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The Effects of Added Dry Whey on Yield and Acceptability of Cheddar Cheese

James M. Wingfield

THE EFFECTS OF ADDED DRY WHEY ON YIELD AND ACCEPTABILITY OF CHEDDAR CHEESE

BY

JAMES M. WINGFIELD

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser Date

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To my wife, Kathy, who always listened and to my parents who instilled in me the value of a good education, this thesis is dedicated.

JMW

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INTRODUCTION

Cheese production and sales are a major part of the U. S. dairy industry. Total hard cheese sales have increased 60% in the past 10 yr. Per capita consumption of cheese for the same period has risen from 2.81 kilograms (kg) to 4.03 kg for a 43% increase. In response to greater consumer demand the amount of milk utilized in cheese production has increased markedly during the past quarter century, rising from the low of 10% of annual milk production in 1950 to 24% in 1976.

This recent increase in cheese production emphasizes the importance of achieving maximum yields of cheese from milk used. The economic burden resulting from increased labor and packing costs make it even more imperative that the greatest possible yields be obtained. Ironically, the current lower solids in milk (2) are resulting in less than 9 to 10% cheese yields from milk that was common 20 yr ago.

Attendant to more cheese being manufactured to meet consumer demands, more whey is being produced as a by-product. Whey has often been discarded; its bulk and low solids content make transport any distance uneconomical and promote lack of usage. Because of the large Biochemical Oxygen Demand (BOD), disposal of whey by dumping into lakes, streams, rivers, or pits has been forbidden by the Environmental Protection Agency; and discharging through the municipal sewage system has resulted in extraordinarily high sewage treatment costs for most cheese plants. This situation has led the dairy industry to seek and consider new ways of utilizing the nutritional and/or functional properties of whey and its components.

The total solids contents of milk approaches 13%; that in whey is 6.3%. Liquid whey contains approximately 4.7% lactose, 0.9% protein, 0.5% ash, and 0.2% lactic acid (29, 71). The whey produced in 1975 alone contained 675 million kg of lactose, 135 million kg of protein, 108 million kg of ash, and 27 million kg of lactic acid.

To recover these solids, whey has been concentrated by reverse osmosis or boiling under vacuum; fractionated by ultrafiltration or electrodialysis; or dried. According to the United States Department of Agriculture (USDA), U. S. whey powder production almost doubled from 183 million kg in 1965 to 347 million kg in 1975. Per capita consumption of dried whey jumped, for a 315% increase, from 0.13 kg in 1960 to 0.54 kg in 1973 (72). The uses for whey are numerous; but by far the two largest users are the dairy and bakery industries which used 32 and 25%, respectively, of all dry whey produced in 1976 (74). However, only one-half of all whey produced is used; hence, new ways of utilizing whey would be distinctly advantageous to the cheese industry.

One objective of this research was to find a process to utilize dry whey powder to increase yields of cheddar cheese. Another objective was to determine whether this addition would affect the curing process and especially if the cheese would meet federal compositional standards and be of satisfactory flavor and body after curing.

LITERATURE REVIEW

Cheese is a concentrated dairy product that requires select microorganisms and their enzyme systems of develop characteristic flavor and texture (71). Cheeses consist of varying ratios of milk proteins, fat, moisture, and ash. Cheese may be made from whole or skim milk, and may or may not contain added cream or nonfat dry milk. The milk casein is coagulated by rennet and/or lactic acid or by other suitable enzymes and acids.

Cheddar cheese is one of the oldest and most prominent types of cheese manufactured. Cheddar cheese originated in the county of Somerset in southwestern England. The name "cheddar" is taken from the town of Cheddar in that county where the cheese was first manufactured.

Whey Supplies and Need for Usage

In 1976, the United States produced 141 million kg of cheese and had a per capita consumption of 4.00 kg (37), which was 12% higher than in 1975. As more cheese is being produced to meet this demand, more whey is being produced as a by-product. Unused whey is a liability to a cheese plant. Because of the high BOD level, whey will put a heavy load on a sewage system and dumping it into streams or lakes is legally forbidden. Whey is toxic to fish in as great a dilution as one volume of whey to twenty-five volumes of water (78). It is also estimated that a cheese plant that produces 3800 liters of whey per day imposes a waste disposal load equal to that from 1800 people per day (26). Unless a cheese plant is equipped to process its whey into a marketable form, the whey must either be hauled away from the factory to some outlet or dumped into the municipal sewage system; either approach is expensive.

Annual whey production in the world is estimated to be 73 billion kg (59). In the U. S. approximately 13.7 billion kg of cheese whey or 945 million kg of whey solids were produced in 1975. Of this amount, about 56% were currently utilized in human and animal feeds; the rest is wasted.

The principle components of whey are lactose (4.7%), protein (0.9%), and minerals (0.5%). The whey proteins are those milk proteins which remain in the serum or liquid phase after the casein is precipitated in cheese making. The major whey proteins are β-lactoglobulin and α-lactalbumin, which are highly digestible and nutritious (14, 15, 54).

The nutritional quality of proteins is dependent upon the composition of the protein, or the presence and concentration of various amino acids; the digestibility of the protein; and the biological availability, or efficiency of amino acid absorption (25). For proper human nutrition, essential amino acids must be supplied in the diet because the cells of the body are incapable of snythesizing adequate quantities of them.

One method of determining protein quality is by biological assay which permits assessment of digestibility and efficiency of amino acid absorption in addition to amino acid composition. The protein efficiency ratio (PER) (which reflects the weight gained per gram of protein consumed by weanling rats after 4 wk of feeding trials using the test protein vs a casein-based diet), is a commonly used biological assay.

In the United States, PER is used to determine the percentage of the Recommended Daily Allowance (US-RDA) of protein supplied by a specific food. If the PER of the protein in a food is equal to or greater than that of casein, 45 g of that protein provides the US-RDA. If the PER is less than that of casein, 65 g of the protein is required to provide the US-RDA (25). The PERs of milk and some other proteins are presented in Table 1. Data in Table 1 show that milk proteins have excellent nutritional value and that the whey proteins have the highest PER value for all proteins listed. It has been shown in other research that the α-lactalbumin fraction has a higher PER than the β-lactoglobulin fraction (14, 15, 54).

TABLE 1. Protein efficiency ratios for various food protein sources.

Food Protein Source	Adjusted Protein Efficiency Ratio (PER) (casein = 2.50)
Casein	2.5
Non Fat Dry Milk	2.7
Egg	2.6
Soy	2.2
Corn	2.2
Whey	3.2

Source: Dairy based ingredients for food products. Distributed by Dairy Research, Inc. 1977. Rosemont, IL. 24 p.

Whey is also a rich source of vitamins and minerals. The vitamins of whey vary with the amounts in the milk used in making the cheese. Riboflavin is probably the only vitamin present in amounts to be of real interest from the nutritional standpoint with normal concentrations of 10 mg per pound of dry whey (12). The calcium and phosphorus in whey have considerable nutritional value especially because in the presence of lactose they are apparently more readily available (68).

Undenatured whey proteins are soluble in both acid and alkaline solutions (76, 77) and have low water absorption properties which permit high concentrations without excessive viscosity. Whey proteins are water soluble (35, 69), yet still exhibit good emulsifying properties over a broad pH range (13, 39). They have been used to produce foams (40), but the percentage overrun and stability of the foams are dependent upon heating temperature, pH, and fat content. Sauces and gravies subjected to freezer temperatures are stabilized by whey against breakdown. The addition of whey does not obscure the natural color, but enhances the flavor and smoothness (73).

Usage of Whey in Foods

Many different methods have been employed to use whey. Whey has been used extensively as part of a ration for livestock (57). Cows have been reported to drink up to 400 pounds of whey per day. Cows have consumed 300 lbs per day for long periods of time and maintained production (43).

