This scheme allows natural cheeses to be grouped into ~13 relatively homogeneous groups based on method of coagulation of milk and characteristic scientific/technological features of manufacture/ripening.

Scheme not without inconsistencies:
No account of species of milk
Some groups remain heterogeneous

But what do we mean by a “cheese variety”...

Cheesemaking

Two well-defined stages.

Milk
Preparation of milk
Selection
Standardisation
Pasteurisation
Others?

Acidification
Coagulation
Synergistic (delysoyation)
Cut
Cook
Agitation
Other operations
Checkin
Kneading/stretching
Pressing
Salting

Ripening (2 wk - 2 yr)

MATURE CHEESE

Development of microflora
Metabolism of residual lactose
Lactate metabolism
Citrate metabolism
Protocell
Lipolysis
Secondary reactions
Fatty acid catabolism
Amino acid catabolism

Stages of manufacture

Milk, heating, and retention
Preparation of ripening
Environment and ripening

Ripening
Development of microflora
Metabolism of residual lactose
Lactate metabolism
Citrate metabolism
Protocell
Lipolysis
Secondary reactions
Fatty acid catabolism
Amino acid catabolism

Cheese manufacturing
Cheese ripening
Cheese modification
Cheese maturity
Bacteriology of cheesemilk

- Milk sterile in udder
  - Unless mastitis
- Mixed flora soon after milking
- Cooling affects rate of multiplication, type of flora
- If milk cooled, Gram -ve psychrotrophs dominate
  - Pseudomonas, Achromobacter, Flavobacterium
- If milk not cooled, Gram +ve lactic acid bacteria
  - Lactobacillus, Lactococcus, Enterococcus...

Bacteriology of cheesemilk

- Milk received at factory perhaps at <50,000 cfu ml⁻¹
  - Stored maybe for 24 h
  - Counts immediately before pasteurization ~10⁵ cfu ml⁻¹
- If counts much >10⁶ cfu ml⁻¹, may affect quality
  - If milk stored under refrigerated conditions, mainly psychrotrophs
- Heat labile organisms but heat stable enzymes
  - Lipases, proteinases
  - Effect on ripening, yield

Pasteurization

- Widespread since 1940s
  - Public health concerns
  - More consistent quality
- Usual in large cheese factories
- >99.9% bacteria in raw milk killed
  - All potential pathogens killed
  - Spores survive (Bacillus, Clostridium)
  - Thermotolerant organisms (Micrococcus, Microbacterium, Enterococcus). Most grow slowly in milk (except enterococci)
- Several enzymes inactivated
  - Lipoprotein lipase
  - Alkaline phosphatase
  - Plasmin (increase)
- Partial denaturation of whey proteins, interaction with κ-casein through –S-S– bonds
Pasteurization

- Heating milk > HTST?
  Mycobacterium avium ssp. paratuberculosis
- High heat treatment of milk causes problems with rennet coagulation
  Longer coagulation times
  Weaker, finer curd which retains more moisture
- Strategies to solve problem…
  Decrease pH of heated milk to about 6.2
  pH cycling (acidify heated milk to pH 5.5 followed by neutralization)
  CaCl₂

Raw vs pasteurized milk cheeses

- Public health concerns (particularly small cheesemakers)
- Genuine difference
  Flavour of pasteurized milk cheese develops more slowly that raw milk cheese
  Differences in NSLAB flora main difference (although inactivation of some enzymes contributes)
- Widespread in southern Europe…
- Regulations?

Raw vs pasteurized milk cheeses

- Safety factors….
  High cooking temperature
  >50°C for some varieties: gives some measure of protection
  USA: aging > 60 d (>1.7C) Time for pathogens to die off?
  “Pasteurize cheese” itself
  i.e., processed cheese made from raw milk cheese (rare)
- Most concern with soft cheeses (↑pH) and small producers
- Essentially impossible to make cheese on very large scale from raw milk…
Standardisation of Cheesemilk

- Composition of milk varies, affected by breed, individuality of animal, feed, stage of lactation, health of animal (e.g., mastitis)
- Therefore, cheesemaking properties vary,
  - Rennet coagulability
  - Strength of coagulum
  - Syneresis of curds
- Composition of curds varies
- FDM of cheese specified
- Yield of cheese varies
- Quality of cheese varies

Standardization

- On-line standardization normal in industry...
- Density meter, in-line IR systems...

