Wisconsin Center for Dairy Research

DAIRY PIPELINE

A Technical Resource for Dairy Manufacturers

Fall 1998, Volume 10 Number 4

The Great Cheddar Debate

Bill Wendorff[1], Mark Johnson[2] and Norm Olson[1]
[1]Dept. of Food Science and [2]Center for Dairy Research, University of Wisconsin-Madison

At our recent Cheese Artisan Course, Cheddar Cheese Flavor Workshop, we were discussing the diversity of Cheddar cheeses produced throughout the world. Someone asked how these diverse Cheddar flavors evolved. Here's the answer.

Nobody really knows what the first Cheddar cheese tasted like. We do know that Cheddar is well-liked. Since its origin in Somerset, England in the 16th century (6), this cheese has traveled far—you can find it throughout the world. Cheddar varies in color from pale white to yellow-orange and its flavor ranges from mild and creamy to sharp and bitter. Initially, cheesemakers produced it from raw whole cow's milk that was coagulated, cut, and the curd piled in the traditional "Cheddaring" manner. We call that "milled curd" Cheddar. Today, you can also produce Cheddar cheese by the "stirred curd" method. The curd particles, after whey drainage, are constantly forked, or stirred, to allow further drainage of whey and to reach the proper moisture in the cheese. Both procedures will produce comparable cheeses if the cheese compositions are similar and mechanical openings are eliminated by vacuum treatments. However, stirred curd Cheddar tends to be curdy and takes longer to knit.

Ripening Cheddar cheese

Cheddar cheese is a ripened cheese—the casein and fat in the fresh curd are slowly altered, producing the desired changes in body and texture while also producing the desired flavor compounds. The activity of residual coagulant and plasmin in the cheese, along with the starter and non-starter proteinases will determine the rate of proteolysis and changes in the body characteristics of the cheese (5). The curdiness of the fresh cheese disappears after two to four weeks of normal aging. Depending on the moisture and pH, the body of a drier cheese becomes shorter or more crumbly as the cheese ages. This is due to continued proteolysis of the casein by starter and non-starter enzymes.

The characteristic flavor of ripened Cheddar cheese is a blend of flavor and aroma compounds formed from the hydrolysis of fat, protein, and carbohydrates (citric acid, lactose) in the cheese. However, the specific reactions that produce those flavor compounds are not well understood. Two facts that all cheese researchers agree on is that milkfat must be present for the perception of Cheddar cheese flavor and lactic starters must be used to develop a good balanced Cheddar flavor (5). Changes in diversity and intensity of flavors continue as long as the cheese is held under ripening conditions. Initial flavors may include a mild acid flavor along with milky or buttery flavors. In well aged cheeses, flavors may include sulfur compounds, volatile fatty acids and aromatic compounds from amino acids and peptides. The rate of cooling the cheese, after pressing the curd, slows the rate of growth of the cheese microflora. This is one of the most important steps to control the cheese microflora and development of cheese flavor (1).

Cheddar Variations in the US

Traditionally, cheesemakers in the Midwest and on the West Coast have used annatto to color Cheddar medium orange, while Vermont cheesemakers produce uncolored Cheddar. Southern Cheddar has an intense pumpkin-orange color.

When it comes to flavor, Midwest Cheddar tends to have a clean, slightly acid flavor in mild Cheddar and a medium intense Cheddar flavor in aged cheese. Aged cheeses may have a slight sulfury flavor but mild Cheddar is generally downgraded if

continued on page 2

What's Inside:

continued from page 1

sulfides are noted. On the other hand, New York and Vermont Cheddars generally have a more intense flavor in both mild and aged cheeses. There is a slight sulfury flavor noted in mild Cheddar and a definite sulfur note in aged cheeses. The New England aged Cheddars also tend to have a sharp acid flavor along with slight rancid and astringent flavor notes.