Utilization of whey in human foods had been limited because of a salty taste and a high lactose-to-protein ratio. However, new processing techniques are drying, ultrafiltration and reverse osmosis have overcome this problem. The drying process has had the biggest impact on whey availability and utilization. The roller drier process was the most commonly used method in the past; it made available a relatively inexpensive product for feed uses. However, roller drying has been mostly replaced by a process involving condensing, lactose crystallization and spray drying which produces a more soluble, lighter colored, and non-hygroscopic dry whey that commands higher prices. With this improved technology, whey has been incorporated into many different products with varying results.

The largest outlet for whey is the ice cream industry (3, 6, 17, 42). Both sweet and acid types of whey have been used with good results. Patel (46), in 1977, used dry acid whey to replace the milk solids-not-fat in an ice cream mix at 10, 15, 20, and 25% replacement. No statistically significant differences were found in regard to taste, sweetness, or texture.

Some researchers (8, 71) have listed whey as an excellent source of milk solids for sherbet. An improved body and texture was noticed compared to a sherbet made by the conventional mix recipe. When cottage cheese whey was used, the customary addition of citric acid to fruit flavored sherbets could be greatly reduced or even eliminated in some cases. Other researchers (27, 49) have found that added whey greatly improves the whipping and overrun properties of sherbets. However, federal law regulates the maximum amount of whey solids that can replace milk solids-not-fat. Although the standards have been debated pro and con many times and are currently being contested in the court system, whey can now replace no more than 25% by weight of milk solids-not-fat in ice cream, ice milk, frozen custard, and sherbet (7, 66).

Dry cottage cheese whey has also been used successfully in the making of water ices. By replacing 16% of the sugar in orange, lemon, lime, and strawberry water ices with dried cottage cheese whey, both taste and nutritive value were reportedly improved (18).

Kosikowski (30) incorporated acid whey powder into cottage cheese dressing at the rate of 2.2 kg/100 kg of dressing and found that along with a decreased pH, an excellent stable flavored cream dressing was produced.

Yogurt has also been manufactured with the addition of whey solids. Jelen and Horbal (28) used a mixture of liquid cottage cheese whey and fresh homogenized milk to reconstitute nonfat dry milk to be used in yogurt manufacture. Yogurts were made from this milk using a commercial yogurt culture and incubated at 45 C for 4 to 6 h. Firmness of yogurts increased with higher total solids and greater proportion of homogenized milk used. Hartman (21) manufactured yogurt containing 2% whey solids which showed a slight whey flavor in plain yogurt but could not be detected in strawberry flavored Swiss style yogurt.

Hippocrates in 460 B. C. often prescribed whey beverages for many human ailments. Cited today for its nutritional benefit as well as its flavor (31), sweet liquid whey has been mixed with 60% fruit juice to give a very acceptable beverage with a protein percentage of approximately 1% (24). Taste panels have given this beverage an average score of 5.9 on a hedonic scale of 1 to 7. With nutrition a major factor in human health and well being, many processors and educators are suggesting Americans turn away from "empty" calorie snacks and beverages. Holsinger (23), in 1973, fortified soft drinks with 0.5 and 1.0% whey protein. A product with 6 mo flavor stability was achieved which received fair consumer reviews, but it could not consistently outrank carbonated soft drinks commercially manufactured.

A variety of new uses for whey has been suggested (70, 73, 78) including its use in the production of cheese and related products, infant food formulations, special dietary products, and confections.

Researchers at South Dakota State University in 1974 found a new use for whey in a Latin-American treat called "Dulce de leche" (60). The amount of whey solids used was varied from 3 to 24% of calculated solids. At 5.5% of product, the whey solids actually improved the flavor and texture. At all levels, whey solids enhanced the degree of color development. However, when dry whey was added at 15% of total solids, the whey flavor was definite and was termed objectionable.

Dry whey solids have been added without much success to different cheese spreads (10, 61), with defects listed as gross sandiness and weaker body as compared to spreads in which dried milk solids were used.

The addition of whey proteins to semi-hard cheeses has very little documentation. However, cheese prepared from milk fortified with whey proteins has been produced with varying results. Brown and Ernstrom (9) added concentrated whey (9.8 to 20.3% total solids and 4.3 to 7.1% protein) to cheddar cheese milk along with a coagulating enzyme. An increase in yield of 4% based on 39% moisture curd was attained along with higher ($P<.001$) differences in moisture and protein but lower values for fat, setting time, pH, and flavor.

Hirschl and Kosikowski (22) used acid whey powders as coagulants in the manufacture of Queso Blanco cheese. Acid whey powder and a partly delactosed liquid concentrate from ultrafiltrated cottage cheese whey were added to separate lots of whole milk in sufficient quantities to lower the pH to 5.3. At 82 C and this pH, almost immediate protein precipitation occurred. The curd was drained, salted, pressed, and packaged. Flavor was typical of cheese made using conventional coagulants and yields were higher than controls for both lots. Addition of less salt was required because some salt was supplied by the whey. Whey also has uses outside the food industry. Whey solids in agriculture foams serve as excellent carriers for herbicides or fungicides or, when used alone, as excellent protection of crops against frost (34).

Methods of Calculating Cheddar Cheese Yields

Maximizing cheese yield starts with proper control of milk production and continues on through the cheese making process. The increasingly complex nature of cheese making necessitates a constant watch by management, the input of trained personnel, and the dedication of production personnel to attain maximum yields. Extensive research in the early 1900's demonstrated that yield of cheddar cheese was closely associated with fat and casein concentrations in milk. This relationship to yield is generally accepted as still valid today. The following formula in which F = % milk fat, C = % casein, and W = lb water in 1 lb of cheese can be used for predicting yield of cheddar cheese:

$$\text{lbs cheese/100 lb milk} = \frac{(0.93\ F + C - 0.1)\ (1.09)}{1.00 - W}$$

It is assumed that 93% of all milk fat is retained in the curd and 7% is lost in the whey, curd fines, and pressing of the cheese. It is also assumed that 0.1 lb of casein is lost for every 100 lb of milk made into cheese (44). The multiplication factor (1.09) may differ for cheeses other than cheddar, depending upon the amount of salt added, moisture content of the cheese, and pH. Draining off the whey at lower acidities (higher pH values) will result in greater retention of milk salts in the cheese. This would raise the factor above 1.09.

The fat content of milk for the yield formula can be accurately measured. The casein percentage however, is more difficult to determine. The concentration of casein in milk may be measured by determining the total protein content, precipitating the casein, and measuring the residual protein. The difference between total and the noncasein protein is the casein content. Casein can also be roughly estimated by assuming that 80% of total milk protein is casein (71).

Two other formulas (A and B) have been suggested for determining cheddar cheese yield (45). In one formula, total protein is used, in the other casein is involved in estimating yield per 100 lb of milk. In these formulas, F = % milk fat, P = % protein, C = % casein, and MNFS = lb of water per lb of nonfat cheese solids. MNFS can be calculated by formula C below.

Formula A

$$\text{Yield} = 0.93\ F + \frac{0.907\ P}{1.00 - \text{MNFS}}$$

Formula B

$$\text{Yield} = 0.93\ F + \frac{1.163\ C}{1.00 - \text{MNFS}}$$

Formula C

$$\text{MNFS} = \frac{\%\ \text{moisture in cheese}}{100 - \%\ \text{moisture in cheese} - \%\ \text{fat in cheese}}$$

These formulas can be used in evaluating performance of a cheese plant in recovering milk solids in cheese. Actual yields are expressed terms of a set amount of moisture (usually 37%); and pounds of cheese achieved are divided by pounds of milk used. This figure multiplied by 100 gives percent actual cheese yield.

