.3
2A	1.56	8.4	7.8	8.0	24.2
2B	1.56	7.0	7.8	7.8	22.6
3A	2.24	8.6	8.2	8.2	25.0
3B	2.24	7.5	7.4	7.4	22.3
4A	3.12	7.5	6.5	6.5	20.5
4B	3.12	8.6	8.0	7.5	24.1
5A	3.90	7.0	6.0	6.0	19.0
5B	3.90	6.8	5.8	5.8	18.4
6A	4.68	8.5	6.0	6.0	20.5
6B	4.68	7.0	6.0	6.0	19.0

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Table 94

The effect of lactose added to cheese curd on the quality and grade score of Cheddar cheese at 9 weeks old

Experiment 3

Cheese no.	Rate of lactose addition, %	Flavour & aroma (10)	Body (10)	Texture (10)	Total (30)
Control	0.00	8.8	8.0	8.8	25.6
1A	0.78	8.0	8.4	8.5	24.9
1B	0.78	8.0	8.6	8.8	25.4
2A	1.56	7.8	8.2	8.6	24.6
2B	1.56	7.5	8.0	8.0	23.5
3A	2.24	7.5	7.5	7.0	22.0
3B	2.24	7.8	7.0	7.0	21.8
4A	3.12	7.5	7.0	7.0	21.5
4B	3.12	7.8	7.5	7.5	22.8
5A	3.90	7.0	6.5	6.5	20.0
5B	3.90	7.0	6.5	6.5	20.0
6A	4.68	7.0	6.0	6.0	19.0
6B	4.68	7.2	6.5	6.5	20.2

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DISCUSSION

The lactose content of the cheese at the time of pressing is one of the most important factors affecting the quality and acidity, as measured by pH methods, of the mature cheese. It appears from the above experiments that lactose in a normally made cheese is not completely utilised until about 21 days have elapsed and that additions of lactose powder to Cheddar cheese curd after salting are only partially utilised during the maturing of the cheese.

Fagen et al. (1952) stated that Cheddar cheese made from raw milk had lactose contents of 0.87%, 0.46%, 0.19% and 0.00% at 1, 12, 19 and 25 days respectively and that cheese made from pasteurised milk had lactose contents of 0.82%, 0.50%, 0.20% and 0.00% at 19, 25, 39 and 53 days respectively. It appears, therefore from the work of Fagen et al. (1952) that lactose was utilised at a faster rate in Cheddar cheese made from raw milk than in Cheddar cheese made from pasteurised milk. In the writer's experiment the milk for cheesemaking was heat treated to 155^{o}F for 15 sec but the rate of lactose utilisation, (Tables 86, 87 and 88) in the control cheese seemed to be similar to that in the cheese made by Fagen et al. (1952) from raw milk. However, comparisons between rate of lactose utilisation in one lot of experimental cheese and another may be misleading unless one takes into consideration such factors as the pH of the cheese, moisture and salt contents and salt concentrations in the aqueous phase, all of which can play an important part in the fermentation of lactose during the maturation of the cheese.

Sjostrom (1956) studied the rate of sugar breakdown in various varieties of cheese made in Sweden. In hard, high temperature of scalding Swedish rennet cheese most of the lactose was utilised before pressing and when a low scalding temperature was used the sugar breakdown went much faster. Nilsson and Guldstrand (1959) studied the sugar fermentation during the

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early stages of the maturing of Herrgard cheese, one normally made cheese and one cheese in which the curd was preheated to 48°C before pressing. They found that in the normally made cheese all sugar had been utilised within 1 day and in the heated cheese it was utilised within 6 days. From the author's experiments of Cheddar cheese it appears that even with small additions of lactose powder to cheese curd its complete utilisation by the lactic acid bacteria is not effected.

Dolby <u>et al</u>. (1937) carried out a limited number of experiments on the addition of lactose to cheese curd. They found that after 4 months of maturing appreciable quantities of lactose still remained in the cheese and this caused them some concern as they stated that the incompleteness of fermentation could not be entirely due to the retarding effect of the low pH. It could possibly be due to the dying off of the lactic streptococci with the appearance of the lactobacilli which ferment lactose to only a small extent.

From work reported in Section 3, Part I of this thesis it is clear that the composition of commercial Cheddar cheese at 8 to 10 weeks old varies a great deal.. The moisture contents varied from about 32% to about 40% while the pH values varied from about 4.9 to about 5.5 pH. In the experiments on the effects of added lactose, the composition of Cheddar cheese, which up to and including the salting stage were part of the same vat, varied greatly depending on the rate of addition of lactose to the cheese curd. Contrary to what one might expect the control cheese at 1 day old had a pH value lower than the majority of the cheese containing added lactose, the greatest difference being 0.1 pH. In general, the pH values at 9 weeks old follow an expected pattern due to the fermentation of part of the added lactose. On occasions the official cheese grader commented that some of the cheese containing added lactose were over acid. This in

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fact, appeared to be true according to the pH value and was due entirely to the fermentation or acid produced from the added lactose. It may be concluded that the addition of lactose to cheese curd to correct what might be anticipated as a "sweet" or low acid cheese would be advantageous. This is not the case as far as overall cheese quality is concerned as the flavour and aroma of the cheese containing added lactose was sometimes described by the grader as being sour, peppery and mouldy, the latter flavours never being encountered by the grader in commercial Cheddar cheese made from milk with the normal content of lactose.

The only experimental difference between the control cheese and the remaining cheese was added lactose. One may conclude, therefore, (Tables 89, 90 and 91) that lactose addition is an effective means of removing moisture from cheese curd. However, one must bear in mind the detrimental effect of even small quantities of lactose added to the cheese curd on the quality of the mature cheese. In work described in Section 3, Part V of this thesis the author has shown that increasing the rate of salt addition also proved effective in removing excessive moisture from cheese curd. Although the net effect is the same i.e. reduction in moisture with increasing quantities of salt or added lactose, the question that might be considered is whether the apparent reduction in moisture is a true figure or not. In the opinion of the author, in the case of extra added salt it is the true figure but where added lactose is concerned the apparent reduction in moisture may be due to the combination of lactose and cheese constituents e.g. protein, and/or the formation and loss of volatile substances during drying at 100°C.

There seems to be a slight tendency for an increase in fat content with increase in added lactose but the increase is not considered to be abnormal. The salt content appears to bear no relationship to either

[illegible]

[illegible] the [illegible] recommendation [illegible]

[illegible] constructed [illegible]

[illegible]

The only exceptional [illegible]

[illegible]

[illegible] more important to be [illegible] In fact, [illegible]

[illegible]

moisture content or lactose content but as stated above the salt values are considered to be within acceptable limits.

Dolby et al. (1937) stated that cheese containing added lactose when graded at 14 days and at 3 months showed a clean acid flavour but that at 6 months a sour, unclean flavour developed. In the present experiment the cheese were graded at about 9 weeks and in Tables 92, 93 and 94 are recorded the scores obtained by each individual cheese. It is apparent that added lactose does not enhance the flavour and aroma and the cheese containing larger quantities of added lactose scored very low marks for flavour and aroma and consequently were placed in the lowest commercial grade. The flavours and aroma encountered were described as peppery and in most cases mouldy and although the grader had more than 20 years experience in judging quality he had not encountered these flavours before. Where the control cheese was criticised for having excessive moisture the addition of the small amounts of lactose resulted in an increased score for body but this did not, except in the case of 1 cheese, Table 86, cheese no. 1A, result in a total score higher than the total for the control cheese. In the cheese containing the larger amounts of added lactose the body was, as expected from the pH values, very mealy, i.e. the cheese broke down into fine crumbs when rubbed between the fingers. The texture of the cheese did not suffer greatly in the cheese containing very small quantities of added lactose but in the cheese containing the larger amounts of added lactose the texture was described as crumbly, curdy, rough, short or very short.

As may be seen from Tables 92, 93 and 94 the lowest and the highest overall scores were 18.4 and 26.1 respectively. It is of interest to note cheese no. 5A, Table 92. When this cheese was scored by the grader the author asked for another core or sample to be taken. This, as was expected,

was worse than the first sample. It indicated, as did the variations in lactose estimations recorded in Tables 86, 87 and 88 the great difficulty in obtaining a reasonably representative sample from cheese in experiments of this kind.

CONCLUSIONS

The results of these experiments demonstrate the importance of the lactose content of young cheese in determining the final quality of the cheese. Added lactose might be used to reduce moisture content and to "correct" a "sweet" or low acid cheese but excessive lactose additions lead to defects in flavour and aroma and also texture. Cheese with a high lactose content in the curd at hooping developed a lower pH on maturing than the control cheese. The body or firmness of a cheese may be improved by the addition of a small amount of lactose which removes excess moisture but defects in flavour and aroma will occur. The larger amounts of lactose which were added to the cheese curd were considerably higher than would be possible to obtain in the cheese curd in ordinary cheesemaking practice but the smaller amounts which were added could be obtained in the cheese curd due to natural variations in the cheese milk and also to variations in the cheese manufacturing process.

SUMMARY

A total of 39 Cheddar cheese were made in this experiment, 3 controls and 36 cheese to which lactose was added to the cheese curd in varying amounts from 0.78% to 4.68%. Lactose estimations were made at 5 different stages during maturation and at 1 day old and 9 weeks old the cheese were analysed for fat, moisture and salt contents, pH determinations also being made. At about 9 weeks old the cheese were graded on a points system, points being awarded for flavour and aroma, body and texture.

[illegible]

Conclusions

[illegible]

Summary

[illegible]

THE pH VALUE OF CHEDDAR CHEESE AT 24 WEEKS OLD MADE WITH VARIOUS AMOUNTS OF LACTOSE ADDED TO THE MILLED CURD

The pH value of the cheese made in the previous experiment was obtained when the cheese were 24 weeks old. This was carried out by mixing equal weights of cheese and distilled water by means of a Silverson blender the pH being determined by a Radiometer pH meter 25 SE.

The results are recorded in Table 95.

Although the total number of cheese was 39, only 30 pH values are recorded above. This is due to the fact that 9 cheese were cut up at about 9 weeks old to ascertain if there were any differences in the texture of the cheese. Since no appreciable differences in the texture throughout a range of lactose contents was observed the remaining cheese were not examined.

DISCUSSION

It may be seen from Table 95 that the addition of lactose to milled curd even at the lower level had the effect of reducing the pH of the matured cheese. Somewhat similar results were obtained when the cheese were examined at 9 weeks old.

During the study of the quality and composition of commercial Cheddar cheese (Section 3, Part I of this thesis) it was observed that a high pH ($>$5.40) was usually associated with an off flavour. The control cheese in Experiment 1 had what the author considers a high pH especially as no off flavours were detectable. This high pH may be explained by the fact that mould growth had penetrated the cheese which had been sampled on several occasions, but no mould was observed on the sample used for the pH determinations. This increase in pH may also be observed in a grated cheese sample held in a sample bottle for about 3 days.

THE pH VALUE [illegible]

[illegible]

The pH value [illegible]

[illegible]

[illegible]

[illegible]

As has been stated above the addition of lactose powder to cheese curd effects a reduction in pH of the mature cheese but from the results recorded in Table 95 there appears to be no direct relationship between the rate of addition of lactose powder and the pH of the cheese at 24 weeks. In Experiments 1 and 2 there was a decrease in pH at the lower levels of lactose addition followed by a gradual increase in pH at the higher levels of lactose addition. In the case of Experiment 3 a general decrease over the range of lactose addition was observed. An interesting point which cannot be explained is the fact that although the control cheese in Experiment 3 has a higher pH (5.22) than the control cheese of Experiment 2 (pH 5.19) the pH values of the cheese containing higher levels of added lactose in Experiment 3 are lower than in the corresponding cheese of Experiment 2. It might be suggested that the composition of the cheese may be a factor in causing this discrepancy but the observed difference i.e. 0.03 pH, could possibly be the result of experimental error.

CONCLUSION

As stated in the main part of this section the addition of lactose to cheese curd prior to hooping caused a reduction in the pH of the cheese. However, care must be exercised if lactose addition is employed to improve acid production as even small additions of lactose powder to cheese curd can give rise to defects in flavour and aroma in the mature cheese. There appeared to be no relationship between the rate of addition of lactose powder and the pH of the cheese at 24 weeks old.

Table 95

__The pH values of Cheddar cheese aged 24 weeks made with various amounts of added lactose__

Experiment 1		Experiment 2		Experiment 3	
__Cheese no.__	__pH__	__Cheese no.__	__pH__	__Cheese no.__	__pH__
Control	5.47	Control	5.19	Control	5.22
1B	4.96	1A	5.00	1B	4.88
2B	4.90	1B	4.98	2A	4.82
3B	4.80	2A	4.79	2B	4.93
4B	4.74	2B	4.80	3B	4.75
5B	4.86	3A	4.81	4A	4.80
6B	4.88	3B	4.71	4B	4.75
		4A	4.78	5A	4.70
		4B	4.79	5B	4.72
		5A	4.73	6B	4.69
		5B	4.79		
		6A	4.87		
		6B	4.82		

Section three

Part IV

The relationship between the pH, titratable acidity, lactic acid content and quality of commercial Cheddar cheese.

THE RELATIONSHIP BETWEEN pH, TITRATABLE ACIDITY, LACTIC ACID CONTENT AND QUALITY OF CHEDDAR CHEESE

INTRODUCTION

The quality of Cheddar cheese manufactured in Scotland under commercial conditions is determined by an official cheese grader of the Company of Scottish Cheesemakers Ltd.who places the cheese in a certain grade, grade 1, graded and no stamp, after examination of a core taken from the cheese by means of a cheese trier or sampling iron. Marks or points are awarded for (a) flavour and aroma, (b) body and (c) texture. Each of these characteristics must obtain a certain minimum number of marks for each of the 3 grades.

The flavour of Cheddar cheese is attributed to a multiplicity of compounds and reactions. Flavour components of Cheddar cheese include carbonyl, nitrogenous and sulphur compounds, fatty acids, alcohols, salt and water. Each of these components has been studied by several workers, (Baker and Nelson, 1948; Calbert and Price, 1948; Dacre, 1955; Mabbitt and Zielinska, 1956 and Patton, Wong and Forss, 1958) but it is sufficient to say for commercial purposes that the flavour of Cheddar cheese should be clean, fully developed and as it is often described, nutty. The body and texture of Cheddar cheese should be close and candle like (Bryan, 1957), it should be firm but have a smooth and mellow feel, and waxy to the touch. A cheese having a low moisture content may be the result of oversalting or scalding to too high temperatures. The fat content of the milk also has an affect on the body of Cheddar cheese as well as affecting the yield and composition, (McDowall, 1936). The texture is affected by too low or too high an acidity and also by excessive salting.

The cheesemaker exercises his skill and judgement during the cheese-making process so that the curd at the critical stages of the manufacturing

process has the correct amount of acid and is developing acid at a steady and uniform rate. Procedures and techniques for varying the composition of cheese are known to the cheesemaker and the acidity values he uses at the various stages are amongst the vital criteria on which the final characteristics of the cheese are based.

Acidity can be measured by either the titratable acidity test or a pH method and the acidity value reached in the manufacturing process gives some indication of the acidity of the finished cheese. If acidity development is restricted during the cheesemaking process and increases only slowly until the curd is milled it can be expected that the finished or mature cheese will display the characteristics of a cheese lacking in acid. It can happen, however, that cheese which is made by apparently correct acidities and times will result in a cheese possessing characteristics of a very low acid or "sweet" cheese.

It is difficult to predict the activity or action of starter organisms in the cheese during maturation or curing. It is possibly more difficult to predict the action of the adventitious flora of cheese milk in the cheese during maturation and so the prediction of a definite acidity at a certain time in the maturation of cheese becomes an almost impossible task. Nevertheless, it is considered that if an acidity value of good quality mature cheese is obtained and if acidity values of mature cheese can be related to overall cheese quality this valuable information could be applied to cheesemaking practices. This study was therefore undertaken to estimate the acidity of mature cheese, by measuring the pH, titratable acidity and lactic acid (lactate) content.

The lactic acid (lactate) content of Cheddar cheese is a subject which has not, as far as is known, been reported on but an effort has been

made by Harper and Randolph (1960) to study the possible relationship between flavour and the amount of lactic acid (lactate) in Cottage cheese. This study also provides an opportunity not alone to compare acidity values with the characteristics, e.g. flavour and aroma, body and texture, of the mature cheese but to ascertain the relationship, if any, between the hydrogen ion concentration (pH), titratable acidity and lactic acid (lactate) content of Cheddar cheese.

EXPERIMENTAL

In order to obtain a wide variation in quality, cheese was selected on the basis of the official cheese grader's remarks. A total of 62 cheese were examined, which included over acid cheese, correct acid cheese and cheese which were "sweet" or lacking in acid. The cheese were scored on the special points system devised by the author and described in Section3, Part I of this thesis. The cheese were graded at the usual age i.e. about 8 to 10 weeks old.

Source of samples

The cheese samples were obtained from 5 creameries in South West Scotland. The number of samples obtained at each creamery varied considerably due to circumstances beyond the author's control e.g. 40 samples were obtained at creamery A because this creamery had available large quantities of cheese at any one particular grading time.

The following are details of the creameries where the cheese samples were obtained.

Creamery	A	B	C	D	E
No. of samples	40	10	6	4	2
Starter used	M.S.	M.S.	S.S.	M.S.	M.S.
Size of vat used, gals.	1,000	2,000	2,000	1,000	1,000

S.S. = Single strain M.S. = Mixed strain

[illegible]

[illegible]

[illegible]

[illegible]

The samples were analysed within 2 h of sampling but when samples were obtained in the late afternoon they were placed in a refrigerator until the following morning.

Methods of analysis

The methods used to determine the pH, titratable acidity and lactic acid (lactate) are described at the beginning of this thesis. The standard curve for lactic acid (lactate) estimations is also given at the beginning of this thesis.

RESULTS

The results obtained for the chemical analyses and grade scores of each cheese sample are given in Tables 96, 97 and 98. In Table 99 are recorded the coefficients of correlation between the various characteristics measured. It can be seen that, except in the case of lactic acid (lactate) against body score, the correlation coefficients are significant either at the 5%, 1% or 0.1% level. There is a very high degree of correlation between pH and lactic acid (lactate) ($P<0.001$), pH and the titratable acidity ($P<0.001$) pH and texture score ($P<0.001$) and between the lactic acid (lactate) and the titratable acidity ($P<0.001$). There is also a high degree of correlation between the scores for (a) flavour and aroma, (b) body and (c) texture. It is interesting to note that pH values are negatively correlated with all other characteristics recorded. The means, minimum and maximum values and standard deviations of the characteristics measured are recorded in Table 100. The minimum values for pH, lactic acid (lactate) titratable acidity and total grade score were 4.97, 0.02%. 0.58% and 17.0 respectively: the corresponding maximum values were 5.69, 0.76%, 1.44% and 27.2, the latter figure being out of a possible 30.0.

