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INFLUENCE OF CALCIUM AND PHOSPHORUS, LACTOSE, AND SALT-TO-MOISTURE RATIO ON CHEDDAR CHEESE QUALITY: PH CHANGES DURING RIPENING

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A combined effect of calcium, phosphorus, residual lactose, and salt-to-moisture ratio (S/M) of the cheese on the changes in cheese pH during ripening was investigated. Eight cheeses with 2 levels of Ca and P (0.67 and 0.47% vs. 0.53 and 0.39%, respectively), lactose at pressing (2.4 vs. 0.78%), and S/M (6.4 vs. 4.8%) were manufactured. All the cheeses were salted at a pH of 5.4, pressed for 5 h, and then ripened at 6 to 8°C. The pH of the salted curds before pressing and the cheeses during 48 wk of ripening was measured. Also, cheeses were analyzed for water-soluble Ca and P, organic P, and bound inorganic P during ripening. Changes in organic acids' concentration and shifts in the distribution of Ca and P between different forms were studied in relation to changes in pH. Cheeses with low S/M exhibited a larger increase in acid production during ripening compared with high S/M cheeses. Cheeses with the highest concentration of bound inorganic P exhibited the highest pH, whereas cheeses with the lowest concentration of bound inorganic P exhibited the lowest pH among the 8 treatments. Although conversion of lactose to short-chain, water-soluble organic acids decreased cheese pH, bound inorganic phosphate buffered the changes in cheese pH. Production of acid in excess of the buffering capacity (which was the case in low Ca and P and low S/M treatments) led to a low pH, whereas solubilization of bound inorganic P in excess to acid production (which was the case in high Ca and P and high S/M treatments) led to an increase in pH. However, for cheeses with high Ca and P and low S/M, changes in cheese pH were influenced by the level of residual lactose. Hence, pH changes in Cheddar cheese can be modulated by a concomitant control on the amount and state of Ca and P, level of residual lactose, and S/M of the cheese.

EFFECTS OF ULTRA-HIGH PRESSURE HOMOGENIZATION ON THE CHEESE-MAKING PROPERTIES OF MILK

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The effects of single- or 2-stage ultra-high pressure homogenization (UHPH; 100 to 330 MPa) at an inlet temperature of 30°C on the cheese-making properties of bovine milk were investigated. Effects were compared with those from raw, heat-pasteurized (72°C for 15 s), and conventional homogenized–pasteurized (15 + 3 MPa, 72°C for 15 s) treatments. Rennet coagulation time, rate of curd firming, curd firmness, wet yield, and moisture content of curds were assessed. Results of particle size and distribution of milk, whey composition, and gel microstructure observed by confocal laser scanning microscopy

were analyzed to understand the effect of UHPH. Single-stage UHPH at 200 and 300 MPa enhanced rennet coagulation properties. However, these properties were negatively affected by the use of the UHPH secondary stage. Increasing the pressure led to higher yields and moisture content of curds. The improvement in the cheese-making properties of milk by UHPH could be explained by changes to the protein-fat structures due to the combined effect of heat and homogenization.

APPLICATION OF FLUORESCENCE SPECTROSCOPY FOR MONITORING CHANGES IN NONFAT DRY MILK DURING STORAGE

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The objective was to determine if fluorescence spectroscopy could be used to characterize the biochemical characteristics of nonfat dry milk (NDM) caused by manufacturing and storage conditions. Nine low-heat NDM samples were collected from 3 manufacturers and stored at 4 temperatures (4, 22, 35, and 50°C) for 8 wk. The spectra of Maillard products, tryptophan, and riboflavin were recorded and analyzed with principal components analysis. Colorimetric indices L*, a*, and b* were also determined. The before-storage NDM samples collected from each manufacturer had different fluorescent characteristics. Inconsistency was observed for the NDM samples collected from 1 manufacturer, whereas the samples from the other 2 manufacturers displayed consistent fluorescence characteristics. Biochemical reactions, such as Maillard reaction, modification of the tryptophan environment, and degradation of riboflavin occurred during the manufacturing process. For each of the data collections, discrimination of the NDM samples stored at 50°C from the samples stored at 4, 22, and 35°C was observed in the similarity maps. The factor loadings of the first 2 principal components for the fluorescence spectra of the samples before storage were similar to the principal components analysis results of the samples during storage. It appears that similar factors are responsible for the variation in the samples before storage and their changes during storage. Additionally, storage of the samples at 50°C accelerated these reactions. The results demonstrate that front-face fluorescence spectroscopy, coupled with multivariate statistical methods, can be utilized as an analytical technique to monitor variation in NDM samples from different manufacturers and changes during storage.