Ultrafiltration of cheesemilk

- Much experimental work
- “Cast” Feta in Denmark, acid-curd cheeses
- Low concentration factor (CF): protein standardization (1.5x maximum)
- Medium CF (2-6x): high moisture cheese
- High CF
Cheese colouring

- Mainly British-type cheeses
- ‘Red’ Cheddar
  - 15% of world’s cheese annatto coloured
- Colouring sometimes added to Dutch cheeses
- Annatto
  - From inedible fruits of Achiote tree (Bixa orellana)
  - 80% to curd; 20% to whey
  - Others...
  - β-carotene

Sheep, Goat and Buffalo Milk

- No carotenoids, very white
- When cows’ milk used to simulate products normally made from sheep, goat or buffalo milk, carotenoids bleached (benzoyl peroxide) or masked (chlorophyll or TiO₂)

Stages of manufacture

- [Diagram showing stages of cheese manufacture]
Starters

- Lactic acid from lactose by lactic acid bacteria; before ~ 1880 depended on indigenous microflora
- Variable, unpredictable poor quality
- A culture of lactic acid bacteria used: **Starter**
  - "Start" acid production
  - Acidification promotes rennet action
  - Aids in whey expulsion
  - Inhibits growth of undesirable microorganisms
- Mesophilic (optimum temperature ~30°C)
- Thermophilic (optimum temperature ~42°C)

Starters

- **Defined-strain cultures**
  - Known combinations of known strains
  - Used commercially in most large Cheddar plants
  - Usually 2-3 strains used in combination
- **Mixed-strain cultures**
  - Unknown numbers of strains of the same species and genus and perhaps other genera

Starters

- Main microorganisms in mesophilic starters are...
  - *Lactococcus lactis* subsp. *lactis*
  - *Lc. lactis* subsp. *cremoris*
  - *Leuconostoc* sp.
- Mixed-strain cultures...
  - "L" cultures contain *Leuconostoc* sp.
  - "D" cultures contain citrate-positive lacticocci ("Streptococcus diacetylactis")
  - "DL" contain both
  - "O" cultures contain no aroma producer
Starters

• Thermophilic cultures contain rod and coccus…
  
  Rod = *Lactobacillus*
  *Lb. helveticus, Lb. delbrueckii ssp. lactis…*
  
  Coccus = *Streptococcus thermophilus*
  
• Rod, coccus usually grown together for yogurt, separately for cheese
• Symbiosis,
  Rod produces amino acids, coccus small amounts of CO$_2$,
  formic acid from lactose

Artisanal cultures…

• Natural microflora of raw milk
• Whey cultures (“backslopping”)

Adjunct cultures…

• Used to improve flavour of hard cheeses not for acidification
• Selected strains of lactobacilli, *Str. thermophilus…*

Secondary cultures

• *Traditional* cultures added for some reason other than acid production
  
  • *Propionibacterium freudenreichii* in Swiss cheese
  *Penicillium camemberti* in Camembert, Brie
  *P. roqueforti* in Blue cheese
  Complex Gram-positive flora in smear cheeses
Metabolism of lactose