Explaining regional differences

Some regional differences might be explained by the guidance of Dr. Walter Price at the University of Wisconsin and Dr. Frank Kosikowski at Cornell University and their selection of cultures and make procedures. These early cheese researchers certainly influenced the type of milk typically used for Cheddar cheese manufacture. Dr. Price was an advocate of manufacturing cheese from pasteurized milk while Dr. Kosikowski concentrated on raw milk cheese. With pasteurized milk, Dr. Price noted there was a slight delay in development of Cheddar flavor but there was a reduction in off-flavors from non-starter bacteria (7). This may have set the pattern for Cheddar flavor for Midwest cheese over 50 years ago. On the other hand, raw milk Cheddars produced in the East were certainly influenced by the non-starter bacteria present in the milk supply (3). These non-starter bacteria tended to produce a wide array of enzymes and flavor compounds that produced more intense and varied flavors. It is probable that low numbers of non-starter bacteria initially benefit developing Cheddar flavor, but high numbers don't (4).

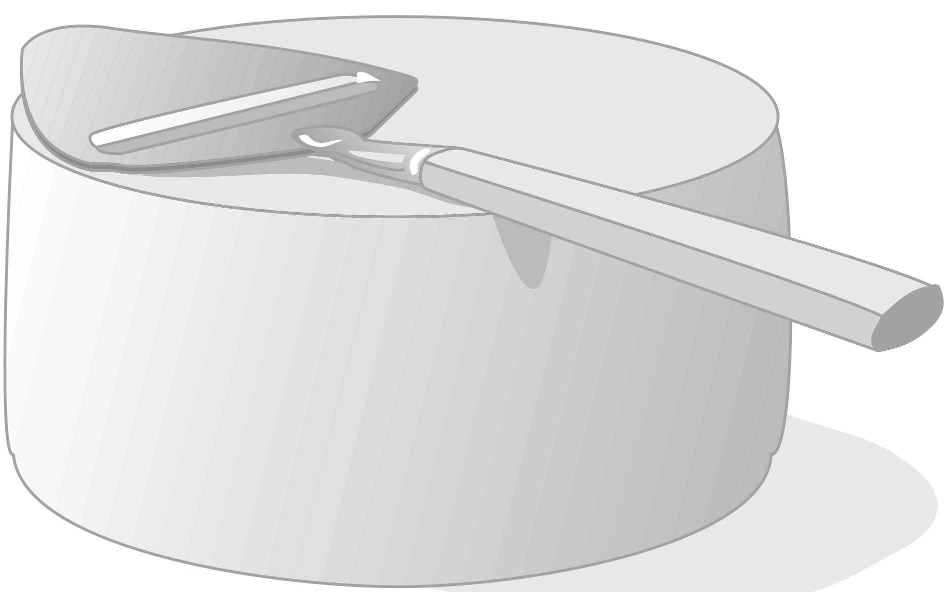
As for Cheddar cheese from the West Coast, the flavor intensity of both mild and aged cheeses tend to be less than what you find in cheeses from both the Midwest and New England. One California dairy official notes that the reason for the mild, clean-flavored Cheddar cheese manufactured on the West Coast is the very low bacterial counts in the raw milk. With the low numbers of non-starter lactic acid bacteria in the cheese, flavors develop slowly.

No matter which region is producing Cheddar cheese, the primary flavor defects when using good quality milk tend to be acid and bitter. These flavor defects are a result of using very active lactic starters that tend to produce high levels of proteases but lack a balanced amount of peptidases to degrade the bitter peptides formed in the cheese. For this reason, many cheesemakers are now using adjunct cultures or debittering enzymes to alleviate this problem.

Branch of annatto tree

Coloring cheese

Cow's milk cheese has a natural yellowish-white color which varies by season. This natural color comes from beta carotene in the feed. Cheesemakers add annatto to cheese to mask the seasonal variation in color, producing a predictable, uniform yellow-orange cheese.



International Cheddars

From the Cheddar samples we have seen, it appears that Canadian Cheddar cheeses closely match those from New England. They generally have a slight sulfury note but lack some of the astringency contained in the New England Cheddars. The commercial English Cheddars and New Zealand Cheddars tend to be a bit more acid than US cheeses and they have a slightly shorter body. They usually do not contain any significant sulfury flavor notes in mild or medium aged cheeses. Farmhouse Cheddars from England tend to have a very intense flavor—a barny, unclean flavor developed from the non-starter bacteria present in the raw milk. Steve Jenkins (2) describes a good Farmhouse Cheddar flavor as a combination of "toffee, nuts, apples, hay, and hard-boiled eggs." He also states that the cheese should have a buttery texture and a sweet, grassy aroma.