LIPOLYSIS IN CHEDDAR CHEESE MADE FROM RAW, THERMIZED, AND PASTEURIZED MILKS

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The evolution of free fatty acids (FFA) was monitored over 168 d of ripening in Cheddar cheeses manufactured from good quality raw milk (RM), thermized milk (TM; 65°C x 15 s), and pasteurized milk (PM; 72°C x 15 s). Heat treatment of the milk reduced the level and diversity of raw milk microflora and extensively or wholly inactivated lipoprotein lipase (LPL) activity. Indigenous milk enzymes or proteases from RM microflora influenced secondary proteolysis in TM and RM cheeses. Differences in FFA in the RM, TM, and PM influenced the levels of FFA in the subsequent cheeses at 1 d, despite significant losses of FFA to the whey during manufacture. Starter esterases appear to be the main con-

tributors of lipolysis in all cheeses, with LPL contributing during production and ripening in RM and, to a lesser extent, in TM cheeses. Indigenous milk microflora and nonstarter lactic acid bacteria appear to have a minor contribution to lipolysis particularly in PM cheeses. Lipolytic activity of starter esterases, LPL, and indigenous raw milk microflora appeared to be limited by substrate accessibility or environmental conditions over ripening.

THE FORMATION OF CALCIUM LACTATE CRYSTALS IS RESPONSIBLE FOR CONCENTRATED ACID WHEY THICKENING

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The use of spray drying for dehydration of acid whey is generally limited by the appearance of uncontrolled thickening and solidifying of the whey mass during the lactose crystallization step. The origin of this physical change is still unknown and probably linked to complex interactions between physical properties and chemical composition of these products. To understand this phenomenon, they simulated the thickening of concentrated acid whey on a laboratory scale by measuring the flow resistance changes as a function of time and whey composition. The thickening process was characterized by an amplitude of torque and a lag time (induction time). Thickening of lactic acid whey concentrate occurred regardless of the presence of whey proteins or lactose crystals. Moreover, this work clearly demonstrated that the thickening process was due to the formation of filamentous structures corresponding to calcium lactate crystals and showed a large dependence on calcium and lactate contents, pH, and phosphate concentration.

INHIBITORY ACTIVITIES OF BOVINE MACROMOLECULAR WHEY PROTEINS ON ROTAVIRUS INFECTIONS IN VITRO AND IN VIVO

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In vitro studies have shown that human lactadherin, in contrast to the bovine ortholog, could inhibit rotavirus infectivity, and that bovine MUC1 and a commercially available bovine macromolecular whey protein (MMWP) fraction proved to be effective. The present work describes the versatility of MMWP against the infection of 2 human intestinal cell lines (Caco-2 and FHs 74 Int) by 4 different rotavirus strains (Wa, RRV, YM, RF). Isolation of a protein fraction (CM3Q3) from MMWP that effectively inhibits rotavirus infectivity in vitro is documented. Purification was achieved by monitoring the rotaviral inhibitory activity in fractions obtained from 2 consecutive steps of ion-exchange chromatography. The major component of CM3Q3 was shown to be bovine IgG, and the attenuating capacity of this fraction is most properly linked to this component. The capacity of MMWP, MUC1, lactadherin, and the CM3Q3 fraction to inhibit the infectivity of the murine EMcN rotavirus strain was analyzed in adult BALB/c mice by using 2 different amounts of virus (10 and 100 times more than 50% the viral shedding doses). Only CM3Q3 was able to significantly affect the shedding of rotavirus in the stools of experimentally infected mice when the high viral dose was given. Detection of rotavirus-specific serum antibodies

showed that the high dose infected all groups of mice. Experiments with the low dose of virus implied that all the tested milk proteins could affect the viral shedding in stools; in addition, use of MUC1, MMWP, and CM3Q3 prevented the appearance of serum viral antibodies. The advantages of using bovine immunoglobulins to induce passive immunity against rotavirus have been substantially investigated, although studies have mainly focused on the use of derivatives from immunized cows, especially colostrum. This report associates considerable activity against rotavirus infectivity with an ordinary whey product, suggesting that there might be alternatives to colostrum-derived products.