Tables 101 and 102 show the frequency distributions of the cheese for the flavour and aroma, body and texture scores, pH, lactic acid (lactate)

Table 96

<u>The pH, lactic acid, titratable acidities and grade scores of commercial Cheddar cheese at 8 to 10 weeks old</u>

Sample no.	pH	Lactic acid, (lactate), %	Titratable acidity, % lactic acid	Flavour and aroma, (10)	Body (10)	Texture, (10)	Total score, (30)
1	4.97	0.70	1.18	9.0	7.8	8.0	24.8
2	5.04	0.76	1.14	8.9	7.6	8.2	24.7
3	5.08	0.68	1.06	6.5	7.8	8.4	22.7
4	5.04	0.70	1.20	7.0	7.8	7.8	22.6
5	5.17	0.41	0.88	9.0	7.5	8.0	24.5
6	5.30	0.30	0.82	9.0	7.8	7.5	24.3
7	5.32	0.34	0.86	8.8	8.1	8.0	24.9
8	5.41	0.30	0.76	9.0	7.8	7.8	24.6
9	5.21	0.56	1.03	8.8	7.6	8.0	24.4
10	5.18	0.48	0.98	8.8	8.6	8.9	26.3
11	5.17	0.52	1.14	9.0	8.5	8.7	26.2
12	5.40	0.41	0.78	8.9	7.8	7.5	24.2
13	5.16	0.62	1.06	9.0	8.7	8.8	26.5
14	5.23	0.50	0.91	8.9	8.6	8.6	26.1
15	5.30	0.44	0.82	8.9	8.5	8.5	25.9
16	5.12	0.54	1.19	9.1	8.8	9.0	26.9
17	5.29	0.26	0.94	5.0	7.0	8.0	20.0
18	5.29	0.21	1.00	5.0	5.0	8.8	18.8
19	5.69	0.02	0.58	6.0	6.0	5.0	17.0
20	5.14	0.23	1.01	9.1	8.8	8.6	26.5
21	5.45	0.06	0.80	9.0	8.6	8.4	26.0
22	5.18	0.23	0.94	9.2	8.9	8.8	26.9

[illegible]

Table 97

The pH, lactic acid, titratable acidities and grade scores of commercial Cheddar cheese at 8 to 10 weeks old

Sample no.	pH	Lactic acid, (lactate), %	Titratable acidity, % lactic acid	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
23	5.18	0.28	0.89	7.0	8.7	8.8	24.5
24	5.32	0.23	0.81	5.0	5.5	8.5	19.0
25	5.14	0.28	0.93	9.3	9.0	8.9	27.2
26	5.15	0.23	0.96	9.0	8.8	8.8	26.6
27	5.12	0.23	0.96	9.2	9.0	8.9	27.1
28	5.12	0.26	0.90	8.8	8.7	8.7	26.2
29	5.05	0.54	1.26	9.1	8.8	8.8	26.7
30	5.12	0.48	1.29	9.0	8.9	8.7	26.6
31	5.16	0.52	1.20	9.1	8.8	8.7	26.6
32	5.10	0.59	1.22	9.1	9.0	9.0	27.1
33	5.18	0.56	1.20	9.1	8.7	8.6	26.4
34	5.13	0.55	1.26	8.9	8.8	8.7	26.4
35	5.09	0.56	1.25	9.0	8.9	8.8	26.7
36	5.18	0.56	1.06	9.1	8.8	8.8	26.7
37	5.08	0.54	1.25	9.2	9.0	9.0	27.2
38	5.04	0.52	1.32	9.1	8.9	8.7	26.7
39	5.30	0.42	1.01	8.4	8.5	8.2	25.1
40	5.22	0.54	0.96	8.5	8.6	8.5	25.6
41	5.05	0.63	1.34	9.0	7.8	8.5	25.3
42	5.21	0.48	0.97	9.1	8.0	8.5	25.6

Table 98

<u>The pH, lactic acid, titratable acidities and grade scores of commercial Cheddar cheese at 8 to 10 weeks old</u>

Sample no.	pH	Lactic acid, (lactate), %	Titratable acidity, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
43	5.07	0.61	1.31	9.0	7.8	8.6	25.4
44	5.09	0.58	1.18	8.9	7.8	8.5	25.2
45	5.15	0.55	1.18	9.1	8.4	8.7	26.2
46	5.15	0.40	1.03	9.1	8.8	8.7	26.6
47	4.99	0.63	1.44	9.0	8.9	8.9	26.8
48	5.14	0.52	1.06	8.9	8.8	8.8	26.5
49	5.30	0.35	0.95	9.0	8.7	8.4	26.1
50	5.16	0.54	0.94	9.1	8.9	8.9	26.9
51	5.08	0.72	1.26	9.2	8.0	9.0	26.2
52	5.19	0.44	1.14	9.0	8.2	8.7	25.9
53	5.19	0.44	1.18	9.2	8.0	8.8	26.0
54	5.20	0.28	1.15	9.1	8.7	8.8	26.6
55	5.19	0.37	1.16	9.0	8.7	8.9	26.6
56	5.15	0.44	1.27	8.9	8.7	8.9	26.5
57	5.17	0.37	1.21	8.9	8.8	8.7	26.4
58	5.16	0.40	1.32	8.8	8.2	8.6	25.6
59	5.25	0.31	1.15	9.1	8.9	8.8	26.8
60	5.06	0.40	1.33	9.1	7.8	8.6	25.5
61	5.11	0.34	1.31	9.1	8.0	8.7	25.8
62	5.28	0.37	1.07	8.9	8.7	8.8	26.4

Table 99

Correlation coefficients of the various characteristics of commercial Cheddar cheese at 8 to 10 weeks old

	pH	Lactic acid, %	Titratable acidity	Flavour & aroma	Body	Texture
Lactic acid, %	-0.673***					
Titratable acidity	-0.771***	0.607***				
Flavour & aroma	-0.356***	0.286*	0.342**			
Body	-0.381**	0.208	0.313*	0.759***		
Texture	-0.627***	0.280*	0.532***	0.381***	0.536***	
Total Score	-0.502***	0.302*	0.442***	0.903***	0.919***	0.680***

*** $(P < 0.001)$

** $(P < 0.01)$

* $(P < 0.05)$

Table 100

The means, minimum and maximum values and standard deviations of various characteristics of commercial Cheddar cheese at 8 to 10 weeks old

	Mean	Minimum	Maximum	Standard deviation
pH	5.18	4.97	5.69	0.12
Lactic acid, (lactate) %	0.44	0.02	0.76	0.16
Titratable acidity, % lactic acid	1.08	0.58	1.44	0.18
Flavour and aroma, (10)	8.6	5.0	9.3	1.0
Body, (10)	8.3	5.0	9.0	0.8
Texture, (10)	8.5	5.0	9.0	0.6
Total score, (30)	25.4	17.0	27.2	2.1

Table 101

<u>Frequency distribution of (a) flavour and aroma, (b) body and (c) texture, awarded to commercial Cheddar cheese at 8 to 10 weeks old</u>

Flavour and aroma (10)	No. of samples	% of total no. of samples	Body (10)	No. of samples	% of total no. of samples	Texture (10)	No. of samples	% of total no. of samples
5.0-5.9	3	4.8	5.0-5.9	2	3.2	5.0-5.9	1	1.6
6.0-6.9	2	3.2	6.0-6.9	1	1.6	6.0-6.9	-	-
7.0-7.9	2	3.2	7.0-7.9	14	22.6	7.0-7.9	4	6.5
8.0-8.9	17	27.4	8.0-8.9	41	66.1	8.0-8.9	53	85.5
9.0-9.9	38	61.3	9.0-9.9	4	6.5	9.0-9.9	4	6.5

Table 102

Frequency distribution of the pH, lactic acid and titratable acidity values of commercial Cheddar cheese at 8 to 10 weeks old

pH	No. of samples	% of total no. of samples	Lactic acid (lactate),%	No. of samples	% of total no. of samples	Titratable acidity, % lactic acid	No. of samples	% of total no. of samples
4.90-4.99	2	3.2	0.01-0.09	2	3.2	0.50-0.59	1	1.6
5.00-5.09	12	19.4	0.10-0.19	-	-	0.60-0.69	-	-
5.10-5.19	29	46.8	0.20-0.29	11	17.7	0.70-0.79	2	3.2
5.20-5.29	9	14.5	0.30-0.39	9	14.5	0.80-0.89	7	11.3
5.30-5.39	6	9.7	0.40-0.49	13	21.0	0.90-0.99	12	19.4
5.40-5.49	3	4.8	0.50-0.59	18	29.0	1.00-1.09	10	16.1
5.50-5.59	-	-	0.60-0.69	5	8.1	1.10-1.19	11	17.7
5.60-5.69	1	1.6	0.70-0.79	4	6.5	1.20-1.29	12	19.4
						1.30-1.39	6	9.7
						1.40-1.49	1	1.6

Table 102

and titratable acidity values. Over 61% of the cheese examined obtained a score for flavour and aroma between 9.0 and 9.9, while only 6.5% for both body and texture obtained scores between 9.0 and 9.9. Sixty-six % of the cheese scored between 8.0 and 8.9 for body, the corresponding figure for texture was over 85%; about 50% of the cheese examined had a pH value between 5.10 and 5.20, over 90% falling into the range 5.00 to 5.39. The lactic acid (lactate) content varied from 0.02% to 0.76%, 82% of the cheese having values from 0.20% to 0.59%. Similarly there is an even distribution in the number of cheese in each range for titratable acidity values over the larger range of 0.70% to 1.29%, the total % cheese in this range was about 85%.

In order that some property of the cheese, e.g. body or texture, might be predicted from the pH value, lactic acid (lactate) and titratable acidity values regression equations were calculated. As a number of these regression equations would be of limited value for prediction purposes they have been omitted and the equations recorded below are considered to be the most useful and interesting from the practical viewpoint. For each equation there is recorded (a) a multiple correlation coefficient, R i.e. the correlation between actual and predicted values, (b) a "% explained" figure which indicates the % variation by which the dependent variable is associated with the independent variable or variables.

(1) Flavour and aroma (10) = 16.4-1.7 pH + 0.4 L.A. + 0.9 T.A.
R = 0.37 13.9% explained

(2) Body (10) = 22.0-2.7 pH-0.5 L.A. + 0.3 T.A.
R = 0.39 15.1% explained

(3) Texture (10) = 25.7-3.3 pH-1.0 L.A. + 0.6 T.A.
R = 0.67 44.3% explained

(4) Total score (30) = 64.1-7.7 pH-1.2 L.A. + 1.8 T.A.
R = 0.51 26.4% explained

The above equations may involve lengthy chemical analyses and calculations with

the result that the following equations which utilise less data might be preferred.

(5) Flavour and aroma (10) = 24.7 - 3.1 pH
R = 0.36 12.7% explained

(6) Flavour and aroma (10) = 17.9 - 2.0pH + 0.9 T.A.
R = 0.37 13.8% explained

(7) Body (10) = 21.6 - 2.6 pH
R = 0.38 14.5% explained

(8) Body (10) = 20.1 - 2.3 pH + 0.2 T.A.
R = 0.38 14.5% explained

(9) Texture (10) = 24.4 - 3.1 pH
R = 0.63 39.4% explained

(10) Texture (10) = 29.3 - 3.9 pH - 0.9 L.A.
R = 0.66 43.0% explained

(11) Total score (30) = 70.8 - 8.7 pH
R = 0.50 25.2% explained

(12) Total score (30) = 59.8 - 6.9 pH + 1.5 T.A.
R = 0.51 26.0% explained

(L.A. = lactic acid (lactate) %)

(T.A. = Titratable acidity, % lactic acid)

By substitution of the values for pH, lactic acid (lactate) and titratable acidity the total score, texture, body and flavour and aroma scores may be obtained.

DISCUSSION

It is generally accepted that the flavour of Cheddar cheese is attributable to a complex association of chemical compounds produced by the degradation of protein, fat and lactose. Franklin and Sharpe (1963) suggested that the characteristic flavour is obtained only when the flavour components are present in certain specific proportions. The factors which may affect or contribute to the cheese flavour are numerous ranging from the starter used to the maturation environment of the cheese. Attempts have been made

to relate the quality of Cheddar cheese to results of various chemical analyses. Phillips (1935) found that when the pH value of the cheese was 4.90 at 4 days, bitter flavours subsequently developed and off-flavours developed in some of the cheese having pH values at 4 days of from 5.15 to 5.25.

In Table 99 one can see that there is a very high degree of correlation between the pH and the flavour and aroma of Cheddar cheese. This is in agreement with the work of Franklin and Sharpe (1963) who carried out carefully controlled experiments on Cheddar cheese flavour.

Dahlberg and Kosikowski (1948) having used 3 different starters concluded that the acidity of the mature cheese was not affected by the starters. The pH of Cheddar cheese is affected by several factors. It has been pointed out in Section 3, Part V of this thesis that the salt content can affect the pH and other characteristics of the mature cheese. It has been demonstrated that too high a salt content inhibits or retards the fermentation of lactose and gives rise to defects in flavour and aroma, body and texture. The pH value of the mature cheese also depends on the manufacturing process, whether too high or too low an acidity development was allowed to take place in the vat or whether starter activity was retarded due to the presence of antibiotics in the milk supply or contamination by bacteriophage. From the results of the experiment recorded above, it can be seen that the coefficient of correlation between pH and total grade score is -0.502 i.e. extremely significant ($P < 0.001$).

Kristoffersen et al. (1959) sought to establish more clearly the factors causing non uniformity in flavour of Cheddar cheese. pH values, moisture and salt contents were determined and they concluded that pH values, moisture and salt contents in general displayed no relationship to quality although the pH of the lower grade cheese was somewhat higher than one would expect to relate the quality of Cheddar cheese to [illegible] of various [illegible] analyses. [illegible] (1983) found that the flavour value of the cheese was [illegible] at [illegible] days, but the flavour subsequently declined and off-flavours developed in some of the cheeses, having [illegible] values [illegible] at [illegible] days.

In Table [illegible] one can see that there is a very high degree of correlation between the pH and the flavour and aroma of Cheddar cheese. This is in agreement with the work of [illegible] and [illegible] (1963) who [illegible] carefully controlled experiments on Cheddar cheese flavour.

[illegible] and [illegible] (1969) having used [illegible] have concluded that the activity of the starter bacteria [illegible] by the [illegible] through the pH [illegible] by several factors. It has been [illegible] in section [illegible] that the [illegible] conditions [illegible] effect on pH and [illegible] of the cheese [illegible]. It has been demonstrated that [illegible] in [illegible] the [illegible] of [illegible] and [illegible] rise to [illegible] flavour and aroma. [illegible] the pH value of the [illegible] also [illegible] in the [illegible] during [illegible] whether [illegible] to [illegible] activity [illegible] development [illegible] to [illegible] or whether [illegible] activity is [illegible] due to the [illegible] in the milk supply [illegible] contamination [illegible]. [illegible] the results of the [illegible] described above [illegible] be [illegible] significant [illegible] correlation between pH and [illegible] and [illegible] extremely significant ([illegible]).

[illegible] et al. (1975) [illegible] to [illegible] more clearly the factors [illegible] particularly in flavour of [illegible] cheeses. [illegible] contents and salt contents were [illegible] the [illegible] that [illegible] values [illegible] salt contents. In general, [illegible] no [illegible] (ref. [illegible]). [illegible] the [illegible] of the [illegible] cheeses [illegible] higher than [illegible].

for the age of the cheese.

From the range of pH values recorded for the 62 cheese in the present study it would be expected that the cheese having the higher pH values had poor flavour and aroma scores and in general displayed poor overall quality. The type of flavour and aroma for cheese with high pH values is variable i.e. it cannot always be assumed that a high pH is associated with a fruity flavour and aroma although this is very often the case. Cooked or caramel type flavours are often encountered with cheese of high pH and this is usually traced to an unusually high salt content. A fruity flavour and aroma associated with a high pH may be the result of contamination by bacteriophage or insufficient salt. Bitter flavours are also usually associated with high pH values. The defects produced by manufacturing Cheddar cheese at too high an acidity are well known and great care should be taken not alone in the addition of the correct amount of starter but in controlling the rate of acid development during the manufacturing process.

Preconceived ideas relating to cheese making and the prediction of cheese quality can be misleading when results statistically treated are obtained. It might be expected that lactic acid (lactate) would be related to a significant degree to the flavour and aroma, body, texture or total grade score. Lactic acid (lactate) is as one might expect closely correlated with the titratable acidity but the correlations between lactic acid (lactate) and flavour and aroma, texture and total grade score are only barely significant, ($P<0.05$) while the correlation between body score and lactic acid (lactate) is not significant. An effort was made by Harper and Randolph (1960) to relate the flavour of Cottage cheese with the lactic acid (lactate) content. They examined 85 samples of "commercially creamed" Cottage cheese and concluded that there was a definite relationship between the lactic acid (lactate) content and the flavour of creamed Cottage cheese.

In commercial practice, methods used for the quality control of dairy products must if possible be rapid and not too complicated. The determination of lactic acid (lactate) usually requires a colorimeter or spectrophotometer and the time required to make a test may be 30 min or longer, more especially if difficulties are encountered during the filtration process. As the titratable acidity test for cheese is simple and inexpensive and as the titratable acidity is significantly related to the overall quality of the cheese as judged by the grade score, there appears to be no advantage in determining the lactic acid (lactate) content. One would expect a high degree of correlation between titratable acidity and pH and this is so; there is a similar degree of correlation between the titratable acidity and pH value and the flavour and aroma, body, texture and overall grade score.

As the correlation coefficients of the various characteristics were significant at different levels (except in the case of lactic acid and body score) the possibility of predicting flavour and aroma, body, texture and total scores from the values for pH, lactic acid and titratable acidity presented itself. It may bee seen, however, that from the equations recorded above that the predicted value or score for a particular property of the cheese e.g. body, may be subject to errors and therefore of limited value. Although as stated previously the correlation coefficients between the various characteristics of the cheese were statistically significant it is only when the correlation coefficients are very high that estimation or prediction can be at all precise. In equation (1) the coefficient of multiple correlation is 0.37. This value, statistically significant ($P<0.01$), indicates that approximately 14% of the variations in the flavour and aroma of Cheddar cheese was associated with the combined influence of the pH, lactic acid (lactate) and titratable acidity values. Similarly with equations (2), (5), (6), (7) and (8) where the multiple correlation coefficients

are statistically significant the % of the variations of each property whose score we wish to estimate is considered too low for prediction purposes. For example in equation (1) the combined influence of pH, lactic acid (lactate) and titratable acidity values are not sufficient for use in predicting the flavour and aroma of Cheddar cheese. Equation (3) indicates a % explained figure of about 44% so that this equation may be useful in the prediction of texture score for Cheddar cheese. Where a pH value of cheese is only available the texture score may be predicted using equation (9) and the accuracy of prediction of the texture score may be increased slightly by usingn equation (10). The prediction of the total score of a cheese may be made by using equation (11) i.e. by using the pH value alone and where the titratable acidity value is also known, equation (12) may be used giving a slight improvement in accuracy of prediction as compared with equation (11).

In Table 99 it is not surprising to see that scores for flavour and aroma are closely related to scores for body and total scores. It must be stressed, however, that one cannot be dogmatic as very often one finds that although a cheese has a good flavour and aroma the score for body or total score may indicate that the overall quality of the cheese was poor. Nevertheless one may say that in general that where one cheese characteristic is poor, the overall cheese quality is also poor and vice versa. This can be seen clearly in the correlation coefficients (0.903, 0.919, 0.680) recorded between total scores and flavour and aroma, body and texture scores respectively.

CONCLUSIONS

The total grade score obtained by Cheddar cheese at about 8 weeks old is highly correlated with the pH value and the titratable acidity. From [illegible] significant [illegible] the variance of [illegible]

[illegible] equation [illegible] the prediction [illegible]

[illegible] equation (1) [illegible]

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(9) and the accuracy of prediction [illegible] flavour score [illegible]

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[illegible] equation (13) [illegible]

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[illegible] flavour and body [illegible]

respectively.

CONCLUSIONS

[illegible] obtained by [illegible] cheeses [illegible] about [illegible]

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the work described above it is shown that the pH value is highly correlated with the lactic acid (lactate) content and the titratable acidity and also with the flavour and aroma and body and texture scores of the cheese. The lactic acid (lactate) content is significant only to a slight degree in its correlation with the results of the subjective measurements of (a) flavour and aroma, (b) body and (c) texture. The titratable acidity is highly correlated with flavour and aroma, texture and total score but only very slightly with body scores. The correlations between flavour and aroma, body, texture and total score are all highly significant indicating that in general where one characteristic e.e. texture, is good then it is likely that the overall quality of the cheese will be good. This conclusion,may be erroneous in specific cases.

From this work, which could be said to be summarised in Table 99, it may be seen that the titratable acidity test is a useful test to obtain information on the possible overall cheese quality. The pH value, although easy to determine and providing valuable information, may require expensive equipment more especially if a high degree of precision and accuracy is being sought. Similarly the test for lactic acid (lactate) can be expensive to carry out and is also time consuming. Furthermore,it appears that a test for lactic acid (lactate) gives no reasonable indication of the quality of the cheese. It is suggested therefore that the titratable acidity is a simple and inexpensive quality control test and is a useful indicator of cheese quality.

SUMMARY

A pH value, lactic acid (lactate) and titratable acidity were determined for a total of 62 commercial Cheddar cheese at about 8 to 10 weeks old. For each cheese scores for flavour and aroma, body and texture were recorded. A total of 21 correlation coefficients were calculated together with regression

[illegible]

[illegible]

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equations which may be used in the prediction of cheese quality. The wide range of values for pH, lactic acid (lactate), titratable acidity and scores for flavour and aroma, body and texture are discussed and it is suggested that the titratable acidity test because of its simplicity, cheapness and its high correlation with overall cheese quality is a useful quality control test. The pH value is also highly correlated with cheese quality but the test may require expensive equipment and therefore may be unsuitable under cheese factory conditions.

Section three

Part V

The effect of various rates of salt addition on the quality and composition of Cheddar cheese.

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THE EFFECT OF VARIOUS RATES OF SALT ADDITION ON THE QUALITY AND COMPOSITION OF CHEDDAR CHEESE

INTRODUCTION

Salt is probably the most widely used of food preservatives and though its use dates from antiquity it is only comparatively recently that reasons for its effectiveness have begun to be understood. Its success depends on the fact that it inhibits objectionable putrefaction and certain pathogenic organisms (Ingram and Kitchell, 1967). In general, relatively low concentrations of salt stimulate micro-organisms while higher concentrations inhibit them. Micro-organisms may be classified as salt-tolerant, salt-facultative or salt-tolerant halophilic.

The effect of salt is often similar to that of drying and in such cases sodium chloride may be replaced by molecular equivalent concentrations of other salts. Scott (1957) has reviewed this subject and suggests that the microbiological effect of salt in a food probably depends on osmotic withdrawal of water. In a salted food, where salt is the main solute, the ratio between the amount of dissolved solute and of water is often expressed as "brine-concentration" (Hankins, Sulzbracher, Kauffmann and Mayo, 1950). In some salted foods the brine concentration is quite high, in butter it may reach 10% and in Cheddar cheese it can very from 3% to 6%.

There may be larger differences in the action of salt under different conditions. It has been found that the maximum salt concentration in which growth occurs is greater at lower temperatures. The influence of the acidity content of a food product is supplementary to that of salt. It is accepted as a general rule that as the acidity rises, less salt is needed to prevent growth of individual bacteria and yeasts.

[illegible]

INTRODUCTION

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Salt is added to Cheddar cheese curd after milling at a rate that will give the finished cheese a salt content of about 1.6 to 1.8%. The salt aids the removal of whey from the cheese curd, restricts the acidity development in the cheese and is essential for the production of clean-flavoured cheese.