<table>
<thead>
<tr>
<th>Organism</th>
<th>Transport</th>
<th>Pathway</th>
<th>Cleavage Enzyme</th>
<th>Products (mols/lactose)</th>
<th>Isomer of Lactate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lactococcus</td>
<td>PEP-PTS</td>
<td>GLY</td>
<td>P-galactosidase</td>
<td>4 lactate</td>
<td>L</td>
</tr>
<tr>
<td>Leuconostoc</td>
<td>Permease</td>
<td>PK</td>
<td></td>
<td>2 lactate + ethanol + 2 CO₂</td>
<td>D</td>
</tr>
<tr>
<td>L. delbrueckii</td>
<td>Permease</td>
<td>GLY</td>
<td></td>
<td>2 lactate</td>
<td>L</td>
</tr>
<tr>
<td>L. helveticus</td>
<td>Permease</td>
<td>GLY</td>
<td></td>
<td>4 lactate</td>
<td>DL</td>
</tr>
</tbody>
</table>

PEP = phosphoenolpyruvate; PTS = phosphotransferase system; PK = pyruvate kinase; P-galactosidase; These species metabolise only the glucose moiety of lactose.
Metabolism of Nitrogen by LAB

- Milk contains low concentrations of amino acids and small peptides
  - Sufficient to support growth of starter to ~ 20% of required population
- Starter must obtain amino acids from milk proteins (mainly caseins)
- LAB weakly proteolytic but have a broad proteolytic system

Nitrogen metabolism

- Intracellular proteinases (3-4)
  - Endopeptidases
    - (PepO, PepF)
  - Aminopeptidases
    - (PepN, PepC, PepA, PCP)
  - Proline-specific peptidases
    - (PepX, PepF, PepR, PepQ, PepP)
  - Dipeptidase
    - (PepV, PepD, PepDA)
  - Tripeptidase
    - (PepT)

Citrate metabolism
Plasmids…

- Extrachromosomal pieces of DNA, easily lost on subculturing
- Genes for proteinase, citrate transport, lactose metabolism, bacteriophage resistance…

Inhibition of acid production

- Natural inhibitors
  "Lactenins" (immunoglobulins, lactoperoxidase system, etc.)
- Antibiotics
  Control of mastitis. Less problem now due to education of farmers; rapid, simple tests
- Bacteriocins
  Peptides produced by bacteria which inhibit (usually closely related) bacteria. Some have broad host range

- BACTERIOPHAGE!

Bacteriophage
Bacteriophage

- Phage resistance mechanisms
  - Inhibition of φ adsorption
  - Restriction / modification
  - Abortive infection

- Detection of φ

Control of φ

- Make sure bulk starter free from φ
  - Severe heating (~85°C x 30 min) of bulk starter material in tank in which starter will be grown
  - Filter air through HEPA filter
  - Slight positive pressure in tank, starter room
  - Aseptic inoculation
  - φ inhibitory media

  - Rotation of φ-unrelated strains
    e.g., A,B followed by C,D then return to A,B
  - Add rennet as soon as possible after starter
  - Hygiene
  - Genetic approaches…

  - Count φ daily in starter, whey?

Production of starters in cheese plants

- Up to 30 years ago, milk used to grow starter
- Now φ-inhibitory media
  - Contain milk or whey solids, yeast extract
  - Citrate, phosphate to bind Ca²⁺ necessary for φ multiplication
- Heat to >85°C x 30 min in tank, cool…
  - ~42°C (thermophilic), ~21°C (mesophilic)
- Inoculate ~1% of culture incubate…
  - 8-10 h (thermophilic), overnight (16 h) mesophilic
Production of starters in cheese plants

- In past, bulk cultures built up progressively
- Minimum subculturing desirable (prevents loss of plasmids, maintains strain balance)
- Now 'bulk set' cultures. Buy in amounts to inoculate 300-1000 L culture
- pH controlled to increase growth of cells
  - External control (pH monitor, alkali)
  - Internal control (insoluble buffer, e.g., MgO, dissolves as pH ↓ and maintains pH ~5.3)

Concentrated cultures

- Straight from packet to vat
  - "Direct vat set", "Direct vat inoculation"

- Relatively expensive but no need for starter rooms…
  - Use as standby?, small plants, some larger plants…

pH and cheese

- Coagulant and proteolysis
- Gel strength
- Syneresis and moisture control
- Affects microflora
- Ca equilibrium
pH and cheese

**Coagulant and proteolysis**

- Gel strength
- Syneresis and moisture control
- Affects microflora
- Ca equilibrium

**Activity of chymosin, plasmin and other enzymes**

- Low pH favours chymosin
- High pH favours plasmin

**Retention of coagulant in the curd**

**Fig. 20** Relation between curd tension and the relation of pH produced by addition of a HCl to nonfat milk powder at 8 and 11% solids.