RESPONSE OF TWO SALMONELLA ENTERICA STRAINS INOCULATED IN MODEL CHEESE TREATED WITH HIGH HYDROSTATIC PRESSURE

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The objective was to determine the response to high hydrostatic pressure and the ability for survival, recovery, and growth of 2 strains of *Salmonella enterica* (*Salmonella enteritidis* and *Salmonella typhimurium*) inoculated in a washed-curd model cheese produced with and without starter culture. Inoculated samples were treated at 300 and 400 MPa for 10 min at room temperature and analyzed after treatment and after 1, 7, and 15 d of storage at 12 ° C to study the behavior of the *Salmonella* population. Cheese samples produced with starter culture and treated at 300 and 400 MPa showed maximum lethality; no significant differences in the baroresistant behavior of both strains were detected. Nevertheless, when starter culture was not present, the maximum lethality was only observed in cheese samples treated at 400 MPa, in the case of *S. enteritidis*. Ability to repair and grow was not observed in model cheese produced with starter culture and cell counts of treated samples decreased after 15 d of storage at 12 ° C. In cheese produced without starter culture, *Salmonella* cells showed the ability to repair and grow during the storage period, reaching counts over 3 log₁₀ (cfu/mL) in both applied treatments and serotypes. These results suggest that high hydrostatic pressure treatments are effective to reduce *Salmonella* population in this type of cheese, but the presence of the starter culture affects the ability of this microorganism to repair and grow during the storage period.

EFFECT OF PROTEIN-TO-FAT RATIO OF MILK ON THE COMPOSITION, MANUFACTURING EFFICIENCY, AND YIELD OF CHEDDAR CHEESE

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Twenty-three Cheddar cheeses were prepared from milks with a protein content of 3.66% (wt/wt) and with different protein-to-fat ratio (PFR) in the range 0.70 to 1.15; the PFR of each milk differed by 0.02. For statistical analysis, the 23 cheeses were divided into 3 PFR groups: low (LPFR; 0.70 to 0.85), medium (MPFR; 0.88 to 1.00) and high (HPFR; 1.01 to 1.15), which were compared using ANOVA. The numbers of PFR values in the LPFR, MPFR, and HPFR groups were 9, 7, and 7, respectively. Data were also analyzed by linear regression analysis to establish potentially significant relationships among the PFR and response variables. Increasing PFR significantly increased the levels of cheese moisture, protein, Ca, and P, but significantly reduced the levels of moisture in nonfat substances, fat-in-DM, and

salt-in-moisture. The percentage of milk fat recovered in the LPFR cheese was significantly lower than that in the MPFR or HPFR cheeses. In contrast, the recovery of water from milk to the LPFR cheese was significantly higher than that in the MPFR or HPFR cheeses. Increasing the PFR led to a significant decrease in the actual yield of cheese per 100 kg of milk but a significant increase occurred in the normalized yield of cheese per 100 kg of milk with reference values of fat plus protein (3.4 and 3.3%, wt/wt, respectively). The results demonstrate that alteration of the PFR of cheese milk in the range 0.70 to 1.15 has marked effects on cheese composition, component recoveries, and cheese yield.

SOLVENT TYPE AFFECTS THE NUMBER, DISTRIBUTION, AND RELATIVE QUANTITIES OF VOLATILE COMPOUNDS FOUND IN SWEET WHEY POWDER

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This study compares the performance of diethyl ether, methylene chloride, methyl formate, and pentane in the analysis of volatile flavor components in sweet whey powder. Extracts were prepared from sweet whey powder using each solvent. Volatile components were isolated by solvent extraction followed by solvent-assisted flavor evaporation. Gas chromatography-mass spectroscopy, coelution with known standards, and retention indices were used to identify the volatile compounds. Sixty total compounds were either positively or tentatively identified across all 4 solvents, but the number, distribution between the molecular classes, and relative quantities detected depended on solvent type. The highest number, widest distribution, and greatest relative quantities were found using methylene chloride and methyl formate, whereas diethyl ether and especially pentane were noticeably less effective. Results are characterized using molecular-based characteristics of solvents and solutes including dipole moment, dielectric constant, Log P (octanol-water partition coefficient), polarizability, water solubility, and Lewis acidity/basicity. Polarity and acidity/basicity were the primary factors that determined solvent performance. This work establishes a molecular-level basis for the selection of solvents in the analysis of sweet whey powder flavors.

DAIRY POWDER REHYDRATION: INFLUENCE OF PROTEIN STATE, INCORPORATION MODE, AND AGGLOMERATION

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A simplified method to study rehydration was used on different dairy powders. The method involved dispersing powder in a stirred vessel equipped with a turbidity sensor. The changes of turbidity occurring during powder rehydration highlighted the rehydration stage, and the influence of the proteins' state on rehydration was clarified. Casein powders had a quick wetting time but very slow dispersion, making the total rehydration process time-consuming. On the other hand, whey powders were found to have poor wettability but demonstrated immediate dispersion after wetting. Mixing casein (80%) and whey (20%) before spray drying greatly improved rehydration time compared with casein powder; whereas mixing whey powder with casein powder at the same ratio after spray drying caused a dramatic deterioration in the rehydration properties. Moreover, agglomeration was found to significantly improve the rehydration time of whey protein powder and to slow down the rehydration time of casein

powder. These opposite effects were related to the rate-controlling stage (i.e., wetting stage for whey protein and dispersion stage for casein).