The effect of salt on the quality of cheese has been investigated by several workers. McDowall and Whelan (1933) stated that there was no very definite correlation between moisture content and salt content. They concluded from their study that there was a considerable variation in salt and moisture contents of samples taken from different cheeses in the same vat. They also stated that the variation in salt content within a cheese might account for discrepancies in estimations of bacterial numbers in cheese.

To obtain an estimate as to what variation might be expected within a vat the author examined 2 vats of cheese made in a commercial cheese factory in South West Scotland. The working capacity of the vats was about 2,200 gal giving about fifty-five, 40 lb blocks of cheese. The salt was added to the milled curd by hand and the cheese was sampled at about 8 weeks old. Six blocks from each vat were examined and the results are recorded below.

Vat 1		Vat 2	
Block no.	Salt, %	Block no.	Salt, %
1	1.18	1	1.25
2	1.15	2	1.41
3	1.32	3	1.51
4	1.45	4	1.27
5	1.07	5	1.45
6	1.27	6	1.36
Range,	1.07 - 1.45		1.25 - 1.51
Mean,	1.24		1.37
Spread,	0.38		0.26

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This variation could lead to defects in the cheese and there is every possibility that a vat of cheese might be placed in a lower grade as a result of the defect in the particular cheese which happens to have been chosen as the sample. It was later shown (O'Connor, 1968) that where salting of the curd was carried out by hand under commercial conditions a spread figure of 0.8% for salt content between blocks of cheese in a vat containing about 65 blocks was obtained.

The rate of penetration of salt into cheese curd was studied by McDowall and Dolby (1936) who stated that at the time of putting the cheese into the press little salt would have reached the centre of each strip of curd but that within 1 day after removal of the cheese from the press the salt would have reached the centre of the curd pieces. Similar work by Breene, Olson and Price (1965) on the salt absorption by Cheddar cheese indicated that the temperature of the curd had an effect on the absorption of the salt. This latter observation should be borne in mind when vats of large capacity and traditional salting methods are used. Marquardt (1936) stated that Cheddar cheese should contain 1.50 to 1.75% salt and suggested a salting schedule which was based on the fat content of the milk. It might be added here that although a salt content of 1.75% is aimed at by most cheesemakers, it is very seldom achieved due to variation in technique of salt distribution.

Tuckey and Rueĉhe (1940) found that there was a close correlation between a low salt content of Cheddar cheese and a bitter flavour. They noted that this bitter flavour was not necessarily associated with characteristic acid defects. This work seems to be partially substantiated by the work of Perry and McGillivray (1964) who suggested that the characteristic Cheddar cheese flavour is due to the action of both starter and non-starter organisms.

If either of these organisms are inhibited or stimulated at the expense of the other due to the concentration of salt in the aqueous phase of the cheese there is every possibility that a defect in either the body, flavour or texture of the cheese would occur. Hoecker and Hammer (1943) agreed with the conclusions of McDowall and Dolby (1936) and also stated that the pH values decreased rather rapidly at both the surfaces and centres of pieces of curd during the first 15 to 24 h in the press, the decreases being greater at the centres than at the surfaces.

Whitehead and Harkness (1954) found that the salt content had an effect on the moisture content of the cheese and stated that the maximum amount of salt added to the curd should not exceed 3% based on the weight of milled curd because the body of the cheese would be affected.

The effect of salt on the growth of lactic acid and gas producing bacteria in skim milk was studied by Sokol'skaya (1955) who stated that Str. lactis was somewhat stimulated by 0.5% salt but was inhibited by increasing salt concentration, lactobacilli had their acid production inhibited completely at 3% salt and that "coliform bacteria were affected to a lesser extent than useful bacteria". Similar work was carried out by Irvine and Price (1961) who grew typical commercial lactic cultures at 100^{o}F in reconstituted non-fat dry milk containing various concentrations of salt up to 5%. They stated that acid development was stimulated by small amounts of salt, but was definitely inhibited at levels of 2.5% salt and greater. Walter, Sadler, Mitchell and Hargrove (1958) studied the effect of salt on acid development in Cheddar cheese and came to the following conclusions; acid production by most single strains of Str. lactis was not inhibited by less than 1.6% salt and not significantly by from 1.6 to 2.0% whereas most single strains of Str. cremoris were inhibited slightly by 1.4%, definitely by 1.6% and almost

completely by 2.0%. Mixtures of Str. lactis and Str. cremoris were much more uniform in salt resistance than single strains of either species. They were not inhibited by less than about 1.5% and not significantly by concentrations between 1.5 and 1.9%. Acid bitterness decreased with increased salt, "fruity" flavours usually accompanied insufficient acid development, and cheese containing 2% salt failed to mature normally.

It may be seen from the above literature that the rate of salting and distribution of salt has an effect on the quality of the mature cheese. The majority of work on the salting of Cheddar cheese was carried out using large amounts (c.5%) of added salt but as a result of a study reported in Section 3, Part I of this thesis where less than 1% salt was found in cheese made at commercial factories it was decided to investigate the effects of small amounts (0.25%) as well as large amounts (6.0%) of added salt on the quality and composition of Cheddar cheese.

PRELIMINARY EXPERIMENT

Some mechanised procedures for making Cheddar cheese are altering methods for the salting of the curd. These new procedures, providing continuous milling, salting and hooping of the curd have shortened the time between salting and hooping (Czulak, Freeman and Hammond, 1961). It has been shown above with a very limited number of samples that salting by the traditional method led to a variation in salt content in cheese taken from the same vat. It was decided therefore to investigate at a commercial cheese factory, the salt distribution in cheese from the same vat salted by the new procedure of Czulak, Freeman and Hammond (1961).

EXPERIMENTAL

Size of vat

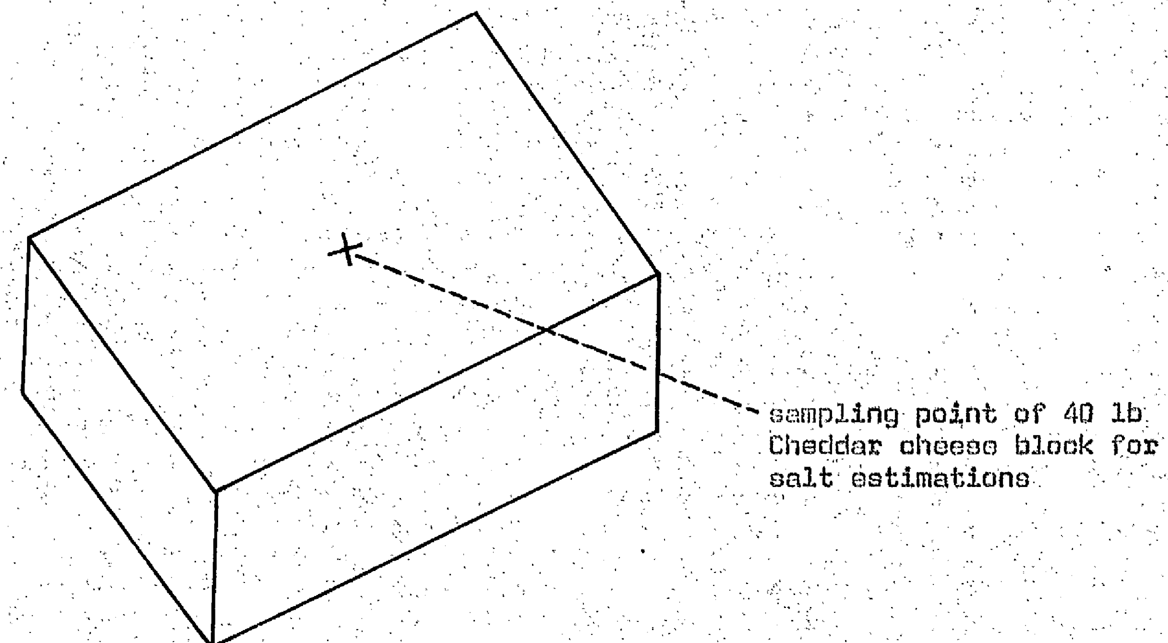
The vat used for making the cheese had a working capacity of about 2,700 gal of milk. This gave about sixty-eight, 40 lb blocks of cheese.

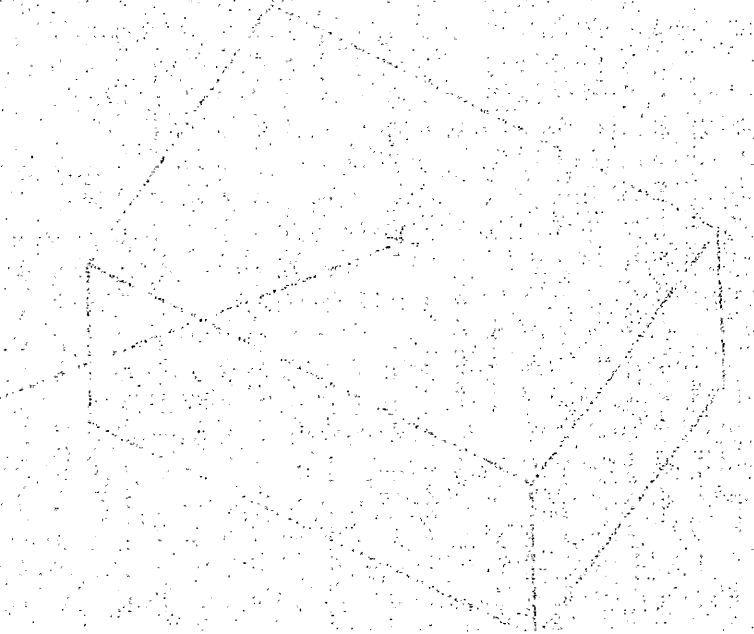
Method of salt addition

The cheddared curd was fed to the mill in as even a manner as possible and the milled curd was spread on to an elevating conveyor. From here the curd passed onto a weighing conveyor where salt was added at a predetermined rate, the amount being proportional to the weight of the curd on the weighing conveyor. After salting the curd was fed to a mixing drum where it was mixed before being discharged into the hoops.

Sampling

As the cheese was made at a commercial factory it was considered desirable from the point of view of mould growth to sample the cheese as it came from the press and prior to wrapping in waxed cellulose paper and heat sealing. The cheese at time of sampling were 18 to 20 h old. In an effort to eliminate variations within a block of cheese each sample was taken (see diagram) from the centre of the largest face of the cheese block. The outer 0.75 in. of the plug or core was replaced in the usual manner. Ten cheese from each of 3 vats were examined.





Analysis

The cheese samples were grated by means of a domestic type (Mouli) grater and salt determinations were made in duplicate by the Volhard method (British Standards Institution, 1963b).

RESULTS

The results of the analysis of the samples from 30 blocks of Cheddar cheese together with the mean, range and spread figures are given below.

Table 103

The salt content of different blocks of cheese from the same vat using an automatic salting procedure

Sample no.	Vat 1 Salt, %	Vat 2 Salt, %	Vat 3 Salt, %
1	1.49	1.54	1.49
2	1.37	1.44	1.33
3	1.53	1.43	1.34
4	1.44	1.77	1.40
5	1.37	1.32	1.41
6	1.46	1.68	1.49
7	1.31	1.47	1.36
8	1.48	1.53	1.45
9	1.43	1.45	1.43
10	1.67	1.53	1.52
Range,	1.31-1.67	1.32-1.77	1.33-1.52
Mean,	1.45	1.52	1.42
Spread,	0.36	0.45	0.19

DISCUSSION

Data such as is recorded above may be discussed under the headings (a) is the spread, i.e. the difference between the maximum and minimum salt contents, large enough to give a wide variation in cheese quality within a vat, and (b) is the amount of salt added sufficient to have the salt content of the cheese at its optimum value.

(a) The figure for the difference between the maximum and minimum salt contents of different blocks of cheese from the same vat tells one first of all the uniformity of distribution of salt. It is likely that a high spread figure points to the fact that the method of salting whether manual of mechanical is inadequate and unreliable. However, as far as cheese quality is concerned the spread figure must be considered together with the range of salt or possibly the average salt content. If the range is 1.2 to 1.6% salt then the spread figure may be of more significance than the same spread figure with the range 1.5 to 1.9% salt.

(b) According to van Slyke and Price (1949) the salt content of Cheddar cheese should approximate 1.5%. Riddet, Valentine, McDowall and Whelan (1933) pointed out that New Zealand cheese of normal body contained an average of 1.66% and Tuckey and Ruehes (1940) who in associating the production of bitter flavour in Cheddar cheese with a salt content of 1.3% salt observed that the defect was not found when the cheese contained 1.7% salt or more.

Depending on the method of salting, whether manual or mechanical, the cheesemaker aiming at 1.8% salt in the finished cheese, finds it necessary to add 2.25% to 3.25% salt by weight of curd. On selecting a salting rate does the cheesemaker take into account the composition of the original milk and also the condition of the curd? Riddet et al. (1933) stated that with

a curd of normal moisture content a salting rate of 2.25% gave less open texture, and better body than salting at 3.25% or 4.25%. They also found that by the use of too small amounts of salt the cheese was weak bodied and open textured while the use of too large amounts of salt produced a harsh bodied, close textured and a slow maturing cheese.

It is obvious, therefore, that the salting stage of the Cheddar cheesemaking process is very important and the cheesemaker should be fully aware of the problems associated with it.

The following experiments were carried out to ascertain the effect of various salting rates on the quality and composition of Cheddar cheese.

SMALL SCALE EXPERIMENT

EXPERIMENTAL

Cheesemaking

Two vats of Cheddar cheese were made giving a total of 24 individual cheese. Each vat contained 500 gal of milk. Details of the ripening period and scalding temperature together with the record of the manufacturing process are given in Tables 104 and 105. It might be added that no attempt was made to influence the cheesemaker as regards the manufacturing procedure which he adopted up to and including the milling stage. After being milled, the curd was mixed well by forking the curd up and down the vat 4 times. Then the curd was piled in the top portion of the vat. The curd was then divided into 12 portions each portion containing 42 lb of curd. This was carried out in the vat in the following manner. Two separate rectangular boxes of aluminium were each divided into 6 equal compartments and the dimensions of these boxes were such that the part of the vat unoccupied by the curd was occupied by the boxes. The diagram below indicates the conditions before the curd was weighed into the boxes.

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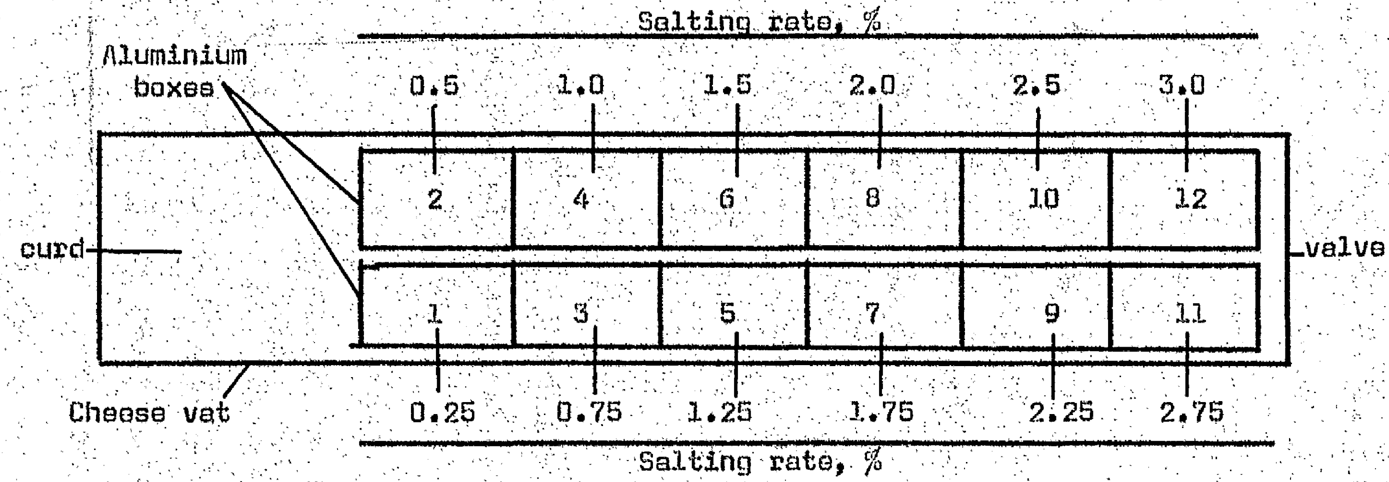

Salt addition

Salt was added at the rate of 0.25% to 3% i.e. 0.25% to the curd in box number 1 up to 3% in box number 12. The boxes were numbered and arranged in such a way as to minimise the possibility of salt "contamination" from a neighbouring compartment i.e. placing the boxes to which the higher addition of salt were added near the whey outlet. The procedure for the addition of salt was as follows: One quarter of the total salt to be added to each box was added to the curd and the contents mixed thoroughly for 1 min and then the curd was left unmixed for 1 min. This procedure was repeated until all the salt was added. The temperature of the curd at time of salting was about 90^{0}F. The curd was left unstirred for about 5 min and then it was hooped. The length of time taken from the last salt addition to the time of pressing varied from 15 to 20 min. About 20 min after applying the pressure the cheese cloths were pulled tight around the cheese and the cheese returned to press until the following morning.

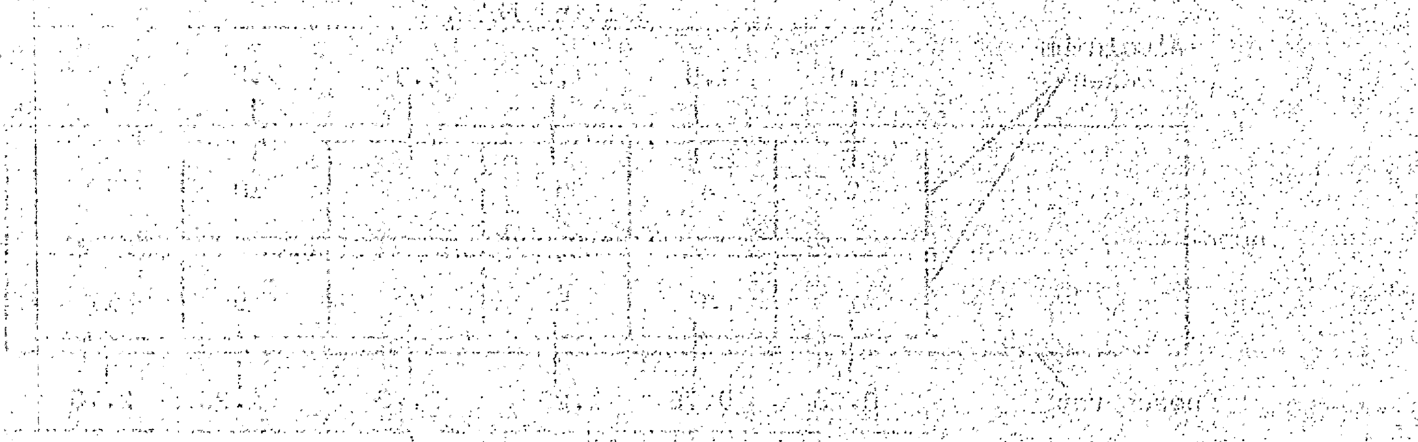

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Plate 1. Cheese vat with aluminium boxes used for adding varying amounts of salt to cheese curd

Sampling and analysis

The cheese were sampled at 2 daysold before being wrapped in waxed cellulose paper and heat sealed. The samples were grated by means of a domestic type (Mouli) grater and then analysed for fat, moisture and salt contents. pH determinations were also made.

Salt. This was determined by the Volhard method (British Standards Institution, 1963b).

Fat. This was determined by the Gerber method (British Standards Institution, 1955).

Moisture. About 3 g of the sample were weighed accurately in an aluminium foil container (Foilpak 10335, supplied by R.R. Brodie Ltd, Glasgow) with a diameter of 3.25 in. and a depth of 0.75 in. The container was placed in a hot air oven maintained at 100°C until the container and the cheese residue reached constant weight. The aluminium foil container was then placed in a dessicator and allowed to cool. The container was then weighed and the moisture content of the cheese sample calculated in the usual way.

pH. Ten g of cheese were mixed thoroughly with an equal weight of distilled water by means of a Silverson mixer until a paste was obtained. The pH value was then determined by means of a Radiometer pH meter 25 SE using glass (G202C) and calomel (K401) electrodes.

Grading of the cheese

All the cheese were examined at 8 weeks by an official of the Company of Scottish Cheesemakers Ltd. who awarded points according to the special scoring system outlined in Section 1, Part I of this thesis. Points (Maximum 10) were awarded for (a) flavour and aroma, (b) body and (c)texture.

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RESULTS

Details of the cheese manufacturing record and the results of the chemical analysis of the cheese both at 1 day and at 8 weeks old are recorded in Tables 104, and 105. In Tables 106 and 107 are recorded the grade scores obtained by each cheese at 8 weeks old.

DISCUSSION

The results of these two experiments are very interesting. The fat content of the cheese did not vary a great deal although the spread in the 2nd experiment was almost twice that of the first experiment i.e. 0.90 and 1.75% fat. It has been pointed out by Feagan et al. (1965) that an increase in salting rate did not affect the fat content. The moisture content of the cheese varied by no less than 4.4% in both experiments. This seems to indicate that the salting rate may be adjusted as a means of removing excess moisture from the curd. When the cheese were being removed from the moulds it was apparent that the cheese with the higher salt contents were very firm in comparison to the cheese with the lower salt content.