**Objective**

- The main objective is to study the relationship between pH and cheese syneresis and moisture control, affecting microflora, Ca equilibrium, coagulant, and proteolysis.

**Gel strength**

- pH 4.5, 5.0, 5.5, 6.0, 6.5, 7.0

**Enzyme activity unit (mmol pdt. mg dry matter -1 hr -1 )**

- pH at whey drainage (chymosin)
- pH of milk (chymosin)
- pH of milk (C. parasitica proteinase)

**Retention of coagulant in the curd**

- pH 4.5, 5.0, 5.5, 6.0, 6.5, 7.0

**Objective**

- The main objective is to study the relationship between pH and cheese syneresis and moisture control, affecting microflora, Ca equilibrium, coagulant, and proteolysis.
pH and cheese

Acidification of milk causes colloidal calcium phosphate to dissolve

$\text{Ca}_3(\text{PO}_4)_2 + 2\text{HCl} \rightarrow \text{Ca}^{2+} + 2\text{HPO}_4^{2-} + 2 \text{Cl}^-$

Transfer of Ca from micelle to serum

If before whey drainage, $\text{Ca}^{2+}$ lost in whey

pH and cheese

Effects on texture: high $\text{Ca}^{2+}$ gives long (rubbery) curd, low $\text{Ca}^{2+}$ leads to short (crumbly) curd

Continues during ripening. Equilibrium between casein-bound Ca and soluble Ca affects hardness
Colloidal stability of milk proteins

- Casein micelles: colloidal aggregates of $\alpha_s1$, $\alpha_s2$, $\beta$- and $\kappa$-casein and "colloidal calcium phosphate"
- $\kappa$-Casein predominantly on the surface of the micelle Stabilizes micelle; otherwise $\alpha_s1$, $\alpha_s2$, $\beta$-casein would precipitate in presence of $\text{Ca}^{2+}$ (due to presence of phosphate groups)

Enzymatic coagulation of milk

- Enzymatic coagulation of milk involves modification of the casein micelle via limited proteolysis of $\kappa$-casein by selected proteinases in preparations called rennets followed by $\text{Ca}^{2+}$-induced aggregation of the rennet-altered micelle

Stages of manufacture

- 1st Stage: Casein + Rennet
- 2nd Stage: $\text{Ca}^{2+}$, >18°C
- Gel
Enzymatic coagulation of milk

- Macropeptides lost in whey: 4-5% total casein, unavoidable loss
- Removal of macropeptides reduces zeta (surface) potential of micelle from $-20$ to $-10$ mV. Also removes steric stabilizing layer
- When ~85% of total $\kappa$-casein hydrolyzed, colloidal stability of micelles reduced so that they coagulate at temperatures $>18^\circ$C in the presence of Ca$^{2+}$ ions

Rennets

- “Rennet” is a general term for proteinase preparations used to coagulate milk. Rennets contain one or more proteinases
- Traditional rennets are brine extracts from stomachs of young milk-fed mammals (calf rennet, lamb rennet, kid rennet)
- Fresh or dried stomachs (vels) are extracted with 10-12% NaCl, and standardised with respect to milk clotting activity and colour (cosmetic);
- Added NaCl and Na benzoate, as preservatives
- Principal proteinase in calf rennet is chymosin
  But ~10% milk clotting activity is due to pepsin (as animal ages, % chymosin ↓, % pepsin ↑)