EFFECT OF β -LACTOGLOBULIN A AND B WHEY PROTEIN VARIANTS ON THE RENNET-INDUCED GELATION OF SKIM MILK GELS IN A MODEL RECONSTITUTED SKIM MILK SYSTEM

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The effect of fortifying reconstituted skim milk with increasing levels of the β -lactoglobulin (β -LG) genetic variants A, B, and an A-B mixture on rennet-induced gelation was studied by small deformation-sensitive rheology. Free-zone capillary electrophoresis and high-sensitivity oscillatory rheology were used to elucidate the role of potential heterotypic associative interactions between whey proteins and casein in a mixed colloidal system, subjected to moderate heating (65°C for 30 min) prior to renneting, on the gelling properties of the system. Increasing levels of added whey protein, in the concentration range of 0.225 to 1.35% of added protein, led to a concomitant progressive increase in the equilibrium shear storage modulus, G' (recorded after $\sim 10,800$ s), in the order β -LG B > β -LG A and β -LG A-B, as the general expected consequence of the setup of denser casein gel networks. The preferential effect of β -LG B over β -LG A on the mechanical strength of the gels may be due to the formation of cross-links and aggregates involving whey proteins and rennet hydrolysis products or an increase in the size of the casein micelle caused by the grafting of β -LG B to its surface, or both. The results of free-zone capillary electrophoresis were consistent with the notion that β -LG B (and not β -LG A) binds to the casein micelle under an optimal stoichiometry of 1:0.045 (mg/mg), even in the absence of heat treatment. The liquid-like character of the gel networks formed, $\tan \delta$, was a parameter sensitive to the level of addition of β -LG A in particular. At low concentrations (up to 0.45%) of β -LG A, $\tan \delta$ increased by almost twice as much, which was interpreted as a result of the increase in the loss modulus, G'' , of the sol fraction because of the presence of unbound β -LG A. At greater incremental concentrations of β -LG (>0.45%), the formation of smaller whey protein aggregates confined to the sol fraction may have led to a progressive decrease in $\tan \delta$. The critical gel time, t_{gel} , was also affected by the concentration of added whey protein and described 3 zones of behavior, irrespective of the type of whey protein variant. The critical gel time was slightly shorter for β -LG B than for β -LG A at 0.45% of added whey protein, but this difference became larger at 0.67%. Even when only β -LG B was found to associate with casein prior to renneting, both β -LG A and β -LG B, either alone or mixed, had a profound influence on the mechanical strength and coagulation kinetics of the rennet-induced casein gels. This knowledge is expected to be useful to exert better control and optimize processing conditions during the manufacturing of cheese and cheese analogs.

VALUATION OF MILK COMPOSITION AND GENOTYPE IN CHEDDAR CHEESE PRODUCTION USING AN OPTIMIZATION MODEL OF CHEESE AND WHEY PRODUCTION

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A mass balance optimization model was developed to determine the value of the κ -casein genotype and milk composition in Cheddar cheese and whey production. Inputs were milk, nonfat dry milk, cream, condensed skim milk, starter and salt. The products produced were Cheddar cheese, fat-reduced whey, cream, whey cream, casein fines, demineralized whey, 34% dried whey protein, 80% dried whey protein, lactose powder, and cow feed. The costs and prices used were based on market data from March 2004 and affected the results. Inputs were separated into components consisting of whey protein, ash, casein, fat, water, and lactose and were then distributed to products through specific constraints and retention equations. A unique 2-step optimization procedure was developed to ensure that the final composition of fat-reduced whey was correct. The model was evaluated for milk compositions ranging from 1.62 to 3.59% casein, 0.41 to 1.14% whey protein, 1.89 to 5.97% fat, and 4.06 to 5.64% lactose. The κ -casein genotype was represented by different retentions of milk components in Cheddar cheese and ranged from 0.715 to 0.7411 kg of casein in cheese/kg of casein in milk and from 0.7795 to 0.9210 kg of fat in cheese/kg of fat in milk. Milk composition had a greater effect on Cheddar cheese production and profit than did genotype. Cheese production was significantly different and ranged from 9,846 kg with a high-casein milk composition to 6,834 kg with a high-fat milk composition per 100,000 kg of milk. Profit (per 100,000 kg of milk) was significantly different, ranging from \$70,586 for a high-fat milk composition to \$16,490 for a low-fat milk composition. However, cheese production was not significantly different, and profit was significant only for the lowest profit (\$40,602) with the κ -casein genotype. Results from this model analysis showed that the optimization model is useful for determining costs and prices for cheese plant inputs and products, and that it can be used to evaluate the economic value of milk components to optimize cheese plant profits.