The pH values varied from 5.11 to 5.43 in the first experiment and from 5.11 to 5.41 in the second experiment. Although intermediate values in both experiments did not correspond and there was no exact linear relationship between rate of salting and pH value the tendency was that as the salt content increased so also did the pH value. The salt content of the finished cheese corresponded very well with the rate of salting. However, one cheese (Vat A, Table 104), block number six, upset what otherwise was a very good pattern. This result could possibly be and is very likely due to sampling error. As expected there was a tendency towards greater losses of salt as the salting rate increased. There was about 108% recovery of salt at the 0.25% salting rate and about 66% retention at the 3% salting rate.

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Tables 106 and 107 show the points scored by each cheese for (a) flavour and aroma, (b) body and (c) texture. The total scores are also recorded.

The cheese obtaining the lowest total score in both trials had a salt content of 0.30%. The variation in total scores obtained by the cheese for the various salt contents is not easily explained. Two cheese (Table 106) with salt contents of 2.02% and 2.04% respectively obtained total scores of 26.2 (maximum 30) and 28.1 respectively. The composition of these cheese appears similar, with the pH values differing by only 0.04 pH. Such discrepancies in total scores of cheese with similar compositions may be largely explained by sampling errors either on the part of the author or the official cheese grader. It should be noted, however, that the samples were obtained by the author and the official grader in similar locations or positions of all cheese. Although it was suggested by Morris (1968) that in cheese there are zones of dissimilar composition, in Cheddar cheese it does appear from discrepancies in total score observed by the author that these zones do not appear or are not present in a uniform pattern for cheese having the same size and shape.

The adhesion of the cloths to rindless cheese during pressing is a problem which arises at commercial cheese factories. When the cloths are being removed from the cheese irregular pieces of cheese are plucked from the surface. This gives the cheese an unsightly appearance, causes losses and lack of uniformity in weights of portions cut for packaging and leads to inclusion of air when the cheese is packaged for maturing. It was observed by the author during this study that the press cloths adhered to those cheese containing less than 1.0% salt. During a study on the composition of commercial Cheddar cheese (Section 1, Part I of this thesis) a small number (about 1%) of the cheese examined had a salt content of less than 1.0%. Where adhesion of cloths to cheese is a commercial problem an insufficient salting rate or poor salt distribution may be a causative factor.

Table 104

The effect of various rates of salt addition on the composition of Cheddar cheese

Processing record   Vat A

Operation	Rennet added	Curd cut	Maximum scald	Curd settled	Whey run	Curd milled
Time, h min	0.00	0.45	1.50	2.35	2.55	4.35
Titratable acidity, % lactic acid	0.152	0.106	0.122	0.150	0.228	0.664
pH	6.58	6.50	6.40	6.29	5.91	5.41

Cheese analyses   1 day old

Salting rate, %	Salt, %	Fat, %	Moisture, %	pH
0.25	0.25	31.50	39.42	5.11
0.50	0.48	31.55	39.14	5.14
0.75	0.72	31.35	38.93	5.19
1.00	0.85	31.00	39.04	5.25
1.25	1.18	31.20	38.37	5.31
1.50	1.52	31.10	37.49	5.33
1.75	1.38	31.80	37.22	5.31
2.00	1.56	31.65	37.09	5.35
2.25	1.72	31.90	36.98	5.37
2.50	2.01	31.50	35.45	5.43
2.75	1.92	31.65	35.76	5.41
3.00	2.14	31.65	34.96	5.43

8 weeks old

Salting rate, %	Salt, %	Fat, %	Moisture, %	pH
0.25	0.30	31.70	39.22	5.10
0.50	0.53	31.50	39.46	5.11
0.75	0.75	30.70	38.98	5.12
1.00	0.98	30.30	39.00	5.11
1.25	1.10	31.20	38.45	5.09
1.50	1.36	30.40	38.24	5.09
1.75	1.30	31.60	37.33	5.11
2.00	1.56	31.80	37.38	5.10
2.25	1.78	31.50	37.14	5.10
2.50	1.81	31.50	36.15	5.12
2.75	2.02	31.80	35.50	5.14
3.00	2.04	31.60	35.62	5.18

Table 106

The effect of various rates of salt addition on the composition of Cheddar cheese

Processing record   Vat B

Operation	Rennet added	Curd out	Maximum scald	Curd settled	Whey run	Curd milled
Time, h min	0.00	0.45	1.50	2.30	3.05	4.55
Titratable acidity, % lactic acid	0.150	0.110	0.120	0.130	0.206	0.640
pH	6.59	6.51	6.38	6.25	5.92	5.37

Cheese analyses   1 day old

Salting rate, %	Salt, %	Fat, %	Moisture, %	pH
0.25	0.23	31.75	39.51	5.11
0.50	0.43	30.50	39.38	5.11
0.75	0.62	31.10	39.05	5.12
1.00	0.86	30.65	38.96	5.14
1.25	1.10	31.10	38.98	5.17
1.50	1.21	31.15	37.89	5.20
1.75	1.40	31.20	37.31	5.25
2.00	1.52	32.20	36.85	5.27
2.25	1.67	31.70	36.58	5.32
2.50	1.80	32.20	35.99	5.36
2.75	1.76	32.35	35.55	5.35
3.00	1.97	32.25	35.11	5.41

8 weeks old

Salting rate, %	Salt, %	Fat, %	Moisture, %	pH
0.25	0.30	31.20	39.88	5.13
0.50	0.49	31.60	39.37	5.13
0.75	0.70	31.10	39.22	5.12
1.00	0.89	31.20	38.91	5.11
1.25	1.09	31.80	38.56	5.11
1.50	1.25	32.20	38.03	5.09
1.75	1.45	32.10	37.65	5.08
2.00	1.53	32.10	37.20	5.08
2.25	1.67	31.90	37.11	5.07
2.50	1.77	32.00	36.34	5.09
2.75	1.85	32.60	35.84	5.09
3.00	1.91	32.80	35.82	5.08

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Table 106

<u>The grade scores of Cheddar cheese at 8 weeks old with various rates of salt addition and salt contents</u>

<u>Vat A</u>

Salting rate, %	Salt content, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
0.25	0.30	9.0	8.0	8.8	25.8
0.50	0.53	9.2	8.4	9.0	26.6
0.75	0.75	9.3	8.8	9.2	27.3
1.00	0.98	9.0	8.4	8.8	26.2
1.25	1.10	9.2	8.5	8.8	26.5
1.75	1.30	9.1	8.0	8.8	25.9
1.50	1.36	9.2	9.1	9.1	27.4
2.00	1.56	9.1	8.7	9.2	27.0
2.25	1.78	9.2	9.2	9.2	27.6
2.50	1.81	9.2	8.8	8.5	26.5
2.75	2.02	9.2	8.5	8.5	26.2
3.00	2.04	9.5	9.4	9.2	28.1

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Table 107

The grade scores of Cheddar cheese at 8 weeks old with various rates of salt addition and salt contents

Vat B

Salting rate, %	Salt content, %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score, (30)
0.25	0.30	8.0	7.5	9.0	24.5
0.50	0.49	8.5	8.0	9.0	25.5
0.75	0.70	9.1	8.0	8.8	25.9
1.00	0.89	9.1	8.4	9.0	26.5
1.25	1.09	9.0	8.2	9.0	26.2
1.50	1.25	9.4	9.0	9.4	27.8
1.75	1.45	9.4	9.2	9.4	28.0
2.00	1.53	9.4	8.7	9.0	27.1
2.25	1.67	9.5	9.4	9.0	27.9
2.50	1.77	9.5	9.4	9.2	28.1
2.75	1.85	9.4	9.0	8.8	27.2
3.00	1.91	9.2	8.7	8.8	26.7

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FULL INVESTIGATION

EXPERIMENTAL

Since the highest salt content of 2.14% obtained in the above experiments was below the maximum salt content found in samples taken from cheese produced in commercial factories in South West Scotland it was decided to increase the rate of salt addition. The rate of salting was varied from 0.5 to 6%. Apart from the variation in salting rate the experimental conditions were as detailed above for the preliminary experiment.

The cheese were anlysed for fat, moisture and salt content and pH at 1 day old and at 8 weeks old. The cheese were graded by the official cheese grader of the Company of Scottish Cheesemakers Ltd. on the special points system described in Section 1,Part I of this thesis.

RESULTS

(a) Salting rate and composition of the cheese

The analyses of the 60 cheese from the 5 trials are shown in Tables 108, 109, 110, 111 and 112 and the effect of varying the salting rate on the composition of the finished cheese is well illustrated. Increased salting rates caused a reduction in the moisture content of the cheese and an increase in the salt content. Although it was not true in all cases, it can be said that in general as the salting rate increased, the salt content of the cheese also increased. However, the increase in salt content was not proportional to the increased amount of salt added to the curd. With the lower salting rates the percentage of salt retained in the cheese was higher than with the higher salting rates (Fig. 3). The pH of the cheese showed a very close relationship with the salt content, increasing salt content resulted in an increase in pH value. The fat content of the cheese also increased with increasing salt content.

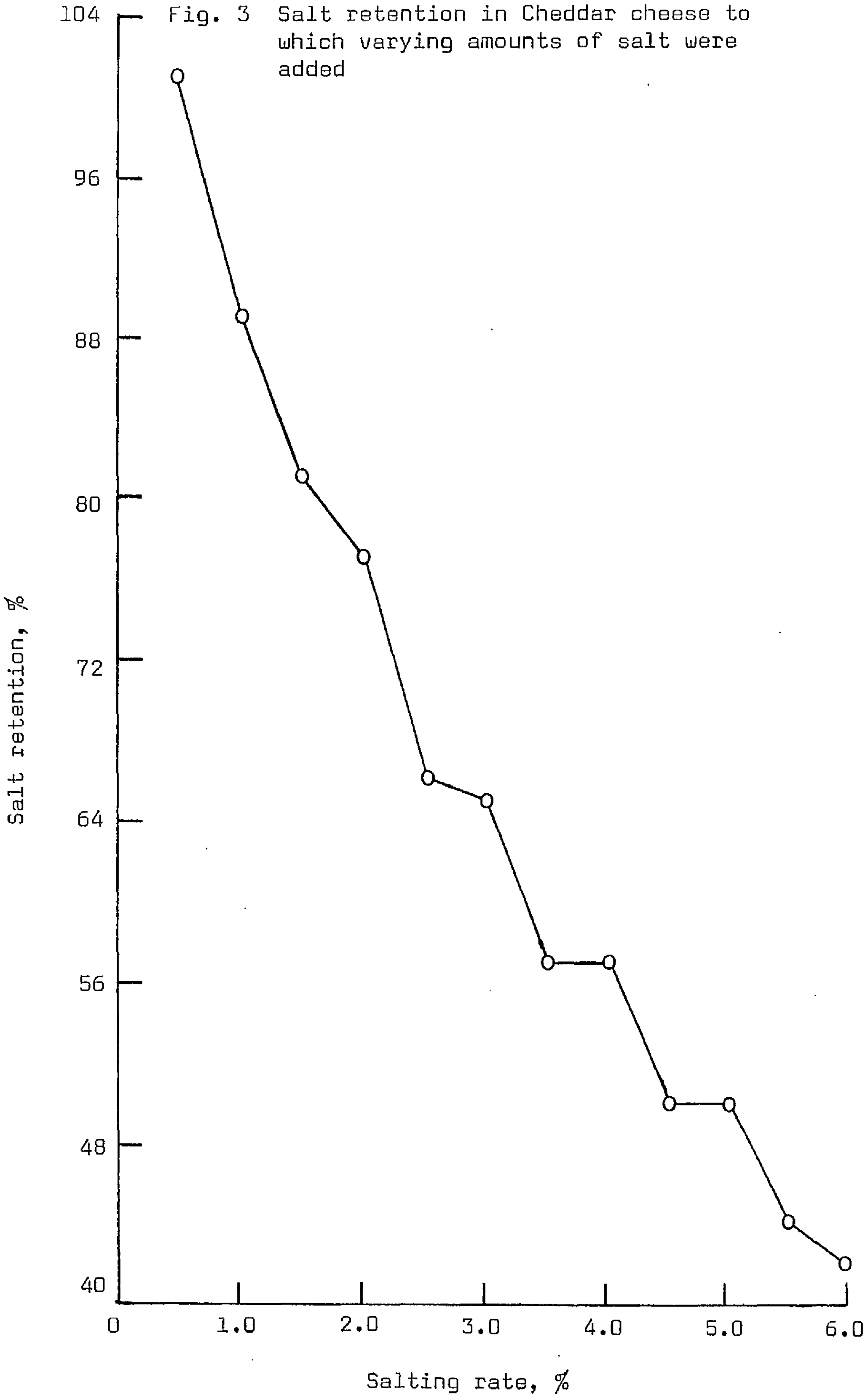

Fig. 3 Salt retention in Cheddar cheese to which varying amounts of salt were added

(b) Relation of salt content to body, flavour and texture of the cheese

Tables 113, 114, 115, 116 and 117 show the scores awarded for flavour and aroma, body, and texture of each individual cheese. As the relationship between salt content of the cheese in the 5 separate experiments is not linear with the rate of salt addition to the cheese curd the Tables are set out with the cheese in order of increasing salt content. On examination of the Tables it may be seen that very low and high salt contents in Cheddar cheese have a detrimental effect on the body and texture of the cheese. The minimum and maximum grade score for a cheese having a salt content of 0.50% was, for body, 6.0 and 7.5 marks (maximum 10) respectively. The corresponding figures for cheese with a salt content about 2.60% were 5.8 and 7.5 marks respectively. Scores for the texture of the cheese showed a similar trend with the lower salt content cheese scoring somewhat higher. The flavour scores for the cheese were in general higher than the scores for body and texture. In the lower salt content cheese the flavour was judged to be slightly off or sour, while at the higher salt contents the cheese were criticised for their lack of flavour and, where there was a flavour, for having a cooked or slightly burnt flavour. The highest flavour and aroma score obtained was 9.4, the lowest recorded being 7.5.

(c) Salting rate and quality of the cheese at time of grading

The salt contents and salt concentrations in the aqueous phase, and scores for flavour and aroma, body, and texture of the 60 cheese are recorded in Table 118. The cheese are arranged in order of increasing salt content rather than rate of salt addition for the reason given above. It may be seen that there is a good relationship between salt content of a cheese and the total score. The lowest average score for flavour and aroma

(b) Relation of earth [illegible]

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(c) [illegible]

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was obtained with cheese having an average salt content of 0.53%. The best average flavour score, 9.2 marks, was obtained for cheese having an average salt content of 1.18%. The lowest score, 6.3 marks, for body and texture was obtained for cheese having an average salt content of 2.58% while cheese having an average of 1.82% and 1.20% salt obtained the highest marks for body and texture respectively. The average overall score for cheese having an average salt content of 1.62% was lower than the score obtained for cheese having average salt contents of 1.51% and 1.82% respectively. This may be due to the fact that one cheese in the 1.56 to 1.68% salt content range scored extremely low marks for body (7.6) and texture (8.0). The number of cheese (4) in this particular salt content range was not large enough to eliminate the effect of this low scoring cheese. The best average overall score was obtained for cheese with an average salt content of 1.18% while the lowest overall score was obtained for cheese with an average salt content of 2.58%.

Salt content and salt concentrations in the aqueous phase

The concentration of salt in the aqueous phase is an important factor in stimulating or suppressing the growth of bacteria in cheese. A value of salt concentration in the aqueous phase rather than a value for salt content of cheese gives an indication of the environmental conditions in which both the desirable and the undesirable bacterial flora must grow. Cheese having the same salt contents may have widely differing values for the concentration of salt in the moisture of the cheese.

The salt concentration in the aqueous phase in a particular cheese is,

$$\frac{\%\ \text{salt}}{\%\ \text{Moisture}} \times 100$$

This value has been calculated for each cheese and Table 118 gives the range and average salt concentrations in the aqueous phase with varying

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Table 108

The effect of various rates of salt addition on the composition of Cheddar cheese

Processing record   Vat no. 1

Operation	Rennet added	Curd cut	Maximum scald	Curd settled	Whey run	Curd milled
Time, h min	0.00	0.55	1.55	2.40	3.10	5.05
Titratable acidity, % lactic acid	0.154	0.108	0.124	0.138	0.222	0.650
pH	6.59	6.51	6.41	6.29	5.88	5.33

Cheese analyses   1 day old

Salting rate, %	Salt, %	Fat, %	Moisture, %	pH
0.5	0.44	31.60	39.03	5.10
1.0	0.84	32.30	38.33	5.15
1.5	1.20	32.40	37.38	5.20
2.0	1.50	32.60	35.69	5.27
2.5	1.59	32.80	35.71	5.31
3.0	1.81	33.70	34.05	5.37
3.5	1.98	33.70	33.39	5.41
4.0	2.10	34.70	32.65	5.44
4.5	2.03	34.70	32.51	5.44
5.0	2.12	34.20	32.20	5.45
5.5	2.29	35.00	31.66	5.45
6.0	2.39	35.40	31.22	5.47

8 weeks old

Salting rate, %	Salt, %	Fat, %	Moisture, %	pH
0.5	0.53	32.10	39.46	5.08
1.0	0.83	31.80	38.46	5.06
1.5	1.12	33.10	37.47	5.07
2.0	1.44	33.10	36.24	5.10
2.5	1.47	34.00	36.25	5.10
3.0	1.79	34.30	35.26	5.12
3.5	1.89	35.00	34.61	5.12
4.0	2.09	34.60	33.33	5.31
4.5	2.15	35.10	33.17	5.31
5.0	2.38	36.20	32.29	5.43
5.5	2.40	34.90	32.52	5.41
6.0	2.49	35.20	32.12	5.44

Table 109

The effect of various rates of salt addition on the composition of Cheddar cheese

Processing record   Vat no. 2

Operation	Rennet added	Curd cut	Maximum scald	Curd settled	Whey run	Curd milled
Time, h min	0.00	0.45	1.45	2.30	3.05	5.00
Titratable acidity, % lactic acid	0.150	0.108	0.114	0.132	0.218	0.712
pH	6.61	6.53	6.45	6.31	5.89	5.35

Cheese analyses   1 day old

Salting rate, %	Salt, %	Fat,%	Moisture, %	pH
0.5	0.46	32.10	39.30	5.16
1.0	0.84	32.40	38.41	5.22
1.5	1.22	32.30	37.65	5.28
2.0	1.65	32.10	36.50	5.37
2.5	1.77	33.10	36.11	5.43
3.0	2.14	33.50	34.38	5.47
3.5	2.03	33.80	33.95	5.46
4.0	2.49	34.60	32.34	5.49
4.5	2.38	34.50	32.14	5.50
5.0	2.60	34.50	31.18	5.47
5.5	2.51	35.30	31.59	5.47
6.0	2.64	35.20	31.37	5.49

8 weeks old

Salting rate, %	Salt, %	Fat, %	Moisture, %	pH
0.5	0.51	32.00	38.90	5.06
1.0	0.91	31.00	38.77	5.07
1.5	1.15	32.10	37.66	5.05
2.0	1.51	32.60	37.06	5.07
2.5	1.66	32.70	36.30	5.13
3.0	1.98	33.20	35.57	5.33
3.5	2.06	34.10	34.46	5.47
4.0	2.36	34.00	33.17	5.46
4.5	2.26	34.00	33.36	5.48
5.0	2.63	35.10	31.61	5.48
5.5	2.57	34.80	33.21	5.38
6.0	2.68	34.80	31.82	5.47

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Table 110

The effect of various rates of salt addition on the composition of Cheddar cheese

Processing record Vat no. 3

Operation	Rennet added	Curd cut	Maximum Scald	Curd settled	Whey run	Curd milled
Time, h min	0.00	0.40	1.45	2.30	3.05	5.10
Titratable acidity, % lactic acid	0.154	0.108	0.118	0.128	0.202	0.616
pH	6.61	6.50	6.42	6.32	5.96	5.44

Cheese analyses 1 day old

Salting rate, %	Salt, %	Fat, %	Moisture, %	pH
0.5	0.43	32.10	40.14	5.12
1.0	0.93	31.20	39.89	5.19
1.5	1.36	32.00	38.86	5.27
2.0	1.53	32.70	37.27	5.34
2.5	1.72	32.80	36.99	5.40
3.0	1.98	33.10	35.53	5.49
3.5	2.06	33.40	34.56	5.48
4.0	2.52	34.70	33.16	5.50
4.5	2.25	34.70	33.00	5.50
5.0	2.53	34.80	32.22	5.50
5.5	2.26	34.90	33.12	5.49
6.0	2.60	35.10	31.90	5.51

8 weeks old

Salting rate, %	Salt, %	Fat, %	Moisture, %	pH
0.5	0.54	32.00	39.73	5.10
1.0	0.89	31.40	39.62	5.09
1.5	1.22	31.40	38.33	5.09
2.0	1.56	33.20	37.79	5.09
2.5	1.68	32.60	37.45	5.08
3.0	2.02	33.70	35.82	5.21
3.5	1.94	33.20	35.65	5.08
4.0	2.32	33.90	34.11	5.31
4.5	2.20	34.20	34.05	5.33
5.0	2.60	34.70	32.50	5.43
5.5	2.32	34.30	33.43	5.37
6.0	2.58	35.00	32.50	5.42

Table 111

The effect of various rates of salt addition on the composition of Cheddar cheese