New Technologies

Cheesemakers are using new adjunct cultures and enzymes to produce a better, or more intense, cheese flavor, and we are seeing a wide variety of results. Since there is a lack of general agreement on what constitutes the ideal Cheddar flavor, the flavors of these new cheeses tend to represent a profile that appeals to consumers in a given region. Generally, those samples that we can identify as being intentionally ripened at an accelerated rate tend to have a greater tendency for slight rancid flavors. This probably is a result of increased lipolytic activity at the higher curing temperatures, combined with the use of adjuncts or the addition of lipase. Some of the samples with added adjunct cultures exhibit less bitterness, but some tend to have brothy flavor notes. Obviously, continued research on improving Cheddar flavors should produce more uniform flavors in cheeses from each region.

Cheddar in the Future

Since nobody knows what the original Cheddar tasted like, we are not sure who is closest to that original Cheddar flavor. Excellent Cheddar cheeses are produced in many different parts of the world—unfortunately, so are many mediocre Cheddars. As we try to improve the flavor of our Cheddar cheeses, will we get closer to the "ultimate Cheddar flavor" or will we value diversity and produce high quality, unique Cheddar that varies by region? Evolving consumer tastes may well dictate that choice.

Acknowledgments

We thank Dr. Vikram Mistry of South Dakota State University and Dr. Art Hill of the University of Guelph for their contributions to this article.

References

1. Fryer, T.F. 1982. The controlled ripening of Cheddar cheese. Proc. 21st Int. Dairy Congress, Moscow, Vol. 1, Book 1, p. 485.

2. Jenkins, S. 1996. Cheese Primer. Workman Publ., New York, NY.

3. Kosikowski, F.V., and V.V. Mistry. 1997. Cheese and Fermented Milk Foods, 3rd ed. F.V. Kosikowski, L.L.C., Westport, CT.

4. Lawrence, R.C., J. Gilles and L.K. Creamer. 1983. The relationship between cheese texture and flavour. N.Z. J. Dairy Sci. Technol. 18: 175.

5. Lawrence, R.C., J. Gilles and L.K. Creamer. 1993. Cheddar cheese and related dry-salted cheese varieties. Pages 1-38 *in* Cheese: Chemistry, Physics and Microbiology, 2nd ed. P.F. Fox, ed. Chapman & Hall, London, UK.

6. Robinson, R.K. 1995. A Colour Guide to Cheese and Fermented Milks. Chapman & Hall, London, UK.

7. Van Slyke, L.L., and W.V. Price. 1979. Cheese. Ridgeview Publ. Co., Atascadero, CA.

"As we try to improve the flavor of our Cheddar cheeses, will we get closer to the "ultimate Cheddar flavor" or will we value diversity and produce high quality, unique Cheddar that varies by region?"

Evaluating a Bioluminescence Method for Predicting Shelf Life in Pasteurized Dairy Products

K. Houck, R. Bishop, Center for Dairy Research (University of WI-Madison), M. Carter, Celsis, Inc.

Every day that milk is processed, we all fight to control microorganisms. On the farm, hygienic conditions are constantly scrutinized because they play such a critical role in preventing contaminants in the raw milk supply. Despite farm efforts, microorganisms make their way into the milk and are delivered to processors. The processor then starts the fight to minimize and eliminate microbes by the end of the production cycle, when the milk is quickly transported to retail outlets. Are all these prevention efforts and processes effective? When do you know?

A 1997 study of consumer attitudes towards dairy products found that consumers clearly value both freshness and quality. (1) Of course, managing these two product attributes poses a challenge for dairy processors since they involve conflicting time spans. The desire for maximum freshness drives the need for faster production and distribution, while reliably determining and assuring bacterial quality lags days behind.