Factors Affecting Cheese Yields

Milk Composition

The importance of composition and properties of milk on yield and quality of cheese has been widely published and discussed (11, 47). Many different factors interact to give rise to changes in milk composition. The breed of cow, stage of lactation, amount and quality of feed, as well as season of the year, affect milk composition. Seasonal variations, mainly in fat and casein levels, are easily recognized but not easily controlled. Concentrations of milk fat and protein and subsequently cheese yield are at lowest levels in spring and summer and highest between October and December (45, 71).

Mastitis can also affect the normal balance of milk constituents. The concentration of whey proteins increases with severity of infection, and casein content drops markedly. The increase in whey proteins has been shown, however, to be sufficient to compensate for decreased casein so that total protein of the milk remains fairly constant. However, the decrease in casein and milkfat resulting from acute mastitis has been shown to reduce cheese yields (52).

Heat Treatment of Milk

Much of the whole milk used to manufacture cheese is pasteurized. Minimum temperature and time is recommended for pasteurization, which requires at least 72 C (161 F) for 15 sec or 63 C (145 F) for 30 min for high-temperature short-time and low-temperature long-time, respectively. However, excessive heat treatment is not recommended

(36, 38, 48, 50, 56). Excessive heat treatment of milk will result in an inferior, slow-curing (36) cheese. Some manufacturers are turning away from pasteurization and opting instead to heat treatment of the milk (50, 56). The purpose of heat treating the milk to a temperature less than that of pasteurization is to retain in the heated milk some of the cheese ripening enzymes and bacteria from the original milk. Such heat treatments alone do not eliminate flavors and odors of raw milk which may contribute flavor to the cheese. Good quality cheese can be made from raw milk; however, the cheese must be cured at least 60 days before it can be sold. After this storage period, all pathogenic and spoilage organisms have been killed by acid and other factors (65). Persons who have heated milk to temperatures and times which duplicated or closely approximated 72 C for 15 sec generally agree (16, 38, 50, 56) that cheese made from pasteurized milk is better in quality than comparable raw milk cheese. The use of pasteurized milk will give higher yields than raw milk cheese (50, 56) although raw milk cheese will develop flavor more rapidly.

One report states that when milk was heated above pasteurization temperatures, the casein of the milk was altered in such a way that the resulting curd tended to lose its cohesive properties, which caused the cheese to have a mealy texture (63). In addition, Moir (38) observed retention of more moisture, an openness in texture, and the development of bitter flavor in the cheese.

Starter Cultures

A good quality lactic acid bacteria starter is essential in the manufacture of good quality cheddar cheese. The predominant organisms in the usual lactic cheese starter are *Streptococcus lactis* and/or *Streptococcus cremoris*. Both are gram positive cocci capable of producing lactic acid from the lactose present in milk during cheese manufacture.

There are four important reasons why a good quality starter should be used: 1) It governs the flavor and the body and texture of the cheese, 2) Through the acid produced, the rennet action is aided, 3) The acid aids in moisture expulsion from the cheddaring curd, 4) The growth of undesirable bacteria in the cheese is checked (75).

Two major types of starter cultures are now available from a number of laboratories. Freeze-dried cultures, first used in the late 1940's, contain select strains of bacteria in a dormant form. Although many millions of organisms are present per gram, many are inactive due to the freeze-drying (53), and for this reason they do not develop rapidly in the milk during the first or second transfer and incubation.

New frozen concentrated cultures are now on the market which can be added directly to the cheese vat without repeated incubation and transfer. The cultures are concentrated, packaged in tin cans, and flash frozen at -196 C in liquid nitrogen then shipped to cheese plants in insulated cartons containing dry ice to maintain the low temperature. Cultures are to be stored at -28.8 C or below if possible, to maintain maximum activity. To use the culture, the can is placed in warm water for 10 to 15 min to allow the culture to melt on the outside edges. The can is then opened and the frozen culture is added directly to the milk and allowed to melt in the milk with constant agitation. Some researchers have claimed improved yields with the frozen concentrates (51); however, more studies are currently under investigation.

Hansen et al. (19), in 1933, compared the influence of the different starters on cheese yield and quality. A mixed culture of Streptococcus lactis and Streptococcus cremoris was compared to a single strain of S. lactis and a mixed culture of S. citrovorus and S. paracitrovorus. No differences in yield or fat loses in whey were reported.

Miscellaneous Manufacturing Variables

A certain amount of casein is generally lost in the whey. On an average the whey will contain approximately 0.10 to 0.12% casein (75). On the basis of the total nitrogen in the milk, this loss will amount to from 3 to 5%. The loss will be high if poor coagulation occurs or if the curd is improperly cut and stirred and/or is handled roughly.

Fat losses in the whey can vary from 3 to 5.4% (75). Although the whey may be separated to recover lost fat, not all the fat will be recovered.

Probably the most important factor in regard to losses in cheese yield occurs during the cutting and subsequent cooking process. When making the crosscut with the perpendicular knife, it is better to leave a couple of inches space than to overlap cuts. Even if some of the strips are long and thin, they will cook out just as evenly as the cubes. However, if the cube of curd has been cut twice, the curd will cook drier due to the smaller size and could more easily pass out with the whey. Other factors that can affect the yield, and are under the control of the cheesemaker are: 1) Accuracy of weighing milk, 2) pasteurization temperature, 3) amount of curd lost on to the floor, 4) amount of salt added, and 5) accuracy in weighing and recording weights (75).

MATERIALS AND METHODS

Cheese Manufacture, Sample Collection, and Analyses Performed

Fresh whole milk (1225 kg) obtained from the South Dakota State University (SDSU) dairy herd was pasteurized by the vat method: 63 C (143 F) for 30 min promptly followed by cold water jacket cooling to 32 C (90 F). The milk was pumped directly into a 1235 liter vat in the SDSU Dairy Products Laboratory. Cheese was made using the conventional method of Wilster (75); whey solids were added to aliquot portions after milling; and the cheese was hooped, pressed, wrapped, and cured as described and depicted in Fig. 1. Each whey addition was replicated six times; i.e., twice each wk for 3 wk.

Fresh active lactic acid-producing mixed strain streptococci cultures, used to inoculate the bulk starter milk, were propagated from a commercial lyophilized culture. Growth was initiated by inoculating a portion of the lyophilized culture into 100 ml of 21 C (70 F) skim milk which had been previously steam heated at 86 C (187 F) for 45 min, cooled to 4 C. Desirable acid development of 0.60 to 0.85% titratable acidity occurred during incubation for 14 h at 21 C (70 F). Transfers (1%) were made into 4 C (39 F) skim milk (steam heat treated) upon completion of the 14 h incubation each morning. The newly inoculated milk was held at 4 C (39 F) until placed in 14 h incubation of 21 C (70 F) in the afternoon. When bulk starter was needed, 100 ml of the culture was added to 12.15 kg (27 lb) of vat pasteurized whole milk. This milk was then incubated for 14 h at 21 C (70 F) to give the desired titratable acidity of 0.60 to 0.85%.

FIG. 1. Flow diagram of cheese manufacture.

Pasteurize milk at 63 C for 30 min, cool to 32 C, and add 1% starter

↓

wait 1 h
(Acidity increased 0.01 to 0.02%)

↓

Add annatto color and rennet extract; wait 20 min; and cut

↓

Cook (32 → 37.8 C)

↓

Drain, ditch, cheddar, and mill

↓

11.7 kg aliquots into 209 liter vats

↓

Third aliquot held in make vat
then added to first vat (cleaned and
sanitized after initial use)

↓

Vat cleaned & sanitized →

control (no whey added) | 3% whey added | 6% whey added

2% salt added (All additions based on curd wt)

↓

Stir 15 min to mix

↓

Hoop, weigh, and press overnight

↓

Weigh, package, and store at 5 C

↓

Monthly sampling, analyses, and sensory evaluation

This high acid milk was added to the 1225 kg pasteurized milk as fresh 1% bulk starter for cheddar cheese manufacture.