Processing record Vat no. 4

Operation	Rennet added	Curd cut	Maximum scald	Curd settled	Whey run	Curd milled
Time, h min	0.00	0.40	1.40	2.25	2.55	4.25
Titratable acidity, % lactic acid	0.154	0.108	0.118	0.136	0.242	0.658
pH	6.60	6.52	6.44	6.28	5.79	5.36

Cheese analyses 1 day old

Salting rate, %	Salt, %	Fat, %	Moisture, %	pH
0.5	0.48	30.30	40.13	5.03
1.0	0.90	30.40	39.38	5.08
1.5	1.18	31.40	38.25	5.10
2.0	1.58	31.90	37.45	5.15
2.5	1.57	32.30	37.23	5.17
3.0	1.84	32.90	35.39	5.24
3.5	1.79	33.30	35.25	5.26
4.0	2.19	33.60	33.72	5.34
4.5	2.11	33.70	33.86	5.35
5.0	2.42	34.20	31.98	5.40
5.5	2.15	34.00	33.19	5.32
6.0	2.49	34.30	31.96	5.37

8 weeks old

Salting rate, %	Salt, %	Fat, %	Moisture, %	pH
0.5	0.50	31.60	39.42	5.07
1.0	0.87	32.40	39.21	5.06
1.5	1.18	31.90	38.00	5.03
2.0	1.46	32.40	37.05	5.04
2.5	1.58	32.40	36.70	5.06
3.0	1.85	32.70	35.57	5.09
3.5	1.85	32.70	35.09	5.10
4.0	2.11	32.90	33.50	5.23
4.5	2.07	34.10	33.80	5.24
5.0	2.29	34.00	32.82	5.35
5.5	2.13	33.60	33.04	5.27
6.0	2.39	34.70	31.81	5.40

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Table 112

The effect of various rates of salt addition on the composition of Cheddar cheese

Processing record   Vat no. 5

Operation	Rennet added	Curd cut	Maximum scald	Curd settled	Whey run	Curd milled
Time, h min	0.00	0.50	1.55	2.40	3.10	5.00
Titratable acidity, % lactic acid	0.154	0.110	0.120	0.140	0.220	0.640
pH	6.60	6.54	6.44	6.24	5.86	5.39

Cheese analyses   1 day old

Salting rate, %	Salt, %	Fat, %	Moisture, %	pH
0.5	0.59	33.05	38.79	5.13
1.0	0.99	32.80	38.21	5.17
1.5	1.33	32.55	37.05	5.25
2.0	1.69	33.50	36.71	5.35
2.5	1.80	33.85	35.06	5.37
3.0	2.22	33.85	34.25	5.48
3.5	2.24	34.80	33.55	5.50
4.0	2.46	35.20	32.83	5.51
4.5	2.69	35.50	32.20	5.55
5.0	2.83	36.00	31.09	5.55
5.5	2.77	36.50	30.83	5.55
6.0	2.65	35.95	31.37	5.54

8 weeks old

Salting rate, %	Salt, %	Fat, %	Moisture, %	pH
0.5	0.55	32.00	38.44	5.12
1.0	0.92	32.90	38.07	5.12
1.5	1.23	32.90	37.38	5.08
2.0	1.55	33.10	36.75	5.08
2.5	1.74	33.30	35.85	5.10
3.0	2.03	33.40	35.10	5.35
3.5	2.16	32.90	34.18	5.41
4.0	2.31	35.10	33.49	5.48
4.5	2.47	34.20	33.03	5.44
5.0	2.55	35.20	32.44	5.49
5.5	2.50	35.30	31.94	5.48
6.0	2.61	35.10	31.54	5.45

Table 113

The grade scores of Cheddar cheese at 8 weeks old with various salt contents and concentrations of salt in the aqueous phase

Vat no. 1

Salting rate, %	Salt content, %	Salt concentration in the aqueous phase %	Flavour and aroma (10)	Body (10)	Texture (10)	Total score (30)
0.5	0.53	1.3	8.5	7.4	8.8	24.7
1.0	0.83	2.1	8.8	7.5	9.0	25.3
1.5	0.12	3.0	9.0	8.5	8.8	26.3
2.0	1.44	4.0	8.6	8.0	9.0	25.6
2.5	1.47	4.0	8.8	8.0	8.8	25.6
3.0	1.79	5.1	9.0	8.8	9.0	26.8
3.5	1.89	5.5	8.8	8.8	8.8	26.4
4.0	2.09	6.3	8.4	7.0	7.0	22.4
4.5	2.15	6.5	8.0	6.0	6.0	20.0
5.0	2.38	7.4	8.0	6.0	6.0	20.0
5.5	2.40	7.4	8.0	6.0	6.0	20.0
6.0	2.49	7.7	8.0	6.0	6.0	20.0

Table 114

The grade scores of Cheddar cheese at 8 weeks old with various salt contents and concentrations of salt in the aqueous phase

Vat no. 2

Salting rate, %	Salt content, %	Salt concentration in the aqueous phase %	Flavour and aroma, (10)	Body (10)	Texture (10)	Total score (30)
0.5	0.51	1.3	7.0	7.5	8.5	23.0
1.0	0.91	2.3	8.6	8.0	9.0	25.6
1.5	1.15	3.0	9.4	8.8	9.0	27.2
2.0	1.51	4.1	9.2	7.5	9.0	25.7
2.5	1.66	4.6	9.2	8.8	9.0	27.0
3.0	1.98	5.6	8.7	8.0	8.0	24.7
3.5	2.06	6.0	8.8	8.2	8.0	25.0
4.5	2.26	6.8	8.8	7.0	7.0	22.8
4.0	2.36	7.1	8.8	8.0	8.0	24.8
5.5	2.57	7.7	8.8	6.0	6.0	20.8
5.0	2.63	8.3	8.8	6.0	6.0	20.8
6.0	2.68	8.4	8.8	6.0	6.0	20.8

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Table 115

The grade scores of Cheddar cheese at 8 weeks old with various salt contents and concentrations of salt in the aqueous phase

Vat no. 3

Salting rate, %	Salt content, %	Salt concentration in the aqueous phase %	Flavour and aroma, (10)	Body, (10)	Texture, (10)	Total score (30)
0.5	0.54	1.3	7.5	6.0	7.0	20.5
1.0	0.89	2.2	8.0	7.5	8.5	24.0
1.5	1.22	3.2	8.6	7.8	8.7	25.1
2.0	1.56	4.1	8.7	8.7	9.0	26.4
2.5	1.68	4.5	8.5	7.6	8.0	24.1
3.5	1.94	5.4	9.0	8.8	8.8	26.6
3.0	2.02	5.6	9.0	8.8	8.7	26.5
4.5	2.20	6.5	8.8	6.5	6.5	21.8
4.0	2.32	6.8	8.8	8.0	7.5	24.3
5.5	2.32	6.9	8.8	7.5	7.7	24.0
6.0	2.58	7.9	8.6	7.5	7.5	23.6
5.0	2.60	8.0	8.8	6.0	6.0	20.8

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Table 116

<u>The grade scores of Cheddar cheese at 8 weeks old with various salt contents and concentrations of salt in the aqueous phase</u>

Vat no. 4

Salting rate, %	Salt content, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body (10)	Texture (10)	Total score (30)
0.5	0.50	1.3	7.5	7.5	8.8	23.8
1.0	0.87	2.2	9.2	8.8	9.0	27.0
1.5	1.18	3.1	9.4	9.2	9.2	27.8
2.0	1.46	3.9	9.2	9.0	8.8	27.0
2.5	1.58	4.3	9.4	9.1	9.0	27.5
3.0	1.85	5.2	8.5	8.0	8.0	24.5
3.5	1.85	5.3	9.1	9.1	9.0	27.2
4.5	2.07	6.1	7.8	8.0	7.5	23.3
4.0	2.11	6.3	7.8	8.0	7.5	23.3
5.5	2.13	6.4	8.7	8.0	7.5	24.2
5.0	2.29	7.0	8.5	7.0	7.0	22.5
6.0	2.39	7.5	8.8	7.0	7.0	22.8

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Table 117

<u>The grade scores of Cheddar cheese at 8 weeks old with various salt contents and concentrations of salt in the aqueous phase</u>

Vat no. 5

Salting rate, %	Salt content, %	Salt concentration in the aqueous phase, %	Flavour and aroma, (10)	Body (10)	Texture (10)	Total score (30)
0.5	0.55	1.4	8.8	7.5	8.8	25.1
1.0	0.92	2.4	9.2	7.5	9.0	25.7
1.5	1.23	3.3	9.4	8.8	9.0	27.2
2.0	1.55	4.2	9.2	8.5	9.0	26.7
2.5	1.74	4.8	9.0	8.8	8.6	26.4
3.0	2.03	5.8	9.2	9.0	8.8	27.0
3.5	2.16	6.3	9.3	8.9	8.7	26.9
4.0	2.31	6.9	9.0	7.5	7.5	24.0
4.5	2.47	7.5	9.0	7.5	7.5	24.0
5.0	2.55	7.9	9.0	6.0	6.0	21.0
5.5	2.58	8.1	9.0	6.0	6.0	21.0
6.0	2.61	8.3	8.8	5.8	5.8	20.4

Table 118

The average grade scores of Cheddar cheese with various salt contents and concentrations of salt in the aqueous phase

Range of salt content, %	Average salt content, %	Range of salt concentration in the aqueous phase %	Average salt concentration in the aqueous phase, %	No. of cheese	Flavour and aroma (10)	Body (10)	Texture (10)	Total score (30)
0.50-0.55	0.53	1.3-1.4	1.3	5	7.9	7.2	8.4	23.5
0.83-0.92	0.88	2.1-2.4	2.2	5	8.9	7.9	8.9	25.7
1.15-1.23	1.18	3.0-3.3	3.1	5	9.2	8.6	8.9	26.7
1.44-1.55	1.51	3.9-4.2	4.0	5	9.0	8.2	8.9	26.1
1.56-1.68	1.62	4.1-4.6	4.4	4	8.9	8.0	8.7	25.6
1.74-1.89	1.82	4.8-5.5	5.2	5	8.9	8.7	8.7	26.3
1.94-2.07	2.02	5.4-6.1	5.7	6	8.7	8.5	8.3	25.5
2.09-2.20	2.14	6.3-6.5	6.4	6	8.5	7.4	7.2	23.1
2.26-2.40	2.34	6.8-7.5	7.1	9	8.6	7.1	7.1	22.8
2.47-2.68	2.58	7.5-8.4	8.0	10	8.8	6.3	6.3	21.4

salt contents. The conditions of the experiment were such that as the salt content increased so also did the salt concentration in the aqueous phase. The cheese having an average salt concentration in the aqueous phase of 3.1% obtained the highest average overall score at 26.7 (maximum 30). Cheese having an average salt concentration in the aqueous phase of 8.0% had a total of 21.4 marks while the lowest scoring (20.0 marks), individual cheese had salt concentrations in the aqueous phase ranging from 6.5% to 7.7%. Salt concentrations in the aqueous phase for the entire experiment ranged from 1.3% to 8.4% with the cheese differing greatly in chemical composition.

DISCUSSION

The cheese in the above experiments were part of the same vat up to and including the stage of milling the curd. The variations in composition and quality as judged by an overall grade score are therefore the result of various rates of salt addition. It was not the intention during these experiments to place each cheese in a specific grade as in commercial cheese grading practice but to award to the cheese points for (a) flavour and aroma, (b) body and (c) texture. It has been observed by the author in the commercial field that it is possible to have a cheese placed in 2nd grade (i.e. "graded" cheese commercially) although it has obtained a higher overall score than a cheese placed in 1st grade. This occurs when either the flavour and aroma, body or texture are not sufficiently good enough to merit 1st grade. It may be said in general, however, that cheese having an overall grade score of between 25.9 and 22.5 corresponded to a 2nd grade cheese commercially and that an overall score of less than 22.5 indicated a cheese of poor quality known in commercial practice in Scotland as a "no stamp" cheese.

van Slyke and Price (1949) have outlined procedures for the removal of excessive moisture in cheese curd. These include variations in scalding temperature, size of the cut curd pieces and salting rate. It is important, however, that any method used to remove moisture should not result in cheese of inferior quality. It has been shown in the above experiments that moisture may be removed from cheese curd by increasing the salting rate. The results outlined above are in agreement with the findings of Morris (1962), Sproule, Irvine and McKinney (1939) and Whitehead and Harkness (1954). In the preliminary trial where maximum and minimum salting rates of 3% and 0.25% by weight of curd respectively were used the difference in the moisture content of these cheese at 8 weeks old was about 4%. Within the limits of these salting rates the fat content of the cheese did not vary markedly. This is in agreement with Feagan <u>et al</u>. (1965). The pH values of these preliminary cheese (Tables 104 and 105) showed a definite increase with increase in salt content but these differences had disappeared in the cheese at 8 weeks old when the maximum difference was 0.09 pH as compared with 0.32 pH in the cheese at 1 day old. This point may be important when an effort is being made to select an age at which cheese is chemically analysed from the results of which it may be possible to predict the storage life of the cheese.

In the experiments where the salting rate was varied from 0.5% to 6% a wide variation in the composition of the cheese resulted. Again by increasing the rate of salt addition to the cheese curd the moisture content of the cheese decreased. On account of other defects which may be introduced by employing high salting rates and thereby decreasing the moisture content of the cheese the condition of the curd at time of milling must be considered before deciding on a specific salting rate.

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There is a tendency in commercial practice to adhere to a definite salting rate with a slight variation from season to season but with little thought for the day to day variations in the composition of the cheese curd or in a particular day's processing record. Therefore the skill of the cheesemaker plays an important part, even at such a late stage of the cheesemaking procedure as the milling time, in determining the compositional quality of the finished cheese. By increasing the salting rate the fat content of cheese is increased where salting rates of up to 6% are used but the resultant cheese is curdy and crumbly in texture. A salting rate of 0.5% was not sufficient to remove excess moisture from the cheese curd with the result that the body of the cheese was weak and pasty. On the other hand a 5 or 6% salting rate removed too much moisture and resulted in a low moisture cheese with an over-firm body.

The overall quality or grade score is affected by the salt content and salt concentration. Irvine (1955) showed that the salt content influenced the grade of the cheese. He also showed that salt concentrations in the aqueous phase of less than 4.33 or higher than 5.33% produced low grade cheese. In an effort to relate the salt content and salt concentration to the body of Cheddar cheese (Morris (1962) found that the best bodied cheese had an average salt content of 1.50% and a salt concentration of 4.31%, with a range of 2.3 to 5.4%. As the writer found that 1st grade cheese had an average salt concentration in the aqueous phase of from 3.1 to 5.2% with average salt contents ranging from 1.18 to 1.82%, the difficulty of assigning definite figures for salt content or salt concentration in the aqueous phase to a particular grade of cheese becomes obvious. With the lower ($< 1\%$) and higher ($> 2.0\%$) salt contents there is a definite falling off in cheese quality and

conditions giving rise to such salt contents in the finished cheese must be carefully guarded against.

As stated earlier, the spread figure i.e. the difference between the lowest salt content and the highest salt content, for cheese within a vat is important. The average salt content for an entire vat must be considered in the light of the spread figure. Taking an average salt content of 1.80% and a spread figure of 0.40% then there is a great danger that a cheese which is submitted to the official cheese grader will have a salt content of about 2.0%. This salt content can give rise to defects in body and texture resulting in the downgrading of the cheese. As it is usual in commercial practice to grade an entire vat consisting of from 25 to 70 cheese, from the assessment by the grader on one cheese the commercial significance of this work becomes apparent. The distribution of salt should be such as to give as low a spread figure as possible but the selection of the correct salting rate for each particular vat must be emphasised. That Cheddar cheese containing less than 1.0% and greater than 2.0% salt can be obtained in commercial conditions is seen from results tabulated in Section 3, Part I of this thesis where the salt contents ranged from 0.60% to 2.95%. This should be a clear indication that methods of salt distribution and the selection of correct salting rates leave much to be desired. It is suggested by the author that where control is exercised over the compositional quality of Cheddar cheese circumstances causing variations in moisture and salt contents may be detected and remedial measures can be taken for subsequently made cheese. The pH value is also a good guide as to the rate of lactic acid production. As Cheddar cheese is usually submitted for grading at about 8 to 10 weeks old remedial measures suggested by the grader are of limited value as the cheese made during the intervening 8 to 10 weeks may also have been subjected [illegible] conditions [illegible] the [illegible]

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to faulty processing techniques. Therefore the importance of chemical analysis of Cheddar cheese at 1 day old as a routine procedure must be stressed if problems concerned with the compositional quality of cheese are to be avoided.

CONCLUSIONS

Excess moisture in the curd at milling may be removed effectively by an increase in the salting rate, However, caution must be exercised that the salt content of the cheese does not exceed 2.0% or fall below 1.0%. The pH value, increased with increase in salt content with salting rates of over 3.0% by weight of curd. The amount of salt retained in the curd is affected by the rate of salting. With a salting rate of 0.5% about 100% of the salt is retained in the cheese while with the 3% and 6% salting rates about 66% and 42% respectively of the salt is retained. Grade 1 cheese was obtained with salt contents varying from about 1.2 to 1.8%, the correct salt content within this range being determined by the condition and composition of the cheese curd. Salt concentrations in the aqueous phase from about 3.0 to about 5.2% were found in grade 1 cheese.

Because of the possibility of an entire vat being assigned a lower grade due to the effect of too high or too low salt content it is very necessary from a commercial viewpoint to devote greater attention to the selection of the optimum salting rate and to the proper distribution of the salt in the vat. In order to detect variations in the composition of the cheese, chemical analysis of cheese 1 day old is recommended. The results may indicate that the cheesemaker should take necessary precautions to correct errors which would not normally be detected until time of grading i.e. 8 to 10 weeks hence.

SUMMARY

Twenty-four, 40 lb blocks of Cheddar cheese were made with salting rates varying from 0.25% to 3.0%, and sixty, 40 lb blocks were made with salting rates from 0.5% to 6.0%.

The amount of salt retained in the cheese decreased with increase in salting rate; about 100% and 42% being retained at the 0.5% and 6.0% salting rates respectively.

The moisture content and pH value are affected by the salt content; the fat content is affected when the cheese contains more than 2.0% salt.

There is a fairly wide optimum salt range for cheese in general but more careful control in the adoption of a salting rate and salt distribution is advocated.

THE PRESENCE OF LACTOSE IN CHEDDAR CHEESE AGED 9 WEEKS MADE WITH VARIOUS RATES OF SALT ADDITION

During the chemical analyses of Cheddar cheese made with various rates of salt addition (0.5 to 6.0%) the observation was made with some cheese samples that the residues in dishes used in moisture testing were slightly brown or dark brown. (The cheese concerned did not contain any artificial colouring material). The degree of browning seemed to correlate very closely with the pH value of the sample e.g. as the pH value increased so also did the intensity of browning. The high pH values of some of the cheese indicated that the lactic acid fermentation had been inhibited or stopped due to conditions in the cheese. These high pH values seemed to indicate the possible presence of unfermented lactose and its components sugars. There was also the possibility that the absence of browning of the moisture residue of the cheese with average (1.5% salt) or low (0.5% salt) salt contents might be due directly to the low salt content and not indirectly to the provision of conditions which favoured the breakdown of lactose.

To ascertain if the salt content of a cheese was directly responsible for lack of browning of moisture residues or whether the presence of a sugar, lactose, glucose or galactose could be responsible for the browning of such moisture residues, the following experiment was made.

EXPERIMENTAL

About 2 g of cheese with a salt content of 0.5% was placed in each of 5 aluminium foil dishes. 0.2 g of the following substances were added to the dishes. Salt was added to dish 1, lactose plus salt to dish 2 and lactose, galactose and D (+) glucose to dishes 3, 4 and 5 respectively. The dishes were placed in an oven at 100°C for 4 h as is the usual procedure when moisture determinations of cheese are made. The dishes were then removed from the oven and examined for degree of browning or discolouration.

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RESULTS AND DISCUSSION

Plate 2 demonstrates clearly the effect of the various sugars and added salt on the discolouration of moisture residues of cheese. The addition of salt had no effect on the colour of the cheese residue while lactose, galactose and dextrose gave a brown and slightly burnt appearance to the residue. This browning of the cheese-sugar mixtures is the well known Maillard reaction. Patton (1955) stated that the two principal reactants in the browning of milk and milk systems were lactose and casein. Neither casein nor lactose browns readily when heated alone but they do so when heated together (Patton, 1952; Harland, Jenness and Coulter, 1947). Browning of Cheddar cheese when moisture determinations were being made was observed by the author during his investigation of the quality and composition of commercial cheese (Section 3, Part I of this thesis). This browning was usually associated with a high pH value (>5.40) and it is suggested that lactose and/or reducing sugars were present in these particular cheese.

Although demonstrating the fact that cheese containing certain sugars appeared brown when heated to high temperatures, further study was necessary to identify the sugars if they were present in the original cheese. A thin layer chromatographic technique was used for the identification of the sugars, the work being outlined below.

The use of Thin Layer Chromatography to detect the presence of sugars in Cheddar cheese 9 weeks old

Procedure

Five ml of distilled water and 5 ml of ethyl alcohol were added to 5 g of grated cheese. The mixture was well mixed by means of a Silverson blender and then filtered through a Whatman No.1 filter paper.