Chymosin

- Chymosin is an aspartyl (acid) proteinase. Two essential Asp residues at active site. Globular structure with cleft. MW ~36 kDa. pH optimum for hydrolysis of Phe-Met bond is 5.1-5.5
- General proteolytic activity of chymosin low proteolysis relative to milk-clotting activity (“proteolysis : MCA” ratio)
Characteristics of good rennet substitutes

- High milk clotting : proteolytic ratio
- Proper specificity
- Good activity in milk
- Easily denatured (in whey)
- Few suitable enzymes…

Rennet substitutes: Pepsins

- Bovine pepsin quite effective. Naturally present in calf rennet (usually ~10% MCA, but can be up to 50% depending on age of animal at slaughter)
- Porcine pepsin. Very sensitive to denaturation > pH 6.7 (useful for making "rennet-free" curd)
- Chicken pepsin. Very proteolytic. Rarely used.

Rennet substitutes: Microbial aspartyl proteinases

- Naturally produced by yeasts, moulds
- Rhizomucor (Mucor) mehei proteinase most important
- Cryphonectria (Endothia) parasitica proteinase (suitable for high-cook cheeses as more proteolytic)
- Also R. pusillus
- Fungal proteinases show pH optima similar to that of chymosin but their temperature optima is significantly higher (>63°C for R. mehei proteinase)
- Commercially available enzymes often destabilised by oxidation to reduce heat stability and non-specific proteolysis
Rennet substitutes: Recombinant chymosins

- Gene from calf chymosin cloned into Kluyveromyces lactis, Aspergillus niger, E. coli
- Calf chymosin produced by fermentation
- MAXIREN (DSM Food Specialities, Delft, NL) CHYMAX (Chr Hansen, DK)
- Excellent results
- Regulatory hurdles?
- Vegetarian status
- Most Irish Cheddar made using these coagulants

Rennet pastes

- Produced by grinding semi-dry stomach into paste (not extraction) with addition of NaCl. In addition to chymosin, contains potent lipase, pregastric esterase which leads to much lipolysis during ripening
- Secreted by a gland at the base of the tongue; secretion is stimulated by suckling; washed by ingested milk into the stomach. The animal (calf, kid of lamb) is slaughtered after suckling, its stomach, with contents, removed and stored for up to 60 days, and then macerated to yield the rennet paste.
- Lipase activity depends on age and state of stomach at slaughter, drying and salting procedures.
- (Low pH used to activate enzyme precursors during manufacture of rennet extracts inactivates lipases)
- Problems: time consuming and complex to prepare (often on farm), insufficient commercial supply, lack of standardization of enzyme activities, lower microbiological quality

Cheeses made using rennet paste

- Cheeses originating around Mediterranean basin
- Provolone, Pecorino varieties, traditional Greek Feta, Kefalotiri, some Spanish Idiazabal…
Plant rennets

- Fig rennet mentioned in Homer’s Iliad
- Most too proteolytic...
- Proteinases from Cynara cardunculus most useful

Coagulation of rennet-altered micelles

Courtesy of Dr Mark Auty, Teagasc, Moorepark
Coagulation of rennet-altered micelles

- Actual reactions leading to coagulation not fully clear
- Ca\(^{2+}\) essential but Ca\(^{2+}\)-binding does not change on coagulation
- Colloidal CaP essential >20% reduction in [CCP] prevents coagulation
- Hydrophobic interactions essential Coagulum soluble in urea
- Electrostatic interactions?
  Moderately high \(\mu\) has adverse effect
- Coagulation very temperature sensitive
  Will not occur <18°C

Causes of aggregation

The C-terminal sequence of \(\kappa\)-casein, i.e. the macropeptide region, is strongly hydrophilic; contains sugars, many polar and few hydrophobic (or aromatic) residues.

Therefore, release of the macropeptide causes:

1. A reduction in the surface (zeta) potential of the micelles form ~ -20mV to ~ -10mV
2. Removal of the stabilizing hairs from the surface of the micelles (loss of steric stabilisation).
3. Reduce solvation.