After addition of the bulk starter, the cheese milk was held at 32 C (90 F) for 1 h to allow the milk acidity to increase 0.01 to 0.02%. Seventy-one milliters of annatto color[1] were then added [30 ml (1 oz) per 450 kg (1000 lb) of milk] to give the milk an attractive light orange color. The annatto was diluted ten-fold with cold water and added to the milk behind the mechanical agitator.

Two hundred forty-three milliters of rennet extract[1] (100% strength), [90 ml (3 oz) per 450 kg (1000 lb) of milk] diluted with twenty times its volume of cold water, was added to the milk behind the mechanical agitator and allowed to mix for 2 min to insure adequate mixing.

The milk was allowed to sit quietly for 20 min to permit coagulation, then the curd was cut using .93 cm stainless steel wire knives that had been sanitized with 200 parts per million (200 ppm) chlorine solution. To cut the curd, two knives (one with vertical and one with horizontal wires) were drawn through the curd to the end of the vat. The horizontal knife was removed from the vat and the vertical knife was given a half-turn, then the horizontal knife was inserted back into the vat on the opposite side from the first pass. Both knives were now in reversed position. Each knife was

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[1]Marschall Division, Miles Laboratory, PO Box 595, Madison, Wisconsin 53701

drawn back through the curd to the other end and carefully removed. The vertical knife was reinserted and the curd cut crosswise throughout the length of the vat to obtain uniform cubes of curd. The knives were then washed and hung up to dry.

The cooking process was initiated 10 to 15 min after the cutting was completed. The temperature was increased slowly at first, at the rate of 0.55 C (1 F) each 5 min for the first 15 min, then slightly faster until the desired temperature of 37.8 C (100 F) was reached; in about 20 min. The product was stirred at this temperature for 1 h.

The whey was drawn off and the curd ditched to a depth of approximately 15 cm (6 in) on each side. The curd, kept at 31 C (88 F), started to mat together in about 15 min. After it had matted, it was cut into 20 cm (8 in) slabs and turned every 15 min for 45 min and then stacked two high and turned every 15 min for 45 min, then stacked three high and turned every 15 min until the desired acidity had been reached. For this research, a 0.50% titratable acidity was established as a minimum.

At this point, the cheese was milled into strips approximately 1.6 cm (5/8 in) wide and 5 to 8 cm (2 to 3 in) long. After milling, 35.1 kg (78 lb) of curd was removed and 11.7 kg (26 lb) aliquots were placed in each to two water-jacketed, 209 liter (55 gal) vats which had been preheated to 37.8 C (100 F). The third 11.7 kg aliquot was placed in a sanitized stainless steel bucket and held in the original vat at 32 C (90 F).

In one of the 209 liter vats 0.23 kg (0.52 lb) (2% of curd weight) of salt was added to the curd, which then was hand stirred for 15 min using a stainless steel stirring paddle. The curd was placed into a tared hoop and total weight taken. The vat was then washed, sanitized with 200 ppm chlorine solution, and the third 11.8 kg (26 lb) aliquot (from bucket in make vat) was added. Sweet whey powder at the level of 3% curd weight (0.35 kg) and salt at the level of 2% curd weight were mixed. This whey powder-salt mixture was added to one aliquot of curd using a flour sifter to insure even distribution and absence of lumps. The curd was then stirred for 15 min, hooped and weighed. To the final aliquot of curd, 6% curd weight (0.70 kg) of whey powder, mixed with salt (2% of curd weight), was added using the flour sifter. The curd was mixed for 15 min, hooped and weighed. The procedure was varied so that any one treatment was not always the first.

All three hoops of cheese were pressed overnight together. The cheese was removed from hoops the next morning and weighed to determine pressing loss. The cheese was then wrapped in a cry-o-vac film and a waxed paper covering; heat sealed, and stored at 5 C (41 F).

The covering was marked off into ten sections and months were randomly assigned to each section to facilitate monthly sampling initially and for 9 mo.

Compositional Analysis

Total protein in milk, cheese, and dried whey was determined by the Kjeldahl procedure of the Association of Official Analytical

Chemists (A.O.A.C.) (4). Casein and whey protein fractions of milk were derived by Rowland's methods (55). Water-soluble nitrogen of cheese was determined by the method of Vakaleris and Price (67).

Total solids of milk, cheese, and dried whey were determined by the Mojonnier method described by Newlander and Atherton (41). Fat content of milk was determined by the A.O.A.C. Babcock procedure (4), while the A.O.A.C. Roese-Gottlieb method was used for measuring cheese and dried whey fat (4). Solids-not-fat values were calculated as the difference between total solids and fat for all samples. Ash content of all samples was determined by the A.O.A.C. method (4), using porcelain crucibles.

For milk and dried whey, lactose was calculated as solids-not-fat minus the sum of total protein and ash. Cheese lactose was determined by the method of Sutherland and Van Leeuwen (64).

Cheese pH was measured using a Leeds-Northrup expanded scale pH meter. The cheese was ground in a blender for 1 min, then the pH electrode was immersed directly into the cheese and pH read directly, according to Standard Methods for the Examination of Dairy Products (1).

The salt analysis procedure by Arbuckle as described by Newlander and Atherton (41) was used to ascertain sodium chloride.

Judging Panel

A panel ranging from two to four experienced judges evaluated the cheddar cheese at monthly intervals of flavor defects in accordance with the ADSA-DFISA score card. Body and texture were judged also after the cheese was 5 mo old. It was reasoned that cheese younger than this age did not exhibit common cheddar cheese characteristics. All three cheeses from the same manufacturing date were judged at the same time. All samples were coded to prevent knowledge of the sample identity prior to the evaluation.

Expression of Yield

Yield data were calculated as: kg 63% solids cheese received; and percent recovery of the materials placed in the hoops.

Statistical Analysis

Statistical analysis of the data utilized least squares analysis of variance for a randomized block experiment with a three factor (replication, treatment, and month) design experiment (62). The main effects of treatment and time were tested by the respective main effect and replication interaction. The remainder was used as the error term to test the interaction of treatment and time.

RESULTS AND DISCUSSION

Cheese Milk Composition

As mentioned earlier, most differences in cheddar cheese yields are attributable to differences in the milk composition (11, 47). The compositions of the six milks used in this study are listed in Table 2. The fresh, pasteurized milk averaged 3.48% fat, 8.58% SNF, 2.90% total protein, 5.06% lactose, and .64% ash. With the exception of fat, which was slightly higher, these values compare well with a recent report of milk composition (79). The low solids percentage can be explained by the fact that the milk was obtained in late June and July when the total solids in milk generally are at a seasonal low (71). Percentages of nitrogen fractions of the milks used are shown in Table 3. Casein percent was low, as reported in an earlier study of South Dakota milk composition (79). Since casein comprises the protein of cheddar cheese, these low values portend low cheese yields.

Dry Whey Composition

Composition of the dry sweet whey used in this study is listed in Table 4. Typical analysis of dried sweet whey is 95.5% solids, 12.9% protein, 1.1% fat, 73.5% lactose, and 8% ash (25). Analysis of the whey revealed a higher total solids content which would explain in part the 2.6% higher lactose value. The amount of protein in the dried whey was 1% lower than the average value, which would also make for higher lactose content. If the initial liquid whey had been centrifuged or clarified extremely well, most of the small cheese

TABLE 2. Compositions of milks used to manufacture cheddar cheese.

Component	Batches						Overall	
	1	2	3	4	5	6	Mean	SE[a]
	%							
Total solids	12.23	11.82	12.50	12.01	12.05	11.97	12.09	.23
Fat	3.6	3.5	3.4	3.5	3.4	3.6	3.48	.11
SNF	8.6	8.3	9.1	8.5	8.7	8.3	8.58	.29
Total protein	3.04	2.80	3.02	2.87	2.92	2.76	2.90	.11
Lactose	4.93	4.87	5.51	4.96	5.15	4.97	5.06	.23
Ash	.66	.65	.62	.67	.62	.64	.64	.02

[a]Standard error

TABLE 3. Nitrogen fractions of milks used to manufacture cheddar cheese.