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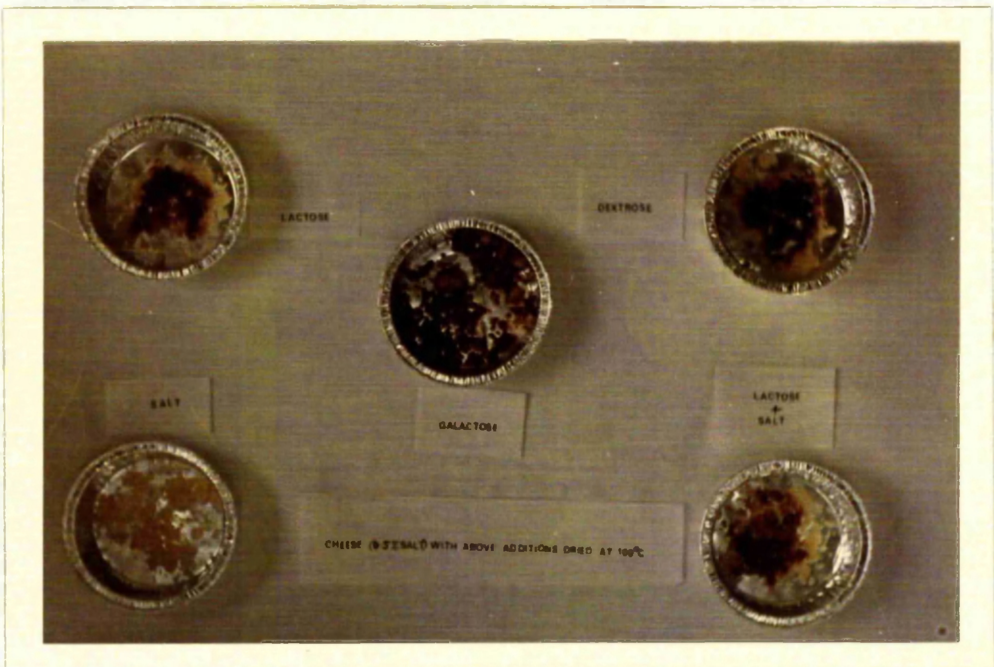

Plate 2. Aluminium foil dishes containing the dried material from Cheddar cheese with additions of salt, salt + lactose, lactose, galactose and dextrose.

About 2.5 to 3.0 μL of the filtrate were spotted on a previously prepared thin layer chromatographic glass plate which measured 9 in. x 9 in. The glass plate was large enough to accommodate 12 samples of cheese and 2 control samples each of lactose, glucose and galactose. The plates were placed in a suitable chromatographic tank containing butanol, acetone and water (4:5:1) and after about an hour the plates were removed from the tank and sprayed. The spraying reagent consisted of 2 g each of triphenyltetrazolium chloride (TTC) and sodium hydroxide (NaOH) dissolved in 100 ml of methanol.

After spraying the plates were dried in an oven at 100°C and then examined for the presence or absence of sugars.

RESULTS

Plates 3, 4, 5, 6 and 7 show the result of the experiment. Each plate contained the test material from 12 cheese each of which received identical treatment up to and including the milling stage but which then were treated with different amounts of salt. The Plates show that lactose was present in the higher salt content cheese. Galactose was also present in some of the cheese but the spots were difficult to detect, disappearing rather quickly during the drying of the glass plates.

DISCUSSION

The rate of lactose utilisation in Cheddar cheese may be dependent on its composition. Fagen *et al.* (1952) stated that lactose was completely removed from Cheddar cheese having a salt content of 1.75% after 14 days and that glucose and galactose disappeared after none and 56 days respectively. van Slyke and Bosworth (1907) stated that lactose was removed from the cheese within 2 weeks of making. The products of the lactic acid fermentation are said to contribute to the flavour of

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Plate 3

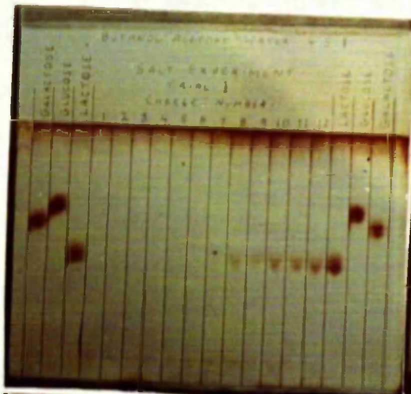

Plate 4

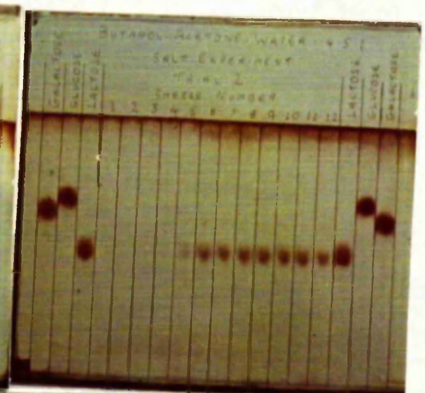

Plate 5

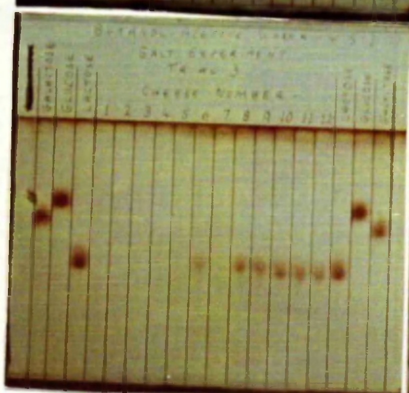

Plate 6

Plate 7

Plates 3, 4, 5, 6 & 7 The identification of sugars in Cheddar cheese at 9 weeks old made with various rates of salt addition (Cheese no.1 was made with 0.5% added salt while no.12 had 6.0% added salt).

Cheddar cheese (van Slyke and Price, 1949) so that the inhibition of this fermentation because of unsuitable conditions in the cheese for the lactic acid producing bacteria could result in cheese of inferior quality.

The high salt content of a cheese also affects the body and texture characteristics because of the increased or decreased moisture and fat contents. A high rate of salting as well as giving a poor quality cheese affects the yield due to loss of moisture. The combined fact of poor quality cheese and reduced yield is commercially very important and strict control over the composition of the finished cheese is necessary.

Section four

Thesis summary

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THESIS SUMMARY

Section one

Part I

The origin of cheesemaking and in particular Cheddar cheesemaking is discussed and the changes in manufacturing techniques and practices from the earlier days to the present time are recorded. The essential steps in Cheddar cheesemaking and the common faults of Cheddar cheese are outlined.

Part II

The extent and rate of acid production in cheesemaking is discussed. The literature on the rate of acid production is reviewed and the importance of the rate of transformation of lactose into lactic acid during cheesemaking is indicated since it largely controls the quality and composition of the cheese curd. The factors affecting the rate of acid production in the cheese vat are discussed.

Part III

The literature on the relationship between the acidity (titratable acidity or pH) and quality of Cheddar cheese is reviewed.

Section two

Materials and methods

Part I

The acidity of milk and cheese is discussed. The limitations of the titratable acidity test are pointed out and the use of pH measurements in cheesemaking indicated. The methods for the determination of pH and titratable acidity of cheese are reviewed. A method for the determination of the titratable acidity of cheese is suggested. The variations in techniques and procedures used for the determination of the titratable

acidity of milk, whey and cheese are stressed as factors limiting the usefulness of the test.

Part II

Methods for the determination of lactose are discussed and as a result of experimental work a method is suggested for the estimation of lactose in Cheddar cheese during maturation.

Part III

The chemistry of lactic acid is included along with a review of methods for the determination of lactic acid (lactate) in milk and cheese. A procedure for the estimation of lactic acid (lactate) in Cheddar cheese is described.

Section three

Part I

As a number of experiments dealing with several aspects of Cheddar cheese manufacture were envisaged it was decided as an initial experiment to investigate the composition and quality of Cheddar cheese made in commercial cheese factories. A total of 300 cheese were examined. The pH values, fat, moisture and salt contents were determined and each cheese was scored on a special points system based on a maximum of 10 points each for (a) body, (b) texture and (c) flavour and aroma. Simple and partial correlation coefficients were calculated between the various parameters and in an effort to predict a particular characteristic, e.g. body of the cheese, regression equations were calculated.

The value of carrying out chemical tests in quality control programmes is discussed and the more useful ones are indicated. It is suggested that the results of certain chemical tests be made available to the official cheese grader at time of grading the cheese. As there is a lack of

published information on the composition of Cheddar cheese manufactured in South West Scotland the results recorded in this Part indicate clearly that a strict compositional quality control system in Cheddar cheese factories is necessary.

Part II

In this Part are detailed the results of a (3^4) factorial experiment which was designed to provide information on the effect of varying a 'standard' Cheddar cheese manufacturing procedure on the quality and composition of the mature cheese. During the manufacturing process, pH and titratable acidity values were determined and at various times during maturation of the cheese pH values, fat, moisture and salt contents were determined. At 2 and 4 months old each cheese was graded on a special points system.

Statistical techniques were used to ascertain the effects of variations in the timings of certain stages of the manufacturing process on the quality and composition of the mature cheese. The results are discussed and attention is drawn to the composition of commercially made cheese (Section three, Part I) and the variation in the composition of the cheese in this controlled experiment. When the cheese were 10 months old the official cheese grader placed the cheese in one of 3 grade categories as in commercial practice and pH values were determined. In commercial practice great emphasis is placed on the stage of the removal of whey from the vat as a factor influencing the overall quality of the mature cheese. However, in this work it was found that variations in the length of time from the settling of the curd to the removal of the whey had no significant effect on the flavour and aroma, body and total score and only a barely significant effect on the score for texture of the

cheese at 2 months old. It is suggested that in commercial practice greater attention should be paid to the earlier stages of the Cheddar cheese manufacturing process as these were found to have a significant effect on the total grade score of the mature cheese.

Part III

In order to determine the rate of utilisation of lactose during maturation and the effect of added lactose on the quality and composition of Cheddar cheese a total of 39 cheese were made to which lactose was added in varying amounts to the milled curd. During maturation, lactose estimations were made using the method devised by the author. Each cheese was analysed for fat, moisture and salt contents and pH values were determined at 1 day and 9 weeks old. The results indicate that although added lactose removes excess moisture and may be used to give an increase in acidity the mature cheese may have defects in flavour and aroma, body and texture as assessed by the official cheese grader. At 6 months old the pH value of the cheese was determined. The results indicate that added lactose resulted in a decrease in pH as compared to the pH of the control cheese. Although the larger amounts of added lactose are unlikely to be found in cheese curd in commercial practice there is a possibility that the defects resulting from the smaller lactose additions may be caused by natural variations in the lactose content of cows' milk or variations in the cheese manufacturing procedure.

Part IV

In this experiment 62 commercial Cheddar cheese were examined. The pH value, lactic acid (lactate) and titratable acidity values were determined for each cheese and the cheese were scored on the special points system devised by the author i.e. scores for flavour and aroma, body and texture were recorded. Correlation coefficients between the various

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parameters were calculated together with regression equations which may be used in predicting cheese quality. The chemical tests are discussed especially in regard to their usefulness and practicability. The titratable acidity test is suggested as a simple and useful quality control tool under commercial conditions.

Part V

The results recorded in Section three, Part I of this thesis indicate the wide variation in composition of commercial Cheddar cheese. The variation in salt content was particularly disturbing and it was decided in this experiment using controlled procedures to ascertain the effect of varying the rates of salt addition to cheese curd on the quality and composition of the mature cheese. The lowest rate of salt addition was 0.25% and the highest being 6.0%. The amount of salt retained by the cheese varied from about 100% at the 1.0% salting rate to about 42.0% at the 6.0% salting rate. The results of this experiment indicate clearly that unless the correct salting rate suitable for the particular cheese is used the cheese quality will be adversely affected. Where too high salting rates are used the yield is considerably reduced. One may conclude from the results of this experiment and those of Section three, part I that curd salting procedures in commercial practice (a maximum of 2.95% salt was obtained) leave much to be desired and the importance of the curd salting stage cannot be too strongly emphasised.

When the cheese were 9 weeks old a thin layer chromatographic technique was used to detect the presence of sugars. The presence of lactose in the high salt content cheese (over 2.5%) indicated that the concentration of salt in the aqueous phase retarded or inhibited the lactic acid fermentation.

Section five

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APPENDIX A

Tables 29 to 55

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese.

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Table 29

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 1

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.142	0.142	0.146	6.69	6.69	6.69
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.160	0.158	0.158	6.57	6.57	6.56
Curd cut	1.35	1.25	1.15	0.108	0.110	0.108	6.49	6.53	6.53
Maximum scald, °F	2.35	2.25	2.15	0.126	0.122	0.120	6.39	6.44	6.47
Curd settled	2.55	3.05	3.15	0.144	0.148	0.156	6.31	6.27	6.20
Whey run	3.10	3.50	3.45	0.170	0.274	0.264	6.10	5.75	5.79
Curd milled	4.50	6.00	4.55	-	-	-	5.29	5.17	5.25

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	4.88	4.90	4.89	4.96	4.95	5.01	4.92	4.94	4.95	4.92	4.89	4.94
Moisture, %	40.01	37.63	37.25	40.07	37.74	37.76	39.91	37.79	37.61	39.48	37.39	37.58
Salt, %	1.28	1.45	1.30	1.37	1.49	1.27	1.29	1.49	1.20	1.31	1.53	1.36
Fat, %	31.30	32.20	33.10	32.10	33.50	33.10	31.95	32.75	33.00	31.95	33.00	33.00

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Fair	7.5	Fair	8.0	Good	9.0	Fair	8.0	Fair	8.0	Fair	8.5
Flavour and aroma, (max, 10)	Good	9.0	Good	9.2	Good	9.6	Fair	9.0	Poor	8.0	Poor	7.5
Texture, (max, 10)	Short	7.0	Short	7.0	Slightly rough	8.5	Very rough	6.0	Very short	6.5	Slightly rough	7.0
Total points scored, (max. 30)		23.5		24.2		27.1		23.0		22.5		23.0

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Table 30

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 2

Operation	Time, h min			Titratable acidity % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.138	0.138	0.142	6.70	6.69	6.69
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.148	0.156	0.150	6.60	6.58	6.58
Curd cut	1.15	1.35	1.25	0.106	0.110	0.104	6.54	6.50	6.52
Maximum scald, °F	2.15	2.35	2.25	0.120	0.128	0.128	6.48	6.39	6.42
Curd settled	2.35	3.15	3.25	0.128	0.154	0.158	6.39	6.22	6.16
Whey run	2.50	4.00	3.55	0.154	0.290	0.248	6.29	5.74	5.84
Curd milled	5.00	5.10	5.25	-	-	-	5.32	5.27	5.27

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	4.88	4.85	4.87	5.01	4.92	4.96	4.99	4.91	4.94	4.96	4.87	4.92
Moisture, %	39.70	38.12	37.17	39.58	37.85	36.74	39.44	37.86	37.23	39.05	36.78	36.66
Salt, %	1.32	1.36	1.38	1.17	1.25	1.41	1.22	1.27	1.39	1.30	1.32	1.43
Fat, %	31.90	33.15	33.25	32.40	33.50	34.00	32.45	34.05	34.25	32.95	34.60	34.40

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Slightly weak	8.5	Weak	8.0	Good	9.0	Slightly weak	8.5	Slightly weak	8.5	Slightly weak	8.3
Flavour and aroma, (max. 10)	Good	9.6	Fair	9.2	Good	9.4	Good	9.2	Fair	8.8	Fair	9.0
Texture, (max. 10)	Good	9.5	Short, crumbly	6.5	Slightly short	8.5	Slightly short	8.0	Slightly short	8.4	Slightly short	8.2
Total points scored, (max 30)		27.6		23.7		26.9		25.7		25.7		25.5

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Table 31

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 3

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.142	0.140	0.143	6.69	6.69	6.69
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.158	0.164	0.162	6.59	6.56	6.56
Curd cut	1.25	1.15	1.35	0.110	0.112	0.112	6.53	6.52	6.51
Maximum scald, °F	2.25	2.15	2.35	0.126	0.124	0.128	6.45	6.45	6.41
Curd settled	2.45	2.55	3.35	0.134	0.136	0.164	6.38	6.33	6.15
Whey run	3.15	3.10	4.20	0.174	0.168	0.304	6.12	6.15	5.70
Curd milled	4.55	5.20	5.30	-	-	-	5.42	5.38	5.31

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	4.90	4.92	4.87	5.08	5.08	4.99	5.06	5.08	5.04	5.07	5.07	4.96
Moisture, %	37.74	37.40	37.12	37.94	37.51	36.98	37.70	37.21	36.98	37.66	37.36	37.06
Salt, %	1.43	1.43	1.31	1.46	1.48	1.43	1.41	1.49	1.39	1.50	1.57	1.47
Fat, %	33.00	33.40	33.60	31.90	32.10	32.40	32.75	32.85	33.10	32.70	33.10	33.60

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Good	9.2	Good	9.0	Fair	8.5	Good	9.2	Good	9.4	Fair	8.5
Flavour and aroma, (10)	Good	9.6	Good	9.4	Good	9.2	Good	9.2	Good	9.4	Good	9.2
Texture, (max. 10).	Good	9.8	Good	9.4	Slightly rough	7.0	Good	9.4	Good	9.5	Slightly short	8.0
Total points scored, (max, 30)		28.6		27.8		24.7		27.8		28.3		25.7

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Table 32

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 4

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.140	0.144	0.144	6.70	6.70	6.70
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.152	0.158	0.150	6.59	6.58	6.58
Curd cut	1.35	1.25	1.15	0.112	0.110	0.114	6.52	6.53	6.54
Maximum scald, °F	2.35	2.25	2.15	0.120	0.124	0.120	6.47	6.46	6.50
Curd settled	3.15	3.25	2.35	0.140	0.148	0.126	6.31	6.23	6.44
Whey run	4.00	3.55	2.50	0.216	0.216	0.140	5.91	5.92	6.32
Curd milled	5.40	6.05	4.00	-	-	-	5.30	5.28	5.69

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	4.86	4.87	4.92	4.97	4.96	5.04	4.97	5.00	5.09	4.92	4.92	5.00
Moisture, %	38.24	37.53	40.43	37.85	37.37	39.73	37.88	36.83	39.38	37.97	37.34	39.30
Salt, %	1.44	1.46	1.29	1.35	1.43	1.42	1.32	1.36	1.37	1.11	1.39	1.32
Fat, %	32.60	33.50	31.70	32.80	33.00	31.80	32.50	33.60	31.55	32.85	33.45	31.90

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Sticky	9.0	Good	9.4	Weak	8.5	Good	9.0	Slightly sticky	8.7	Slightly weak	8.8
Flavour and aroma, (max. 10)	Good	9.7	Good	9.7	Fair	9.[illegible]	Good	9.3	Good	9.0	Good	9.3
Texture, (max. 10)	Good	9.8	Good	9.8	Good	9.5	Good	9.0	Good	9.0	Good	9.0
Total points scored, (max. 30)		28.5		28.9		27.4		27.3		26.7		27.1

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Table 33

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 5

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.142	0.144	0.142	6.69	6.69	6.69
Starter added	0.00	0.00	0.00	-	-	-	-	-	6.69
Rennet added	0.45	0.45	0.45	0.152	0.152	0.158	6.60	6.60	6.60
Curd cut	1.35	1.25	1.15	0.110	0.110	0.110	6.54	6.54	6.57
Maximum scald, °F	2.35	2.25	2.15	0.122	0.116	0.114	6.48	6.50	6.53
Curd settled	3.35	2.45	2.55	0.154	0.122	0.126	6.21	6.45	6.44
Whey run	4.20	3.15	3.10	0.304	0.166	0.154	5.66	6.16	6.25
Curd milled	6.30	4.25	4.50	-	-	-	5.16	5.44	5.39

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	4.88	4.94	5.00	4.95	5.03	5.02	4.94	5.04	5.05	4.92	5.01	5.04
Moisture, %	36.59	38.40	38.94	36.70	38.44	38.78	36.89	38.55	38.90	36.56	38.23	38.56
Salt, %	1.60	1.29	1.72	1.48	1.30	1.42	1.43	1.27	1.40	1.46	1.27	1.39
Fat, %	33.30	32.40	32.20	33.70	32.10	31.90	33.80	32.40	32.25	34.45	32.80	32.10

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Dry, curdy	8.8	Slightly weak	9.5	Slightly weak	9.4	Good	9.0	Slightly sticky	8.8	Very good	9.4
Flavour and aroma, (max. 10)	Fair	9.0	Good	9.6	Good	9.6	Good	9.4	Good	9.3	Very good	9.6
Texture, (max. 10)	Slightly short	8.5	Good	9.7	Good	9.7	Short	7.5	Good	9.0	Very good	9.4
Total points scored, (max. 30)		26.3		28.8		28.7		25.9		27.1		28.4

Table 34

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 6

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.136	0.136	0.140	6.71	6.71	6.71
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.152	0.156	0.158	6.63	6.61	6.60
Curd cut	1.15	1.35	1.25	0.110	0.108	0.110	6.59	6.54	6.53
Maximum scald, °F	2.15	2.35	2.25	0.120	0.122	0.128	6.49	6.45	6.45
Curd settled	3.15	2.55	3.05	0.142	0.142	0.154	6.28	6.28	6.19
Whey run	4.00	3.25	3.20	0.238	0.222	0.204	5.86	5.91	5.96
Curd milled	5.10	5.05	5.30	-	-	-	5.35	5.35	5.29