Therefore, stability of micelles reduced.
Factors affecting RCT

- **Temperature**
  - Optimum ~40°C but milk set at ~30°C because of starter.

Why does milk not coagulate < 18°C?

- Possible hypothesis… (Bansal et al.)
  - β-casein depopulated milk does not coagulate in the cold. But if hydrolysis of β-casein inhibited after renneting (by pepstatin), milk does not coagulate. Perhaps effect related to hydrolysis of β-casein? Some more work needed.

Factors affecting RCT

- **pH**
  - Rate of coagulation increases as pH decreases as moving closer to optimum for chymosin.
Factors affecting RCT

- **[Ca\(^{2+}\)]**
  Effect mainly on 2\(^{nd}\) stage of rennet coagulation (slight effect on 1\(^{st}\) stage due to ↓ pH)

- **Pre-heating**
  Initially, slight ↓ in RCT as precipitation of CCP causes ↓ pH
  However, heating >70ºC causes denaturation of β-lg, interacts with κ-casein via –S-S–
  Major adverse effects on 1\(^{st}\), 2\(^{nd}\) stage of rennet coagulation
Factors affecting RCT

- [Rennet]

Factors affecting RCT

- [Protein]
**Rennet Hysterisis**

- Heating milk > 65°C x 30 min or > 75°C x 15 s increases RCT.
- If heated milk is cooled and held cold before renneting, RCT increases further.
- The lower the storage temperature and the longer the time → the greater the increase.
- This increase is referred to as Rennet Hysteresis.

---

**Causes of Rennet Hysteresis**

Adverse effects of heating caused by denaturation of β-lg offset to some extent by beneficial effect of lower pH on caused by heating. However, heat-induced changes to milk salts equilibria are partly reversible on cooling so full adverse effects of protein-protein interaction become apparent.

---

**Determination of cutting time**

- Traditional...
- Multi-vat factories cut at predetermined TIME
- In-vat sensors?
Factors that affect Gel Strength

- Casein concentration
- Ca\textsuperscript{2+} concentration
- pH
- Pre-heat treatment
- Homogenisation
- Inversely related to RCT

Stages of manufacture

Conversion of gel to curd

- After gel has formed, it is subjected to various treatment to encourage expulsion of whey
- Rennet gels stable if undisturbed, but if cut, broken or exposed to pressure, para-casein matrix contracts expressing aqueous phase
- SYNERESIS
- Allows cheesemaker to control moisture (hence quality, ripening, stability of cheese)
Cutting of Gel

- High moisture cheese: gel not cut, scooped into moulds
- Medium- and low-moisture cheese:
  - Cut manually using
    - harp or spina
    - Horizontal and vertical wire knives
    - Mechanically, stripper attached vats
- Size of curd particles
  - Syneresis proportional to surface area

Examples of Cutting Equipment
Influence of milk composition on syneresis

- ↑ [Fat] ↓ syneresis
  - Increasing fat increases cheese yield by 1.2 x mass of additional fat
- ↑ [Casein] ↑ syneresis
- ↓ pH of milk ↑ syneresis (syneresis optimal at pH 4.6)
- Ca\(^{2+}\) generally improves syneresis
- NaCl added to milk (e.g., Domiati)
  - low [NaCl] improves, high [NaCl] disimproves syneresis

Processing variables influencing syneresis

- Size of curd particles
  - Smaller the pieces, the greater the surface area for whey expulsion hence the greater the syneresis
  - Curd for high moisture cheeses not cut but scooped into mould
- Rate of acidification
  - Lower the pH, greater the syneresis
Processing variables influencing syneresis

- **Cooking temperature**
  - "Cooking", "scalding" promotes syneresis
  - Camembert (high moisture) ~31°C
  - Gouda, Edam ~36°C
  - Cheddar 38-39°C
  - Emmental, Parmigiano-Reggiano 52-55°C