Component	Batches						Overall	
	1	2	3	4	5	6	Mean	SE[a]
	%							
Non-casein nitrogen	.08	.09	.09	.10	.10	.09	.09	.008
Non-protein nitrogen	.02	.02	.02	.03	.03	.03	.02	.005
Protein nitrogen	.45	.41	.45	.42	.43	.41	.42	.01
Casein nitrogen	.39	.34	.38	.35	.35	.34	.35	.02
Serum protein nitrogen	.06	.07	.07	.07	.08	.07	.07	.006

[a]Standard error

TABLE 4. Composition of dry sweet whey (Extra Grade) added to cheddar cheese.

Component	%
Total solids	97.76
Moisture	2.24
Fat	1.58
SNF	96.18
Lactose	76.17
Protein	11.88
Ash	8.13

particles (fines) would have been recovered and only whey proteins (no casein), lactose, minerals, and traces of fat would have been left to be dried. This could result in a lower protein percentage in the dried product.

Cheddar Cheese Composition

The average compositions of the cheddar cheeses at 0 and 9 mo of age are presented in Tables 5 and 6, followed in Table 7 by a summary of statistical analysis of cheese composition. The total solids contents of the three cheeses were not statistically different from one another at 0 or at 9 mo of age. The average value of 63.77% total solids is legal for cheddar cheese by federal and South Dakota standards (66). Since the development of acid in the curd during manufacture and the resulting moisture components were variable, a more meaningful comparison of composition and yields was possible by adjusting all components except total solids to a 63% total solids basis. Solids and moisture contents were not run at monthly intervals; however, the amount of moisture was interpolated from 0 and 9 mo calculations so monthly comparisons of the percentages of the various components could be made.

Fat content of the cheeses was significantly ($P<.05$) different with level of whey additions and the age at which the cheeses were analyzed. The differences in fat between treatments are directly attributable to the addition of a high solids-low-fat whey powder to experimental lots, which would increase the solids-not-fat and, therefore, lower the relative fat percentage. As can be seen in

TABLE 5. Average composition of fresh (0 month) cheddar cheeses[a].

Component	Treatment			Overall	
	Control	3% whey addition	6% whey addition	Mean	SE[c]
	- - - - - - - -	- - - - - - - -	%[b] - - - - - - - -	- - - - - - - -	- - - -
Total solids	63.25	63.76	64.31	63.77	.20
Fat	32.26	32.02	31.13	31.80	.23
SNF	31.06	30.97	31.85	31.29	.34
Total protein	24.35	25.24	23.33	24.31	.17
Ash	3.41	3.47	3.50	3.46	.02
Salt (NaCl)	1.16	1.08	1.08	1.10	.02

[a]Values are means of six replications

[b]Percentages for all cheese components except total solids are adjusted to basis of 63% solids in the cheese

[c]Standard error

TABLE 6. Average composition of cheddar cheeses 9 months of age[a].

Component	Treatment			Overall	
	Control	3% whey addition	6% whey addition	Mean	SE[c]
	%[b]				
Total solids	64.49	65.05	64.64	64.72	.20
Fat	31.51	30.85	29.90	30.75	.21
SNF	31.48	32.14	33.09	32.23	.31
Total protein	24.84	25.13	24.70	24.89	.17
Ash	3.31	3.18	3.44	3.31	.02
Salt (NaCl)	1.34	1.12	1.16	1.20	.03

[a]Values are means of six replications

[b]Percentages for all cheese components except total solids are adjusted to basis of 63% solids in the cheese.

[c]Standard error

TABLE 7. Statistical analysis of effects of levels of whey solids addition and age at analysis on the composition of cheddar cheeses[a].

	Component %								
Factor	Total Solids	Fat	SNF	Total Protein	Soluble Nitrogen	Salt	Lactose	Ash	pH
Levels of whey solids addition	NS	*	**	*	NS	NS	**	NS	**
Age in months	NS	*	NS	**	**	NS	**	NS	NS
Whey solids addition x age in months	NS	NS	NS	NS	**	NS	NS	NS	**

[a]Percentages for all cheese components except total solids were adjusted to the basis of 63% solids in the cheese

*Significant (P<.05)

**Highly significant (P<.01)

NS = not significant

Table 5, the fat content of the 6% whey addition cheese did not comprise 50% of total solids, as required by federal and South Dakota standards (66). The fat contents were significantly less ($P<.05$) as the age of the samples increased. Many reports (5, 20, 32, 33, 58) have stated that lipolysis is a major factor in flavor development. This hydrolysis resulted in lower fat values obtained from 9 mo old cheese than in the 0 mo cheese, since the resultant free fatty acids and glycerol were not measured by the test that was used to determine fat.

SNF values for fresh cheeses (0 mo) were higher ($P<.01$) in the cheese containing 6% whey solids than in the control cheese. At 9 mo of age both whey addition cheeses had higher SNF than did the control. This was expected since the added whey contained 96% SNF; obviously this would have increased the cheese SNF.

Ash, total solids, and salt were not significantly different among levels of whey solids addition or ages of cheeses. Although an increase in ash was noted in cheese with added whey solids, and a decrease in ash at 9 mo, these differences were not statistically significant. No reason has been established for the decrease of ash at 9 mo of age. The total solids of the cheese did definitely increase with the addition of the whey solids but the increase was not significant. The cheese with added whey wolids became less pliable and more crumbly; this will be discussed in more detail in another section.

Salt was added at a constant amount for all cheeses, and no statistically significant difference was noted between any of the cheeses.

Differences in the lactose content of cheeses were highly significant (P<.01) for both levels of whey solids and age of cheese at time of analysis. Cheeses containing whey were much higher in lactose then were the controls. This result was expected since the dry whey added was 76% lactose. The age of the cheese also had an effect on the lactose content. The fermentative action of microorganisms present in the cheese culture dramatically reduced the amount of lactose present (P<.01) as the cheese aged. Lactose values are depicted in Fig. 2.

Monthly total "protein" values (nitrogen % x 6.38) of the cheeses as shown in Table 8 were significantly lower (P<.05) in cheeses with added whey solids and increases in protein values with increasing age of cheeses were highly significant (P<.01). It was hoped that the added dry whey would increase the protein content; however, this was not the case. The cheese to which whey was added had a lower protein value than did the controls. Upon further thought, it was realized that the addition of dried whey, which is mostly lactose, would overshadow any protein present and lower the relative protein content of the cheese. However, as the cheese got older, the total nitrogen level increased in all the cheeses. It was thought that the increasing loss of moisture and subsequent rise in solids would explain the increase; however, the difference in solids content averaged over months was not statistically significant.

FIG. 2. Average lactose values of cheddar cheeses at various ages[a].