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	4.86	4.90	4.89	4.99	4.98	4.93	4.98	4.95	4.93	4.98	4.95	4.96
Moisture, %	36.71	37.96	38.63	36.54	37.53	38.45	36.82	37.88	38.25	36.71	37.60	37.83
Salt, %	1.47	1.32	1.53	1.41	1.36	1.37	1.23	1.30	1.34	1.36	1.39	1.41
Fat, %	34.50	32.60	32.40	33.80	32.90	32.90	33.75	32.85	32.55	34.35	33.55	33.05

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Fair	9.0	Good	9.5	Sticky	8.5	Very good	9.4	Slightly sticky	8.9	Weak	8.6
Flavour and aroma, (max. 10)	Good	9.4	Good	9.6	Good	9.4	Very good	9.6	Fair	9.0	Fair	9.0
Texture, (max. 10)	Fair	9.2	Good	9.6	Short	8.0	Very good	9.4	Slightly rough	9.0	Poor, short	7.5
Total points scored, (max. 30).		27.6		28.7		25.9		28.4		26.9		25.1

[illegible]

Table 35

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 7

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.152	0.152	0.152	6.69	6.69	6.69
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.162	0.164	0.160	6.58	6.57	6.57
Curd cut	1.25	1.15	1.35	0.114	0.120	0.118	6.52	6.51	6.51
Maximum scald, °F	2.25	2.15	2.35	0.122	0.126	0.136	6.46	6.48	6.41
Curd settled	3.05	3.15	2.55	0.152	0.152	0.142	6.30	6.25	6.33
Whey run	3.35	3.30	3.40	0.200	0.176	0.226	6.05	6.14	5.95
Curd milled	5.45	4.40	5.20	-	-	-	5.29	5.48	5.31

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	4.93	4.99	4.95	5.03	5.07	5.07	4.98	5.04	4.97	5.02	5.06	4.96
Moisture, %	37.85	38.07	38.30	37.82	37.94	38.29	38.02	37.50	38.35	37.58	37.48	37.82
Salt, %	1.30	1.66	1.37	1.43	1.66	1.49	1.37	1.64	1.46	1.45	1.65	1.41
Fat, %	33.70	33.10	33.40	34.00	33.30	33.50	33.65	33.45	33.20	34.20	33.60	34.50

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Good	9.2	Slightly weak	8.8	Good	9.2	Good	9.4	Slightly sticky	9.0	Slightly sticky	8.8
Flavour and aroma, (max. 10)	Good	9.5	Good	9.4	Good	9.5	Good	9.6	Good	9.4	Good	9.5
Texture, (max. 10)	Good	9.6	Slightly open	9.4	Good	9.6	Good	9.4	Slightly rough	9.0	Slightly rough	8.8
Total points scored, (max. 30).		28.3		27.6		28.3		28.4		27.4		27.1

Table 36

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 8

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.146	0.150	0.148	6.69	6.69	6.69
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.162	0.166	0.162	6.59	6.59	6.58
Curd cut	1.25	1.15	1.35	0.114	0.112	0.120	6.53	6.53	6.50
Maximum scald, °F	2.25	2.15	2.35	0.128	0.128	0.126	6.50	6.49	6.47
Curd settled	2.45	2.55	3.35	0.136	0.140	0.162	6.44	6.38	6.20
Whey run	3.30	3.25	3.50	0.180	0.170	0.194	6.13	6.13	6.02
Curd milled	5.40	4.35	5.30	-	-	-	5.39	5.54	5.32

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	4.80	4.88	4.82	5.07	5.10	5.00	5.04	5.05	4.94	5.05	5.08	4.98
Moisture, %	38.00	36.83	38.47	38.06	37.30	38.37	38.09	37.50	38.66	37.80	37.13	37.86
Salt, %	1.59	1.56	1.44	1.43	1.53	1.54	1.37	1.50	1.46	1.42	1.52	1.49
Fat, %	33.40	34.10	33.20	33.30	33.40	33.10	32.15	32.80	32.55	33.75	33.78	33.75

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Slightly weak	9.0	Very good	9.6	Fair	8.8	Slightly sticky	9.0	Very good	9.5	Weak	8.0
Flavour and aroma, (max. 10)	Good	9.8	Very good	9.8	Fair	9.0	Good	9.4	Very good	9.7	Poor, off	8.5
Texture, (10)	Good	9.8	Very good	9.8	Fair	8.8	Good	9.2	Very good	9.6	Very rough	7.0
Total points scored, (max. 30)		28.6		29.2		26.6		27.6		28.8		23.5

Table 37

The effect of variations in the manufacturing process on the composition and quality of Chedder cheese

Day 9

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.148	0.152	0.152	6.67	6.67	6.67
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.162	0.168	0.168	6.54	6.54	6.54
Curd cut	1.25	1.15	1.35	0.120	0.118	0.126	6.47	6.47	6.44
Maximum scald, °F	2.25	2.15	2.35	0.134	0.130	0.146	6.38	6.40	6.30
Curd settled	3.25	2.35	3.15	0.162	0.140	0.166	6.12	6.30	6.13
Whey run	3.40	3.20	3.45	0.232	0.234	0.288	5.90	5.87	5.73
Curd milled	5.50	4.30	5.25	-	-	-	5.16	5.37	5.18

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	4.82	4.82	4.76	4.99	5.05	4.93	4.95	4.97	4.87	4.99	5.01	4.92
Moisture, %	37.01	36.52	37.89	36.57	36.77	37.47	36.69	37.06	37.54	36.26	36.95	36.88
Salt, %	1.57	1.69	1.55	1.47	1.56	1.38	1.51	1.66	1.41	1.45	1.49	1.39
Fat, %	34.60	33.90	33.20	33.90	34.10	33.70	33.10	34.15	33.80	35.10	34.60	34.80

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Good	9.0	Good	9.0	Fair	8.0	Slightly weak	8.5	Fair	9.0	Slightly weak	8.5
Flavour and aroma, (max. 10)	Fair	8.6	Good	9.2	Good	9.0	Fair	8.8	Good	9.2	Slightly off	8.5
Texture, (max. 10)	Slightly short	8.6	Slightly short	9.0	Very short	7.0	Slightly short	8.0	Slightly rough	9.0	Very short	6.5
Total points scored, (max. 30)		26.2		27.2		24.0		25.3		27.2		23.5

Table 38

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 10

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.156	0.150	0.154	6.68	6.68	6.68
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.166	0.166	0.166	6.59	6.57	6.57
Curd cut	1.15	1.35	1.25	0.116	0.118	0.118	6.55	6.51	6.53
Maximum scald, °F	2.15	2.35	2.25	0.122	0.128	0.122	6.48	6.41	6.43
Curd settled	3.15	2.55	3.05	0.152	0.142	0.142	6.33	6.36	6.32
Whey run	3.45	3.10	3.50	0.200	0.170	0.250	6.04	6.18	5.87
Curd milled	5.55	4.20	5.30	-	-	-	5.27	5.54	5.29

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	4.99	5.04	5.00	5.01	5.03	4.98	4.98	5.02	5.01	5.02	5.07	5.01
Moisture, %	37.67	38.08	38.06	37.77	38.26	37.24	37.83	38.57	37.49	37.76	38.37	37.80
Salt, %	1.73	1.49	1.42	1.58	1.43	1.40	1.60	1.42	1.52	1.62	1.41	1.45
Fat, %	32.90	32.50	31.90	32.40	32.60	32.40	32.95	32.70	32.90	32.85	32.35	33.10

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Slightly sticky	9.0	Good	9.4	Slightly sticky	9.0	Good	9.4	Good	9.6	Slightly weak	9.0
Flavour and aroma, (max. 10)	Fair	9.2	Good	9.4	Good	9.4	Good	9.4	Good	9.6	Good	9.4
Texture, (max. 10)	Slightly rough	9.0	Good	9.4	Slightly short	8.8	Good	9.4	Very good	9.7	Slightly short	8.8
Total points scored, (max. 30)		27.2		28.2		27.2		28.2		28.9		27.2

Table 39

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 11

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.154	0.152	0.148	6.68	6.68	6.68
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.162	0.164	0.160	6.60	6.59	6.60
Curd set	1.35	1.25	1.15	0.118	0.118	0.118	6.52	6.55	6.55
Maximum scald, °F	2.35	2.25	2.15	0.134	0.130	0.134	6.42	6.44	6.43
Curd settled	3.15	3.25	2.35	0.158	0.168	0.144	6.23	6.16	6.32
Whey run	3.45	3.40	3.20	0.242	0.218	0.242	5.89	6.01	5.88
Curd milled	4.55	5.20	5.30	-	-	-	5.37	5.38	5.34

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	4.89	4.94	4.92	4.96	4.97	4.95	4.95	5.03	4.99	4.95	5.01	4.96
Moisture, %	38.35	36.94	37.24	37.71	37.28	37.04	38.26	37.07	37.30	37.86	36.60	37.22
Salt, %	1.56	1.52	1.46	1.48	1.45	1.40	1.54	1.45	1.36	1.53	1.42	1.46
Fat, %	32.20	33.80	33.80	33.10	33.20	33.60	33.20	33.50	34.10	33.75	34.20	34.40

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Fair	8.0	Good	9.2	Fair	8.4	Fair	9.0	Fair	9.0	Weak	6.5
Flavour and aroma, (max. 10)	Good	9.0	Good	9.4	Good	9.2	Good	9.4	Good	9.2	Fair	8.8
Texture, (max. 10)	Short	7.0	Slightly rough	8.8	Short	7.0	Slightly short	7.3	Short	8.5	Very short	6.5
Total poinsts scored, (max. 30)		24.0		27.4		24.6		25.7		26.7		23.8

Table 40

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 12

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.144	0.144	0.148	6.69	6.69	6.69
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.156	0.164	0.160	6.60	6.59	6.59
Curd cut	1.35	1.25	1.15	0.116	0.114	0.120	6.54	6.54	6.55
Maximum scald, °F	2.35	2.25	2.15	0.136	0.126	0.134	6.44	6.45	6.48
Curd settled	2.55	3.05	3.15	0.146	0.150	0.156	6.34	6.27	6.22
Whey run	3.25	3.20	4.00	0.200	0.184	0.264	6.04	6.09	5.83
Curd milled	5.35	4.30	5.40	-	-	-	5.39	5.63	5.34

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	4.93	5.03	5.00	5.02	5.06	5.00	5.04	5.07	4.98	5.02	5.11	5.03
Moisture, %	38.55	37.45	37.45	38.12	38.21	37.61	38.22	37.48	37.11	37.27	37.30	36.91
Salt, %	1.29	1.61	1.39	1.53	1.55	1.46	1.49	1.46	1.48	1.48	1.47	1.43
Fat, %	31.40	31.40	33.20	31.60	31.90	32.80	32.45	33.55	33.25	32.85	34.05	33.90

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Slightly sticky	9.0	Good	9.4	Slightly sticky	9.0	Slightly sticky	9.0	Very good	9.5	Good	9.2
Flavour and aroma, (max. 10)	Good	9.6	Good	9.5	Good	9.4	Very good	9.5	Very good	9.6	Good	9.4
Texture, (max. 10)	Good	9.5	Good	9.5	Rough	9.0	Good	9.2	Very good	9.6	Slightly rough	9.0
Total points scored, (max. 30).		28.1		28.4		27.4		27.7		28.7		27.6

[illegible]

Table 41

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 13

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.148	0.150	0.144	6.68	6.67	6.68
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.156	0.162	0.156	6.60	6.58	6.57
Curd cut	1.35	1.25	1.15	0.116	0.114	0.110	6.50	6.53	6.54
Maximum scald, °F	2.35	2.25	2.15	0.130	0.122	0.120	6.45	6,48	6.49
Curd settled	3.35	2.45	2.55	0.162	0.132	0.134	6.26	6.44	6.40
Whey run	4.05	3.00	3.40	0.232	0.152	0.198	5.93	6.29	6.05
Curd milled	5.45	5.10	4.50	-	-	-	5.22	5.45	5.45

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.10	5.24	5.27	4.98	5.04	5.07	4.96	5.03	5.09	4.96	5.05	5.12
Moisture, %	37.51	38.03	36.03	37.32	38.06	36.36	37.34	37.79	36.57	36.84	37.74	36.28
Salt, %	1.49	1.39	1.68	1.43	1.41	1.66	1.43	1.44	1.72	1.48	1.43	1.69
Fat, %	33.70	33.70	34.30	34.60	33.70	34.60	34.00	33.15	33.70	34.85	33.80	34.70

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Very sticky	8.0	Very Slightly weak	9.2	Slightly weak	9.0	Slightly sticky	8.5	Good	9.4	Slightly sticky	9.0
Flavour and aroma, (max. 10)	Good	9.2	Good	9.5	Good	9.5	Fair	9.0	Good	9.6	Good	9.4
Texture, (max. 10)	Short	7.0	Good	9.4	Good	9.4	Short	7.0	Good	9.5	Slightly rough	9.2
Total points scored, (max. 30)		24.2		28.1		27.9		24.5		28.5		27.6

Table 42

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 14

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.150	0.144	0.144	6.68	6.69	6.69
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.160	0.162	0.160	6.58	6.58	6.58
Curd cut	1.15	1.35	1.25	0.112	0.114	0.110	6.53	6.51	6.51
Maximum scald, °F	2.15	2.35	2.25	0.124	0.130	0.128	6.47	6.43	6.44
Curd settled	2.55	3.35	2.45	0.140	0.160	0.132	6.36	6.19	6.39
Whey run	3.40	4.05	3.00	0.216	0.252	0.164	5.97	5.85	6.19
Curd milled	5.50	5.15	4.40	-	-	-	5.30	5.31	5.44

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.09	5.06	5.17	5.00	4.99	5.00	5.04	4.99	5.06	5.08	5.03	5.10
Moisture, %	35.86	36.20	37.13	35.57	35.41	37.06	36.00	35.77	37.18	35.77	35.29	37.08
Salt, %	1.49	1.34	1.59	1.45	1.39	1.60	1.53	1.36	1.60	1.47	1.38	1.55
Fat, %	35.60	35.80	34.10	34.70	34.50	32.40	34.90	34.85	34.45	35.70	36.50	34.35

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Slightly sticky	9.0	Good	9.0	Good	9.2	Fair	9.0	Good	9.3	Sticky	8.5
Flavour and aroma, (max. 10)	Fair	9.0	Bitter	8.0	Good	9.4	Slightly off	9.0	Slightly off	9.0	Slightly off	8.8
Texture, (max. 10)	Slightly rough	9.0	Short	7.0	Good	9.4	Slightly rough	8.8	Slightly rough	9.0	Good	9.2
Total points scored, (max. 30)		27.0		24.0		28.0		26.8		27.3		26.5

Table 43

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 15

Operation	Time, H min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.142	0.144	0.142	6.69	6.69	6.69
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.156	0.156	0.156	6.58	6.58	6.58
Curd cut	1.25	1.15	1.35	0.116	0.114	0.110	6.54	6.55	6.54
Maximum scald, °F	2.25	2.15	2.35	0.120	0.118	0.124	6.48	6.49	6.46
Curd settled	3.25	2.35	3.15	0.146	0.126	0.144	6.28	6.43	6.34
Whey run	4.10	3.05	3.30	0.272	0.158	0.174	5.75	6.26	6.13
Curd milled	5.50	5.15	4.40	-	-	-	5.15	5.37	5.43

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.04	5.13	5.22	4.92	5.02	5.03	4.94	5.05	5.10	5.00	5.08	5.11
Moisture, %	36.42	36.32	37.71	36.43	37.65	36.45	36.56	37.63	36.77	36.05	37.55	36.42
Salt, %	1.30	1.38	1.52	1.43	1.43	1.43	1.35	1.34	1.30	1.39	1.40	1.38
Fat, %	34.70	34.10	33.70	34.45	33.80	33.25	34.45	33.80	33.70	35.15	34.20	34.40

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Fair	9.0	Fair	8.0	Good	9.4	Good	9.0	Good	9.4	Good	9.2
Flavour and aroma, (max. 10)	Good	9.0	Fair	8.5	Good	9.5	Good	9.4	Good	9.6	Good	9.5
Texture, (max. 10)	Fair	9.0	Fair	8.0	Good	9.4	Slightly short	8.5	Good	9.4	Good	9.2
Total points scored, (max. 30)		27.0		24.5		28.3		26.9		28.4		27.9

[illegible]

Table 44

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 16

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.148	0.144	0.146	6.68	6.67	6.67
Starter added	0.0	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.154	0.160	0.158	6.59	6.58	6.58
Curd cut	1.25	1.15	1.35	0.112	0.116	0.118	6.54	6.54	6.52
Maximum scald, °F	2.25	2.15	2.35	0.128	0.124	0.132	6.44	6.47	6.42
Curd settled	3.05	3.15	2.55	0.138	0.154	0.142	6.28	6.23	6.34
Whey run	3.50	3.45	3.10	0.244	0.226	0.180	5.86	5.92	6.13
Curd milled	5.00	5.25	5.20	-	-	-	5.39	5.35	5.42

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.16	5.16	5.13	4.97	4.95	4.94	5.02	5.00	5.03	5.03	5.04	5.01
Moisture, %	35.74	35.85	38.01	35.15	35.72	37.63	35.38	35.65	37.78	35.13	35.47	37.39
Salt, %	1.45	1.44	1.34	1.53	1.39	1.26	1.44	1.32	1.20	1.45	1.38	1.28
Fat, %	34.40	34.00	33.10	35.35	34.95	34.20	35.30	35.10	34.25	35.25	35.65	33.95

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Slightly sticky	9.0	Good	9.4	Weak	8.0	Good	9.2	Good	9.4	Slightly sticky	8.8
Flavour and aroma, (max. 10)	Fair	9.0	Good	9.4	Good	9.2	Good	9.5	Good	9.5	Good	9.5
Texture, (max. 10)	Slightly rough	9.0	Good	9.5	Fair	9.0	Good	9.2	Good	9.4	Slightly rough	9.0
Total points scored, (max. 30)		27.0		28.3		26.2		27.9		28.3		27.3

[illegible]

Table 45

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 17

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.136	0.138	0.140	6.69	6.69	6.69
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.150	0.152	0.158	6.61	6.60	6.60
Curd cut	1.15	1.35	1.25	0.114	0.116	0.110	6.56	6.52	6.52
Maximum scald, °F	2.15	2.35	2.25	0.122	0.130	0.130	6.49	6.43	6.42
Curd settled	2.35	3.15	3.25	0.132	0.158	0.160	6.41	6.29	6.20
Whey run	3.20	3.45	3.40	0.182	0.212	0.206	6.15	6.01	6.02
Curd milled	5.00	5.55	4.50	-	-	-	5.55	5.38	5.39

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.16	5.12	5.11	5.06	4.97	4.92	5.13	5.02	5.00	5.16	5.07	5.04
Moisture, %	37.54	37.66	38.62	37.82	37.83	38.40	38.01	37.77	38.16	37.52	37.58	37.78
Salt, %	1.40	1.33	1.73	1.55	1.45	1.56	1.39	1.62	1.43	1.47	1.39	1.55
Fat, %	33.00	33.50	32.50	33.10	32.85	33.05	32.60	33.65	32.85	32.80	33.95	33.65

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Slightly weak	8.5	Good	9.2	Weak	8.0	Weak	8.0	Fair	8.8	Fair	8.6
Flavour and aroma, (max. 10)	Good	9.0	Good	9.0	Good	9.0	Slightly off	8.4	Fair	8.8	Fair	8.6
Texture, (max. 10)	Good	9.2	Good,	9.2	Short	8.0	Fair	9.0	Fair	9.0	Slightly short	8.4
Total points scored, (max. 30)		26.7		27.4		25.0		25.4		26.6		25.6

Table 46

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 18

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.150	0.146	0.146	6.69	6.69	6.69
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.158	0.160	0.160	6.60	6.59	6.59
Curd cut	1.25	1.15	1.35	0.110	0.114	0.116	6.55	6.55	6.54
Maximum scald, °F	2.25	2.15	2.35	0.126	0.122	0.130	6.48	6.49	6.44
Curd settled	2.45	2.55	3.35	0.132	0.136	0.164	6.39	6.33	6.18
Whey run	3.00	3.40	4.05	0.158	0.198	0.244	6.24	6.03	5.82
Curd milled	4.10	5.20	6.15	-	-	-	5.64	5.34	5.19

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.10	5.05	5.02	5.12	5.05	4.98	5.11	5.11	5.01	5.04	5.08	4.93
Moisture, %	37.63	35.58	38.88	38.36	35.74	36.95	38.42	35.71	37.18	38.06	35.52	36.40
Salt, %	1.24	1.39	1.41	1.42	1.45	1.38	1.30	1.35	1.27	1.34	1.42	1.37
Fat, %	33.58	34.20	33.60	33.20	34.80	34.50	33.00	34.35	33.75	34.60	34.95	34.80

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Good	9.2	Good	9.6	Fair	8.0	Slightly sticky	8.6	Good	9.5	Slightly weak	8.0
Flavour and aroma, (max. 10)	Good	9.2	Good	9.6	Good	9.0	Good	9.5	Good	9.5	Fair	8.5
Texture, (max. 10)	Good	9.2	Good	9.5	Very short	6.0	Good	9.2	Very slightly rough	9.2	Short	7.5
Total points scored, (max. 30)		27.6		28.7		23.0		27.3		28.2		24.0