- **Cook temperature must match starter**
  - Acid production by lactococci slowed ~35°C, many strains killed >40°C (cf., Cheddar cooking temperature)
  - Thermophilic starter do not grow >~52°C and so at 55°C (cook temperature of Swiss cheese) syneresis is due to heat (starter grows as curd cools < 52°C)
  - Cooking normally done using jacketed vats
  - Dutch-type cheeses: 30-40% whey removed, replaced with hot water
    - "Curd washing", reduced lactose, controls pH
  - Rate of cooking important
    - If too fast at early stages, "case hardening" which retards further whey loss

- **Stirring curds/whey mixture**
  - Stirring facilitates cooking, prevents curd pieces from fusing, promotes syneresis by collisions with other curd pieces, vat wall
  - Stir gently after cutting curd
    - Otherwise curd shattering (yield losses)
    - Often leave 5-10 min "healing time"
  - Cheddar: stir and cook to desired pH (6.1-6.2)
    - Many varieties (e.g., Emmental): drain whey at desired temperature
  - "Dry stirring" promotes syneresis
    - Stirred-curd Cheddar, Colby
Processing variables influencing syneresis

- Salting promotes syneresis
  But NEVER used to control moisture
- Other factors...
  Severely heated milk \( \downarrow \) syneresis
  Homogenization \( \downarrow \) syneresis
  \( \uparrow \) [psychrotrophic enzymes], \( \uparrow \) [plasmin] \( \downarrow \) syneresis
  \( \uparrow \) [rennet] \( \downarrow \) syneresis (slightly but other problems!)

Mechanism of syneresis

- Initially, rate proportional to amount of whey remaining in curd (1º reaction)
- Volume of whey <70% of initial volume rate of syneresis becomes dependent on factors other than [whey]
- Caused by protein-protein interactions
  Ionic interactions, H-bonds, \( \varepsilon \)-amino groups of Lys implicated.
  Later hydrophobic, ionic interactions
- Continuation of gel assembly process
Treatment of Curd

Curd separated from whey:
- Various methods, characteristic of variety

Washing of curd, e.g., Dutch varieties:
- To reduce lactose content, control pH, etc

Curd placed in moulds: characteristic size and shape;
- Significant for ripening → not just cosmetic

Draining of whey continues

Pressure may be applied: characteristic of variety

Saliing

Stretching (pasta-filata)

Whey drainage

- Drain whey at desired pH (e.g., Cheddar) or at max scald (e.g., Emmental)
- Usually drain through perforated screens (avoiding yield losses)
- pH at whey drainage critical
  - Low pH, much dissolution of colloidal calcium phosphate, low [Ca^{2+}] in curd, crumbly texture
  - High pH, high [Ca^{2+}] in curd, elastic curd
“Cheddaring”

- Traditionally, curd flows under its own weight, curds fuse, particle deformation, at end of cheddaring, “texture of chicken breast meat”

“Cheddaring”

- Strong evidence that cheddaring simply only allows time for acidification
- Physicochemical changes to curd…

“Cheddaring”

- Modern continuous cheddaring systems
Cheddar Process

Pasta-filata cheeses

- Curds stretched at end of acidification
- Curds heated in hot water (~78°C) to curd temperature 58-60°C and kneaded
- Optimum pH 5.15
  - Hydration as pH, curd less smooth
  - pH > 5.4, poor plasticization
- Casein hydration determined by pH, [Ca], ratio of soluble to colloidal Ca
- Casein fibres assume parallel orientation, hot molten sheets, fat coalesces into elongated pools. Fat lubricates flow of paracasein matrix
- Extension and shear stresses aids in displacement of contiguous planes of paracasein matrix
- Inactivation of much rennet activity
Mozzarella curd at end of acidification prior to stretching (Turin 2005)

Pasta-filata cheeses

- Cheese develops a fibrous, meat-like texture
- Essential for good meltability/stretchibility of Mozzarella
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