[a]Values are means of six replications

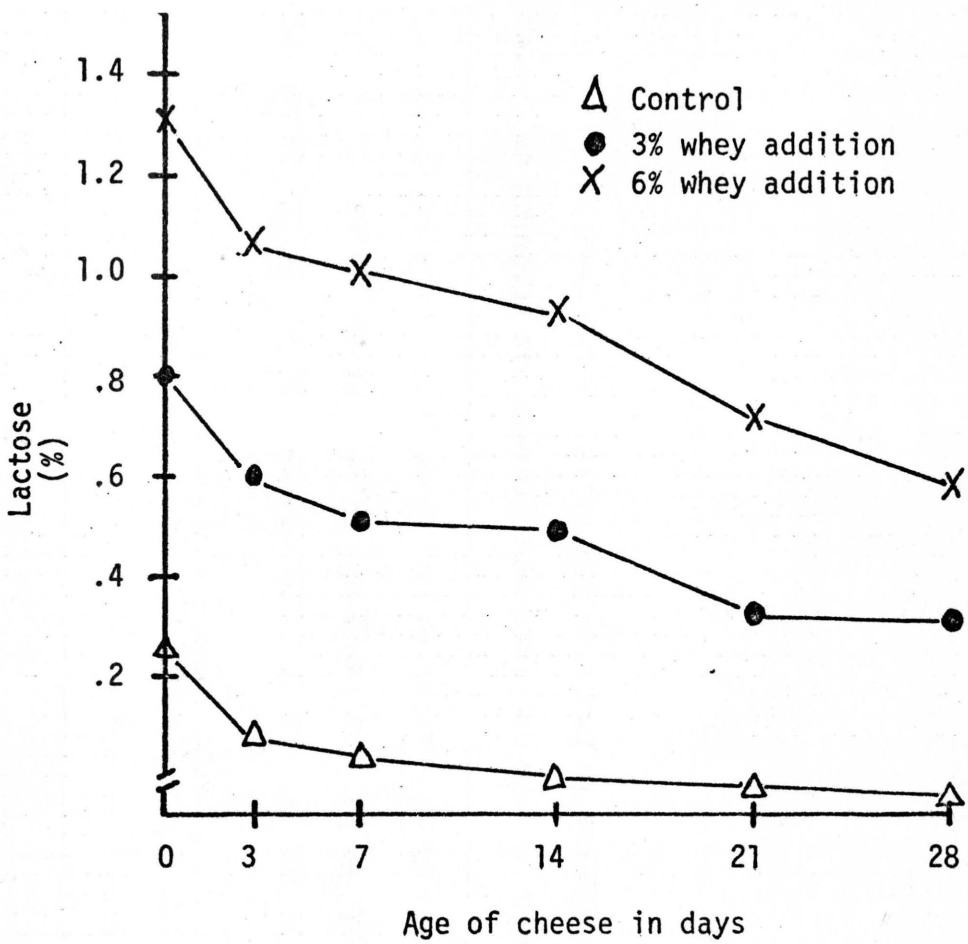
Control
3% whey addition
6% whey addition
Lactose (%)
1.4
1.2
1.0
.8
.6
.4
.2
0
3
7
14
21
28
Age of cheese in days

TABLE 8. Average monthly "protein" values of cheddar cheeses[a].

Level of whey addition	0	1	2	3	4	5	6	7	8	9	Overall[c]	
											Mean	SE
	%[b]											
Control; no addition	24.35	24.17	24.37	24.29	24.83	24.70	24.97	24.70	25.17	24.84	24.64	.10
3% whey addition	25.24	24.03	24.14	23.98	24.63	24.68	24.63	24.67	24.75	25.13	24.59	.10
6% whey addition	23.33	23.38	23.98	23.86	23.86	24.20	24.46	24.23	24.40	24.70	24.04	.10

[a]Monthly values means of six replications; Protein was computed as nitrogen % x 6.38.

[b]Percentages are adjusted to basis of 63% solids in the cheese.

[c]Standard error.

As cheese ages, acid and enzymes hydrolyze the casein into water-soluble nitrogen compounds. By measuring the amount of nitrogen in these compounds, the rate of cheese ripening can be monitored. It was thought that if more lactic acid was produced, the cheeses would ripen faster. Addition of whey solids did not have a significant effect on the amount of soluble nitrogen; however, the monthly increase in soluble nitrogen during ripening was highly significant ($P<.01$) and agreed with the results of work done by Vakaleris and Price (67). Increases in water soluble nitrogen values for all cheeses are apparent in Fig. 3.

There were highly significant ($P<.01$) differences in the pH of the cheeses, depending upon the level of whey addition, but there was no significant correlation between pH and age of cheese. The pH was lower in the whey-added cheeses as a result of the fermentation of the extra lactose, which produced more lactic acid and resulted in a lower pH than that of the controls. The pH of typical cheddar cheese is approximately 5.0 after 2 days but increases during curing due to alkaline products liberated during protein hydrolysis (71). pH values of all cheeses are shown in Fig. 4.

Cheddar Cheese Yields

Average yields of the cheddar cheeses made during these trials are presented in Tables 9 and 10, followed by the statistical summary in Table 11. Yields were expressed by two different methods. Yield expressed as kg of 63% solids cheese takes into account differences in cheese moisture, whereas percent recovery of hooped curd (curd

FIG. 3. Average soluble nitrogen values of cheddar cheeses at monthly intervals during curing[a].

[a]Values are means of six replications

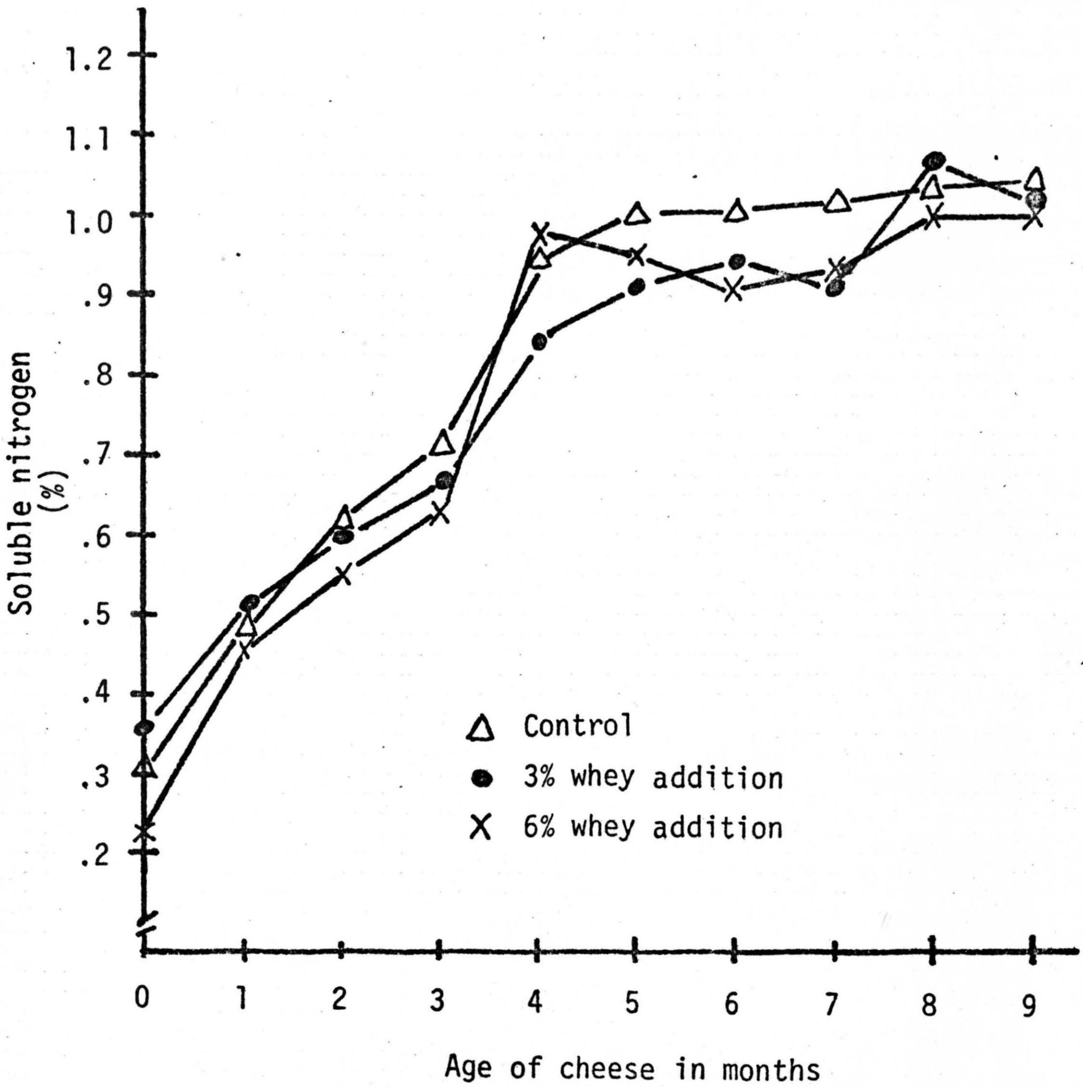
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
Soluble nitrogen
(%)
Control
3% whey addition
6% whey addition
0
1
2
3
4
5
6
7
8
9
Age of cheese in months

FIG. 4. Average pH values of cheddar cheeses at monthly intervals during curing[a].