Table 47

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 19

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.152	0.148	0.148	6.67	6.68	6.68
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.158	0.160	0.162	6.59	6.60	6.60
Curd cut	1.15	1.35	1.25	0.114	0.118	0.116	6.53	6.51	6.51
Maximum scald, °F	2.15	2.35	2.25	0.128	0.132	0.128	6.46	6.43	6.44
Curd settled	3.15	2.55	3.05	0.160	0.144	0.154	6.28	6.35	6.29
Whey run	3.30	3.40	3.35	0.198	0.232	0.228	6.07	5.92	5.94
Curd milled	5.10	5.50	4.45	-	-	-	5.34	5.22	5.37

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.07	5.06	5.11	5.05	4.91	4.97	5.07	5.05	5.07	5.06	5.01	5.01
Moisture, %	35.89	36.82	37.88	36.84	36.66	37.09	36.41	36.71	37.04	36.15	36.91	36.88
Salt, %	1.41	1.36	1.66	1.49	1.34	1.28	1.32	1.29	1.25	1.45	1.33	1.31
Fat, %	35.00	33.90	32.90	34.35	34.10	33.90	34.05	34.10	33.90	35.30	34.70	34.50

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Good	9.4	Weak	8.0	Good	9.2	Slightly sticky	8.8	Weak	8.0	Fair	8.8
Flavour and aroma, (max. 10)	Good	9.4	Slightly sour	8.5	Good	9.2	Fruity	8.8	Sour	8.0	Slightly fruity	9.0
Texture, (max. 10)	Good	9.4	Short	6.5	Good	9.4	Fair	9.0	Very short	6.5	Slightly short	8.6
Total points scored, (max. 30).		28.2		23.0		27.8		26.6		22.5		26.4

Table 48

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 20

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.148	0.146	0.150	6.68	6.68	6.68
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.162	0.158	0.162	6.57	6.57	6.58
Curd cut	1.35	1.25	1.15	0.114	0.112	0.114	6.54	6.55	6.55
Maximum scald, °F	2.35	2.25	2.15	0.128	0.122	0.126	6.48	6.48	6.50
Curd settled	3.35	2.45	2.55	0.146	0.128	0.136	6.29	6.44	6.39
Whey run	3.50	3.30	3.25	0.180	0.178	0.180	6.14	6.16	6.13
Curd milled	5.00	5.10	5.35	-	-	-	5.39	5.41	5.37

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.12	5.14	5.11	5.02	5.04	5.04	5.07	5.10	5.08	5.06	5.09	5.07
Moisture, %	36.58	36.85	36.41	36.32	36.99	37.15	36.35	37.07	36.63	36.46	36.83	36.61
Salt, %	1.26	1.57	1.65	1.40	1.44	1.50	1.28	1.36	1.37	1.34	1.41	1.40
Fat, %	33.80	33.80	34.10	34.30	34.05	33.05	34.15	33.35	33.85	34.75	33.60	34.65

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Slightly sticky	9.2	Slightly weak	8.8	Good	9.5	Good	9.5	Slightly sticky	9.0	Good	9.4
Flavour and aroma, (max. 10)	Good	9.4	Fair	9.0	Good	9.5	Good	9.6	Good	9.4	Good	9.6
Texture, (max. 10)	Good	9.4	Good	9.0	Good	9.5	Good	9.5	Good	9.5	Good	9.5
Total points scored, (max. 30)		28.0		26.8		28.5		28.6		27.9		28.5

[illegible]

Table 49

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 21

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.146	0.148	0.146	6.68	6.68	6.68
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.158	0.164	0.166	6.60	6.59	6.59
Curd cut	1.35	1.25	1.15	0.116	0.116	0.118	6.52	6.53	6.53
Maximum scald, °F	2.35	2.25	2.15	0.132	0.124	0.132	6.43	6.47	6.49
Curd settled	2.55	3.05	3.15	0.142	0.150	0.154	6.35	6.28	6.24
Whey run	3.40	3.35	3.30	0.218	0.212	0.192	5.97	6.00	6.07
Curd milled	4.50	5.15	5.40	-	-	-	5.43	5.34	5.33

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.19	5.15	5.10	5.06	5.02	5.05	5.04	5.02	5.01	5.02	4.99	5.02
Moisture, %	36.60	36.76	36.77	36.97	37.13	36.68	36.91	37.21	36.73	37.10	36.96	36.76
Salt, %	1.41	1.45	1.18	1.41	1.41	1.26	1.26	1.25	1.16	1.39	1.36	1.25
Fat, %	33.40	34.50	34.00	33.10	33.20	33.40	33.95	33.90	34.45	33.85	34.40	34.45

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Slightly sticky	8.9	Slightly weak	8.0	Slightly weak	8.4	Good	9.6	Slightly sticky	9.0	Good	9.2
Flavour and aroma, (max. 10)	Good	9.4	Good	9.2	Good	9.2	Good	9.4	Good	9.4	Fair	9.2
Texture, (max. 10)	Good	9.3	Short	7.8	Slightly rough	7.9	Good	9.6	Slightly rough	9.0	Good	9.3
Total points scored, (max. 30)		27.6		25.0		25.5		28.6		27.4		27.7

[illegible]

Table 50

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 22

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	-	-	-	6.67	6.67	6.67
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	-	-	-	6.60	6.60	6.59
Curd cut	1.25	1.15	1.35	-	-	-	6.53	6.54	6.51
Maximum scald, °F	2.25	2.15	2.35	0.122	0.128	0.134	6.47	6.49	6.45
Curd settled	3.05	3.15	2.55	0.144	0.148	0.140	6.38	6.30	6.39
Whey run	3.20	4.00	3.25	0.162	0.236	0.176	6.23	5.93	6.17
Curd milled	5.00	6.10	4.35	-	-	-	5.46	5.24	5.55

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.14	5.09	5.20	5.02	4.91	4.99	5.07	4.95	5.03	5.15	4.92	5.02
Moisture, %	37.53	38.38	39.69	37.60	37.84	38.91	37.80	37.81	38.91	37.30	37.52	38.69
Salt, %	1.21	1.56	1.52	1.44	1.48	1.35	1.34	1.38	1.32	1.43	1.46	1.36
Fat, %	33.10	33.30	32.40	33.10	33.35	32.25	32.30	33.70	33.10	33.40	33.95	32.90

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Good	9.2	Weak	7.5	Weak	8.0	Very slightly weak	9.3	Slightly weak	8.5	Slightly sticky	8.8
Flavour and aroma, (max. 10)	Good	9.4	Fair	9.0	Good	9.2	Good	9.5	Good	9.4	Good	9.4
Texture, (max. 10)	Good	9.4	Very short	6.5	Slightly rough	8.4	Good	9.5	Slightly short	7.8	Very slightly rough	9.2
Total points scored, (max. 30)		28.0		23.0		25.6		28.3		25.7		27.4

Table 51

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 23

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.148	0.148	0.150	6.68	6.68	6.68
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.160	0.168	0.170	6.59	6.57	6.57
Curd cut	1.35	1.25	1.15	0.120	0.114	0.120	6.52	6.51	6.52
Maximum scald, °F	2.35	2.25	2.15	0.136	0.136	0.134	6.44	6.44	6.45
Curd settled	3.15	3.25	2.35	0.160	0.168	0.142	6.28	6.18	6.36
Whey run	3.30	4.10	3.05	0.196	0.320	0.188	6.06	5.65	6.11
Curd milled	5.40	5.20	4.45	-	-	-	5.24	5.22	5.36

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.05	5.02	5.05	4.96	4.91	4.97	5.02	4.95	5.01	5.01	4.94	5.06
Moisture, %	38.04	36.76	38.14	38.52	37.07	38.36	38.48	36.82	38.32	38.23	36.48	38.16
Salt, %	1.36	1.64	1.32	1.39	1.53	1.32	1.26	1.43	1.24	1.32	1.51	1.31
Fat, %	31.90	34.10	33.30	33.30	34.15	33.20	33.30	33.75	33.15	33.65	34.50	33.60

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Weak	7.8	Weak	8.0	Slightly sticky	8.8	Slightly weak	8.5	Slightly weak	8.5	Good	9.4
Flavour and aroma, (max. 10)	Fair	8.6	Fair	8.9	Good	9.4	Fair	8.8	Good	9.2	Good	9.5
Texture, (max. 10)	Very short	7.0	Very short	6.0	Very slightly rough	9.0	Slightly short	8.0	Short	6.0	Very slightly rough	9.4
Total points scored, (max. 30)		23.4		22.9		27.2		25.3		23.7		28.3

Table 52

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 24

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.146	0.150	0.150	6.68	6.67	6.68
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.162	0.170	0.162	6.59	6.58	6.59
Curd cut	1.15	1.35	1.25	0.118	0.120	0.120	6.53	6.51	6.52
Maximum scald, °F	2.15	2.35	2.25	0.128	0.136	0.132	6.47	6.43	6.45
Curd settled	2.55	3.35	2.45	0.138	0.160	0.140	6.38	6.23	6.41
Whey run	3.25	3.50	3.30	0.186	0.208	0.206	6.14	6.06	6.05
Curd milled	5.05	6.00	4.40	-	-	-	5.35	5.20	5.41

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.02	5.04	5.08	5.04	4.98	5.02	4.99	4.92	4.97	5.04	4.98	5.03
Moisture, %	38.35	38.95	38.60	38.36	38.71	38.69	38.55	38.57	38.73	38.14	38.01	37.79
Salt, %	1.35	1.66	1.47	1.34	1.40	1.38	1.32	1.43	1.34	1.28	1.39	1.32
Fat, %	33.50	32.40	33.30	33.60	32.85	33.15	34.00	33.80	33.45	33.95	33.35	33.35

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Sticky	8.0	Weak	8.0	Slightly sticky	8.2	Slightly weak	8.8	Slightly weak	8.5	Good	9.5
Flavour and aroma, (max. 10)	Good	9.0	Fair	8.8	Good	9.1	Good	9.5	Good	9.4	Good	9.6
Texture, (max. 10)	Slightly short	8.4	Very short	6.0	Slightly short	8.4	Very slightly rough	9.4	Poor, very short	6.0	Good	9.4
Total points scored, (max. 30)		25.4		22.8		25.7		27.7		23.9		28.5

Table 55

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 25

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.142	0.146	0.150	6.68	6.68	6.68
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.162	0.162	0.162	6.60	6.59	6.59
Curd cut	1.25	1.15	1.35	0.118	0.116	0.122	6.55	6.54	6.52
Maximum scald, °F	2.25	2.15	2.35	0.124	0.124	0.134	6.50	6.49	6.46
Curd settled	3.25	2.35	3.15	0.154	0.134	0.154	6.30	6.42	6.33
Whey run	3.55	2.50	4.00	0.228	0.158	0.254	5.97	6.35	5.88
Curd milled	5.05	4.30	6.10	-	-	-	5.38	5.54	5.28

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.14	5.14	5.08	5.03	5.07	4.97	5.00	5.07	4.95	5.03	5.08	4.96
Moisture, %	35.52	37.90	36.91	36.12	37.72	37.15	35.69	37.77	37.09	35.98	37.74	37.14
Salt, %	1.53	1.37	1.52	1.58	1.34	1.52	1.57	1.32	1.48	1.48	1.30	1.47
Fat, %	34.40	32.70	33.80	33.90	33.75	33.50	34.95	33.10	34.45	34.45	33.20	34.30

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Good	9.4	Weak	8.0	Body	8.0	Slightly stick	9.2	Slightly weak	9.2	Sticky	8.5
Flavour and aroma, (max. 10)	Good	9.4	Fair	9.0	Good	9.0	Good	9.6	Good	9.6	Good	9.4
Texture, (max. 10)	Good	9.2	Slightly rough	8.8	Very short	5.5	Slightly rough	9.4	Good	9.6	Short	7.5
Total points scored, (max. 30)		28.0		25.8		22.5		28.2		28.4		25.4

Table 54

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 26

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.152	0.154	0.152	6.68	6.68	6.68
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.160	0.168	0.170	6.60	6.58	6.57
Curd cut	1.15	1.35	1.25	0.120	0.126	0.124	6.54	6.51	6.52
Maximum scald, °F	2.15	2.35	2.25	0.130	0.132	0.136	6.48	6.46	6.46
Curd settled	2.35	3.15	3.25	0.138	0.156	0.170	6.42	6.31	6.23
Whey run	3.05	3.30	4.10	0.174	0.184	0.300	6.24	6.14	5.73
Curd milled	4.15	5.10	6.20	-	-	-	5.57	5.36	5.16

Cheese analyses

Age of cheese	1 day			21 day			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.18	5.07	5.03	5.12	5.04	4.96	5.12	5.04	4.94	5.15	5.09	4.98
Moisture, %	36.73	37.45	36.73	37.24	37.40	36.67	37.13	37.21	36.57	36.84	36.48	36.58
Salt, %	1.41	1.22	1.39	1.34	1.25	1.35	1.36	1.25	1.38	1.29	1.22	1.34
Fat, %	33.50	33.10	33.60	33.20	33.00	33.05	33.55	33.60	34.45	33.50	34.30	34.50

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Slightly weak	8.5	Good	9.2	Fair	8.0	Weak, sticky	8.5	Slightly weak	9.0	Weak	8.5
Flavour and aroma, (max. 10)	Fair	8.8	Good	9.2	Fair	8.8	Fair	9.0	Fair	9.2	Slightly off	8.5
Texture, (max. 10)	Good	9.0	Good	9.0	Very short	6.2	Good	9.4	Very slightly rough	9.2	Very short	5.5
Total points scored, (max. 30)		26.3		27.4		23.0		26.9		27.4		22.5

Table 55

The effect of variations in the manufacturing process on the composition and quality of Cheddar cheese

Day 27

Operation	Time, h min			Titratable acidity, % lactic acid			pH		
Vat no.	1	2	3	1	2	3	1	2	3
Milk	-	-	-	0.154	0.152	0.152	6.68	6.68	6.68
Starter added	0.00	0.00	0.00	-	-	-	-	-	-
Rennet added	0.45	0.45	0.45	0.162	0.164	0.164	6.59	6.58	6.57
Curd cut	1.15	1.35	1.25	0.118	0.114	0.122	6.55	6.53	6.53
Maximum scald, °F	2.15	2.35	2.25	0.128	0.130	0.130	6.48	6.44	6.47
Curd settled	2.55	3.35	2.45	0.140	0.156	0.136	6.39	6.30	6.42
Whey run	3.10	4.20	3.15	0.154	0.225	0.172	6.30	5.95	6.22
Curd milled	4.20	6.00	5.24	-	-	-	5.68	5.44	5.48

Cheese analyses

Age of cheese	1 day			21 days			8 weeks			16 weeks		
Vat no.	1	2	3	1	2	3	1	2	3	1	2	3
pH	5.21	5.16	5.13	5.17	5.10	5.15	5.13	5.02	5.02	5.16	5.08	5.08
Moisture, %	38.06	35.71	38.08	37.97	35.78	37.99	38.00	36.16	38.39	38.23	35.93	37.77
Salt, %	1.49	1.47	1.37	1.61	1.46	1.29	1.61	1.49	1.35	1.51	1.48	1.28
Fat, %	31.60	33.10	32.40	32.05	33.50	32.40	32.55	33.00	32.40	31.95	33.45	32.60

Grader's examination

	Remarks and points scored											
	8 weeks						16 weeks					
Vat no.	1		2		3		1		2		3	
Body, (max. 10)	Very weak	7.5	Good	9.0	Slightly weak	9.0	Slightly sticky	8.8	Good	9.6	Slightly weak	9.0
Flavour and aroma, (max. 10)	Fair	8.8	Good	9.0	Good	9.4	Good	9.4	Good	9.6	Good	9.5
Texture, (max. 10)	Slightly rough	8.5	Slightly rough	8.8	Good	9.2	Good	9.4	Good	9.5	Good	9.4
Total points scored, (max. 30)		24.8		26.8		27.6		27.6		28.7		27.9

APPENDIX B

Statistical terms used in this work

STATISTICAL TERMS USED IN THIS WORK

Standard deviation

The most important measure of dispersion is the standard deviation which is denoted by the Greek letter σ. The standard deviation is easily calculated and its usefulness may be explained as follows:

If one has any distribution, i.e. the heights of men or the moisture contents of cheese, which is reasonably symmetrical about its average and which is unimodal then one would make very little error in assuming that two-thirds of the distribution lies less than one standard deviation away from the mean, that 95% of the distribution lies less than two standard deviations away from the mean, and that less than 1% of the distribution lies more than three standard deviations away from the mean.

One may have distributions with the same standard deviation or spread but different mean values and distributions with the same mean, but different standard deviations.

The standard error of the mean, $\sigma/\sqrt{n}$, where n is the number of items, has a useful application where one is dealing with large samples. A numerical example (Moroney, 1963) may help to explain its application. Suppose that from the heights of 90,000 men measured for the army medical examination one finds that the distribution for the heights of individual men had a mean value of 67.5 with a standard deviation of 2.62 inches. To ascertain how close the mean value was to the true value one calculates $\sigma/\sqrt{n}$,

$$\sigma/\sqrt{n} = 2.62/\sqrt{90,000} = 0.0087 \text{ in.}$$

One should be pretty confident that the true result for the whole population of the country in this age group, did not lie more than two

standard deviations i.e. 2 x 0.0087 = 0.0174 in. away from the average value found and almost certain that it was not more than three standard deviations, 0.0261 in. away from the average value.

Correlation coefficient

"No quantity has been more characteristic of biometrical work than the correlation coefficient, and no method has been applied to such various data as the method of correlation" (Fisher, 1950).

If one has a set of points (x,y) plotted and they show a trend, one may say that the variable quantity x and y are correlated. This means that although there is not a strictly functional relation between them one can make a prediction of the value of y given a knowledge of the value of x. Where an increasing value of y is associated with an increasing value of x one cay say that the two variables are positively correlated. When an increase in value of x results in a decrease in the value of y, the variables are said to be negatively correlated.

The correlation coefficient, r, cannot exceed +1 or be less than -1 in value. When r is equal to +1, this denotes perfect functional relationship between y and x, an increasing x being associated with an increasing y. When r is equal to 0, x and y are not correlated. Values intermediate between +1 and -1 indicate that while there is not a strictly functional relationship between x and y, there is a trend. When r is positive, increasing x tends to be associated with increasing y and if r is negative, increasing x tends to be associated with decreasing y.

Having calculated the correlation coefficient one might wish to calculate an equation between y and x i.e. a regression equation. This regression equation takes the form,

$$y = a \pm bx$$

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

where a is a constant and b is known as the regression coefficient of y on x. This equation may be used to estimate a value for y from a given value of x. Because the regression line gives only a 'best estimate' of the value of the quantity in question it may be necessary to assess the degree of uncertainty in the estimate by calculating the <u>Standard Error of Estimate</u>. This is given by,

$$Sy = \sigma y \sqrt{1 - r^2}$$

$$\text{or} \quad Sx = \sigma x \sqrt{1 - r^2}$$

depending whether we are estimating y or x.

When one has calculated Sy or Sx one may say that in about 95% of cases the actual values will lie within plus or minus two standard errors of the estimate values given by the regression equation and that almost without exception actual values will be found to depart from the estimated value by not more than three standard errors.

In certain experiments estimations may be very rough because it is only when the correlation coefficient is very high that estimation can be at all precise.

Usually one wishes to know whether the observed correlation coefficient could have arisen by chance with fair probability in a sample of the size dealt with. This may be tested using tables of the distribution of Student's t, by calculating the quantity,

$$t = r\sqrt{N - 2} / \sqrt{1 - r^2},$$

where N is the number of samples, and entering the tables with N - 2 degrees of freedom.

A numerical example would be as follows:

If t = 9 with 16 degrees of freedom one may conclude that the observed value of r is extremely significant.

If N is large, e.g. not less than 100, and provided the value of r is small one may regard the standard error of the correlation coefficient as,

$$\text{Standard error of } r = 1 - r^2/\sqrt{N}$$

For example if one found that $r = 0.2$ and $N = 400$ then the standard error of $r = 0.048$. The observed value of r is four times its standard error, and so definitely significant. (According to Fisher (1950), "it is a convenient convention to take twice the standard error as the limit of significance").

Significance

In statistical analysis the word "significance" invariably is mentioned as for example in the above discussion on the correlation coefficient, r. When one obtains a result which is very unlikely to have arisen by chance one says that the result is statistically significant. The degrees of significance are indicated as, Probably Significant, Significant or Highly Significant. A result that would only arise in one trial in twenty on the basis of pure chance one could describe as Probably Significant; a result that would arise on the basis of pure chance only one in a hundred trials one could describe as Significant and a result that would arise on the basis of pure chance only once in a thousand trials one could describe as Highly Significant. It is usual however, to denote the level of probability as, $P = 0.05$, $P = 0.01$ or $P = 0.001$ i.e. significant at the 5%, 1% or 0.1% levels.

Variance Ratio

The variance ratio is defined as,

$$F = \frac{\text{greater estimate of the variance of the population}}{\text{lesser estimate of the variance of the population}}$$

the variance being σ^2 or the square of the standard deviation. In a test for significance one has to calculate the value of F and also the numbers of items in the two samples whose variances are being compared. From tables

which have been drawn up showing the value of F for various sample sizes one can ascertain the degree of probability and record the result as for example $P < 0.05$.