[a]Values are means of six replications

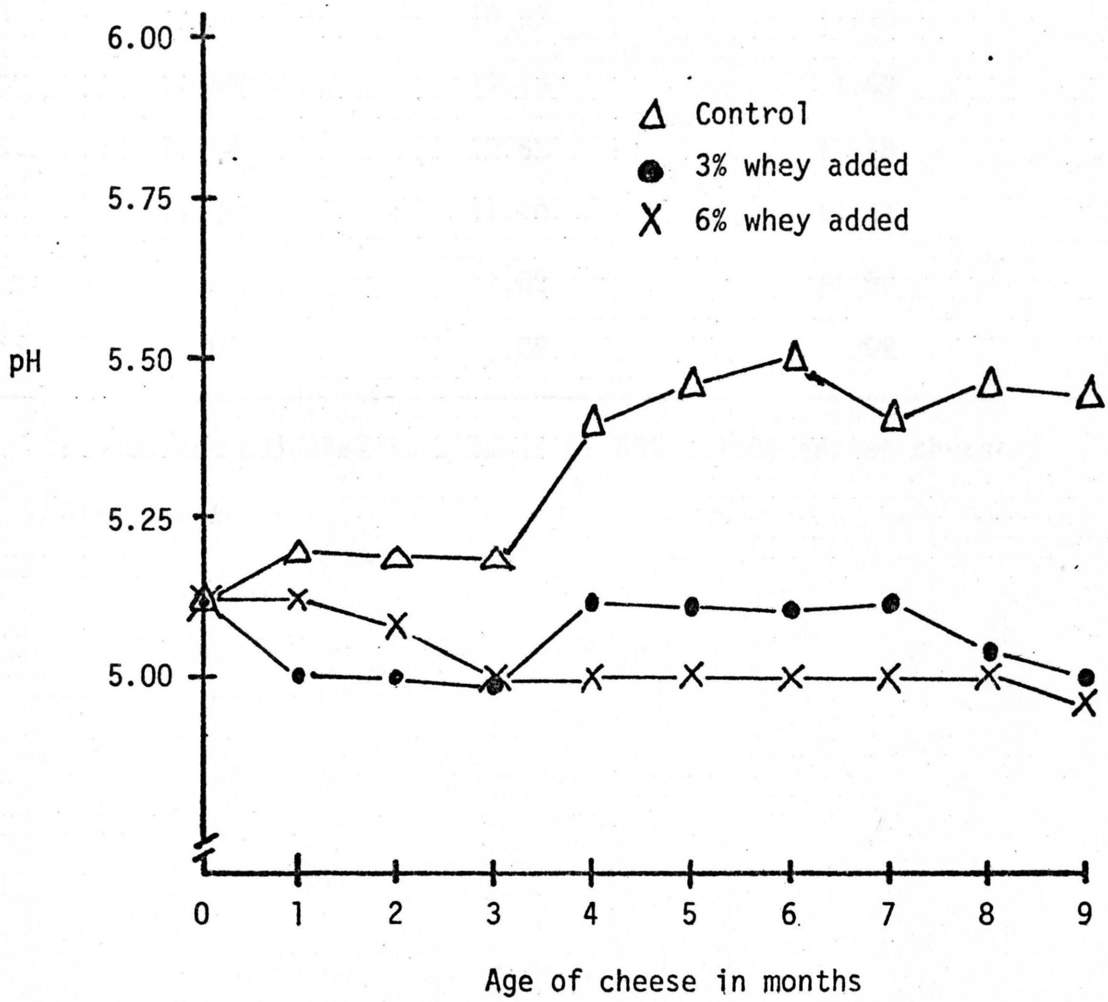
Control
3% whey added
6% whey added
pH
6.00
5.75
5.50
5.25
5.00
0
1
2
3
4
5
6
7
8
9
Age of cheese in months

TABLE 9. Yields (kg) of cheddar cheeses from 11.7 kg milled curd[a].

Batch	Control	3% whey addition	6% whey addition
	- - - - - - - - - - - -	kg - - - - - - - - - - - -	
1	11.22	11.35	11.72
2	10.37	10.53	11.80
3	10.57	10.92	11.20
4	10.94	11.19	11.69
5	10.68	10.68	11.18
6	11.05	11.50	11.46
Mean	10.80	11.02	11.50
SE[b]	.09	.09	.09

[a]Values are adjusted to a basis of 63% solids in the cheese

[b]Standard error

TABLE 10. Yields of cheddar cheeses expressed as percent recovery of hooped materials.

Batch	Control	3% whey addition	6% whey addition
	- - - - - - - - - - - - -	% - - - - - - - - - - - - - -	
1	92.12	88.59	84.51
2	90.19	87.94	87.64
3	89.27	87.69	87.36
4	88.86	90.69	87.78
5	88.86	86.48	85.35
6	88.17	88.09	87.57
Mean	89.57	88.24	86.70
SE[a]	.59	.59	.59

[a]Standard error

TABLE 11. Statistical analysis of effects of whey solids addition on cheddar cheese yields.

	Yield	
Factor	kg cheese[a]	Recovery of hooped materials (%)
Whey solids addition	**	*

[a]Values are adjusted to a basis of 63% solids in the cheese

*Significant (P<.05)

**Highly significant (P<.01)

plus salt and whey) measures the efficiency of recovery of material placed in the hoop. Probably the most popular method of calculating cheese yields, however, is expressed as kg of 63% solids cheese obtained from 100 kg of milk. Since three identical aliquots of curd were taken after milling and then the treatment applied, this method could not be used in this study.

Yields expressed as kg of 63% solids cheese was significantly greater ($P<.01$) for cheeses with added whey solids than for the controls. Differences in yield expressed as percent recovery of hooped curd were significant ($P<.05$) with the controls averaging a higher percent recovery of material. This is because more solids were lost from the whey-added cheeses during pressing.

The dried whey did not go readily into solution and mix into the curd, which kept the cheese from knitting together tightly. An open, moist, sticky cheese resulted that was weak in body and had a tendency to break as the cheese was being wrapped and sealed. After 2 or 3 days, the stickiness and excess surface moisture disappeared, leaving a seamy, mottled cheese as shown in Fig. 5.

Judging Panel

Each week for a period of 9 mo, a panel of two to four experienced judges evaluated the cheddar cheeses. Flavor evaluations started at 1 mo of age and body and texture evaluations started when the cheese was 5 mo old. Average flavor and body and texture scores are listed in Tables 12 and 13, respectively. A summary of statistical analysis for flavor and body and texture is shown in Table 14.

FIG. 5. Appearance of experimental cheeses at 6 mo of age.

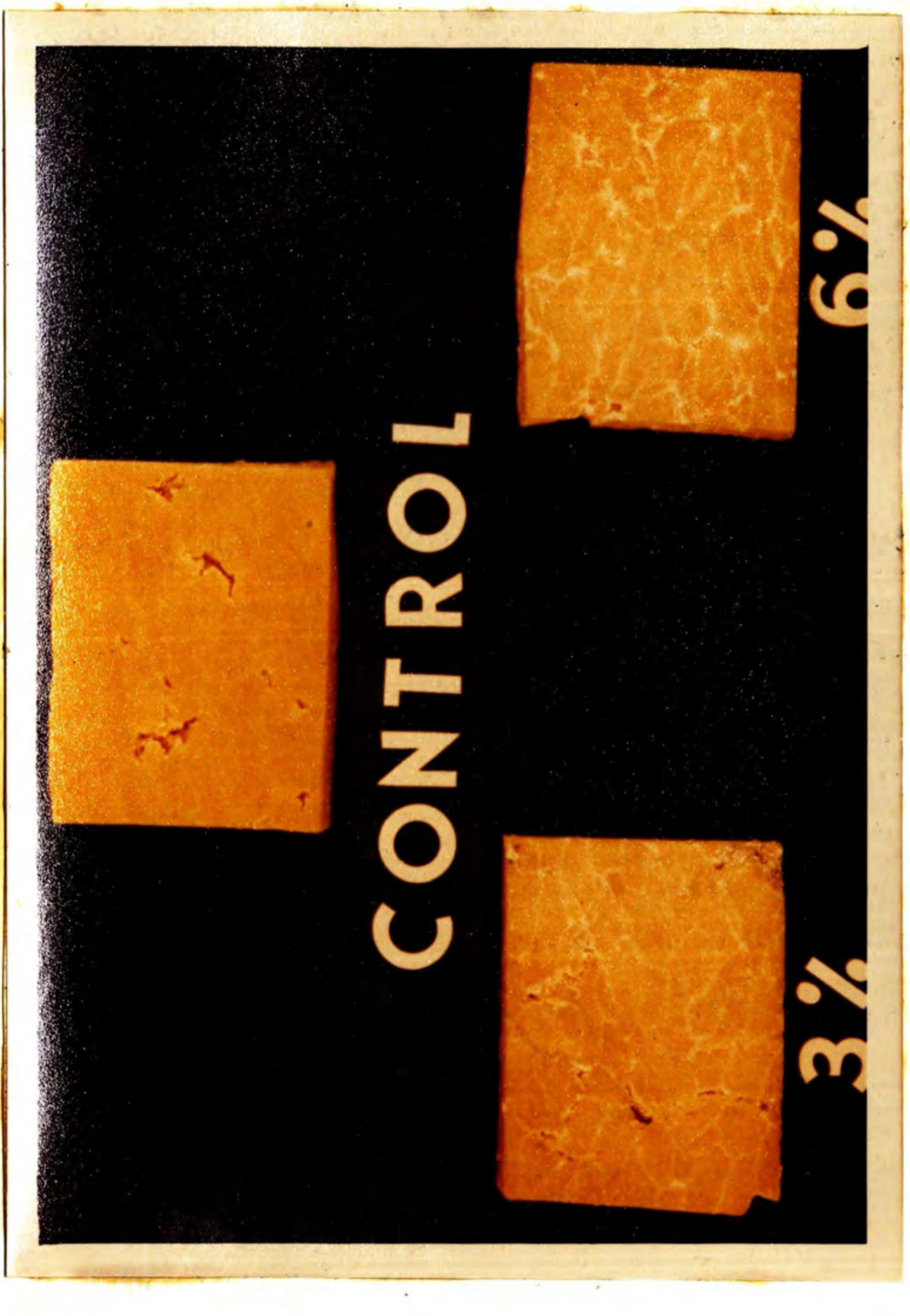
CONTROL
6%
3%

TABLE 12. Average monthly flavor[a] scores of cheddar cheeses[b].

Level of whey addition	Months									Overall	
	1	2	3	4	5	6	7	8	9	Mean	SE[c]
Control; no addition	8.06	8.33	8.51	8.70	8.99	9.05	8.71	8.76	8.46	8.62	.05
3% whey addition	7.90	7.76	8.01	8.06	8.05	8.19	7.81	7.63	7.55	7.89	.05
6% whey addition	7.68	8.00	7.90	7.78	8.04	7.67	7.58	7.38	7.50	7.72	.05

[a]Based on a hedonic scale with 10 as perfect score

[b]Monthly values are means of six replications

[c]Standard error

TABLE 13. Average monthly body and texture scores[a] of cheddar cheeses[b].

Level of whey addition	Months					Overall	
	5	6	7	8	9	Mean	SE[c]
Control; no addition	4.43	4.37	4.01	4.05	3.98	4.17	.05
3% whey addition	3.28	3.49	3.21	3.13	2.96	3.22	.05
6% whey addition	3.14	3.15	3.01	2.63	2.86	2.96	.05

[a]Based on a hedonic scale with 5 as perfect score

[b]Monthly values are means of six replications

[c]Standard error

TABLE 14. Statistical analysis of treatment effects on cheddar cheese flavor and body and texture.

Factor	Flavor[a]	Body and Texture[b]
Whey addition	**	**
Age of cheese	NS	NS
Whey addition x age of cheese	*	NS

[a]Based on a hedonic scale with 10 as a perfect score

[b]Based on a hedonic scale with 5 as a perfect score

*Significant (P<.05)

**Highly significant (P<.01)

The whey-addition treatment had a highly significant (P<.01) effect upon flavor and body and texture, with the controls consistently preferred over the whey-added cheeses. The main flavor defect noticed was a whey taint which was termed objectionable by most of the judges. While in some cases individual judges liked the flavor as well as that of the controls. The 3% whey addition cheese had a mean flavor score .73 (on a 10 point hedonic scale) lower than the control while the 6% whey addition cheese had a mean score .9 lower than the control over a 9 mo period.

Body and texture of the whey-added cheese was consistently judged inferior (P<.01) with criticisms such as mealy, gritty, short, and open being the most prevalent.

The age at which cheese was sampled did not have a significant effect; however, the cheese appeared to exhibit the best flavor development during the sixth month, when the highest ratings were received. After this period, more off-flavors such as unclean and bitter were noticed and the cheeses received lower ratings.

SUMMARY AND CONCLUSIONS

One objective of this research was to find a process to further utilize dry whey powder in human foods. Another objective was to determine whether this addition would increase cheese yields and still give an acceptable product after 9 mo of curing.

Fresh pasteurized milk was used to manufacture a total of six vats of cheddar cheese. Cheese was made using a conventional process and three identical aliquots were removed after the milling process and each was placed in a 190 liter vat. One aliquot, which served as the control, received 2% salt and was hooped. To one of the remaining aliquots, a mixture of salt (2% of curd weight) and whey (3% of curd weight) was added. To the final aliquot, a mixture of 2% salt (of curd weight) and 6% whey (of curd weight) was added. All three cheeses were pressed overnight, removed the following morning, wrapped, sealed, and stored at 5 C. Monthly samplings were taken for 9 mo.

Weights were accurately taken to ascertain yield information. Milk, dry whey, and cheese samples were analyzed for total solids, fat, total nitrogen, lactose, and ash. Cheese was also analyzed for soluble nitrogen, salt, and pH. Total protein was calculated by multiplying total nitrogen by 6.38. Solids-not-fat, milk lactose, and dried whey lactose were derived by difference. Flavor and body and texture was evaluated by a panel of judges on a monthly basis for 9 mo.

Using least squares analysis of variance to test the data, a highly significant increase (P<.01) in yields (expressed as kg of 63% solids cheese) was found to result from whey addition to cheeses. Highly significant differences (P<.01) were noted in flavor as well as body and texture, with the controls consistently receiving the highest ratings, in both categories. The cheese with 3% level of whey addition was preferred over that with the 6% level of whey addition; and both levels of whey addition produced an undesirable whey taint flavor. Not withstanding higher yields with whey addition, excessive pressing losses of the added whey solids, as well as flavor and body and texture defects, this process and the two levels of whey addition cannot be recommended for cheddar cheese production. However, modifications of this process could have some value at lower levels of whey addition with a stirred curd cheese such as colby, having smaller curd size, and hence, more surface area for absorption of whey constituents.

Due to lower protein values for the whey addition cheeses, the nutritive value of the resultant cheese was actually decreased.

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