To meet the demand for the freshest product possible, processors ship products for sale well before they know key microbial test results. Although significant advances in pasteurization and production processes allow a high degree of confidence, assurance of overall quality typically trails a gallon of milk by 3-9 days. For example, if you use the Mosely Keeping Quality test, results are available in 7 to 9 days. The Virginia Tech Shelf Life Program requires 2-3 days. (2)

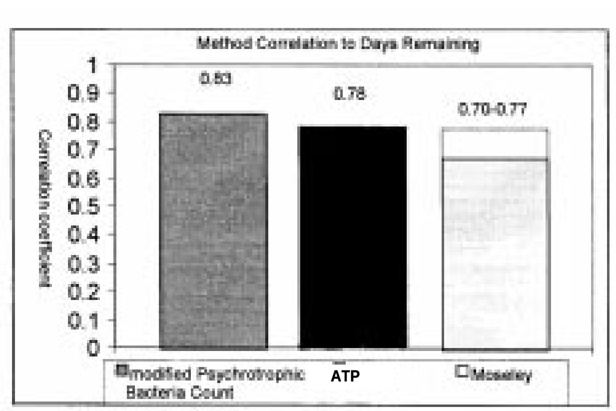
Managing the freshness/quality balance

ATP bioluminescence technology has been applied to bring a rapid microbial test to the dairy industry—allowing more effective management of the freshness/quality balance. The Wisconsin Center for Dairy Research (University of Wisconsin-Madison), evaluated the performance of an ATP bioluminescence pasteurized milk screen for 24-hour contamination detection and shelf life prediction.

Since previous studies have found a high correlation between ATP and the amount of bacteria in raw milk ATP testing has been used to test the sterility of ultra high temperature (UHT) milk. (3, 4, 5) The evaluated method also measures ATP from bacteria found in the milk. The CDR shelf life study evaluated the feasibility of ATP monitoring and compared ATP technology to plating methods.

Pasteurized milk samples were collected over a three-month period from three different dairies. Samples were then tested at varying time points, using the ATP 24-hour method and conventional plating methods. Sensory evaluations were also conducted to determine actual shelf life. Our results show that the correlation of the ATP 24 hour method to shelflife is 0.78, better than or at least equal to that of the commonly used Moseley Keeping Quality test (0.70 to 0.77)[5]. (See Figure 1.)

The 0.78 correlation of logRLU (the Relative Light Unit, a measure of ATP) vs. shelf life (days remaining) is better than or at least equal to that of the Moseley count with a time savings of 8 days, but is less than impedance (0.91 referenced data) (7) or the plating method used in this study (0.83). Time savings is an advantage of the ATP 24-hour method, 2 days for plating compared to 1day for the impedance test.



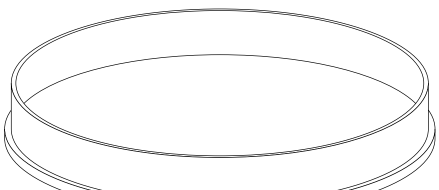
Variation between plants

Individual plant data showed a somewhat different picture, with correlation values of log RLU vs. shelf life of Plant A 0.87, Plant B 0.86, and Plant C 0.60. This indicates that the ATP 24 hour method is very good for Plants A and B, but not Plant C. We expected some variation between plants, but not this much. We also found variation between plants using modified psychrotrophic bacteria counts, however, they had consistently higher correlation coefficients and the degree of variance was smaller. Correlations for raw log mPBC (modified psychrotropic bacteria count) data vs. days remaining were -0.83 overall and -0.80, -0. 91, and -0.74 for plants A, B, and C respectively.

Sometimes shelf life methods don't work, partly due to resident micro flora of the plant. This may explain the lower correlation values for Plant C. Time savings remain an advantage of the ATP 24 hour method, 1 day results compared to impedance and plating.

The ATP Pasteurized Milk Screen that we evaluated is a tool for dairies to quickly identify a problem when significant levels of microorganisms have somehow found their way into finished product. Armed with this valuable information, dairy processors can begin the response process quickly—potentially sparing additional production days exposed to the source of contamination. When corrective action can start days sooner, shelf life quality will certainly increase.

We would like to acknowledge and thank Celsis, Inc. for their support of this project.



References

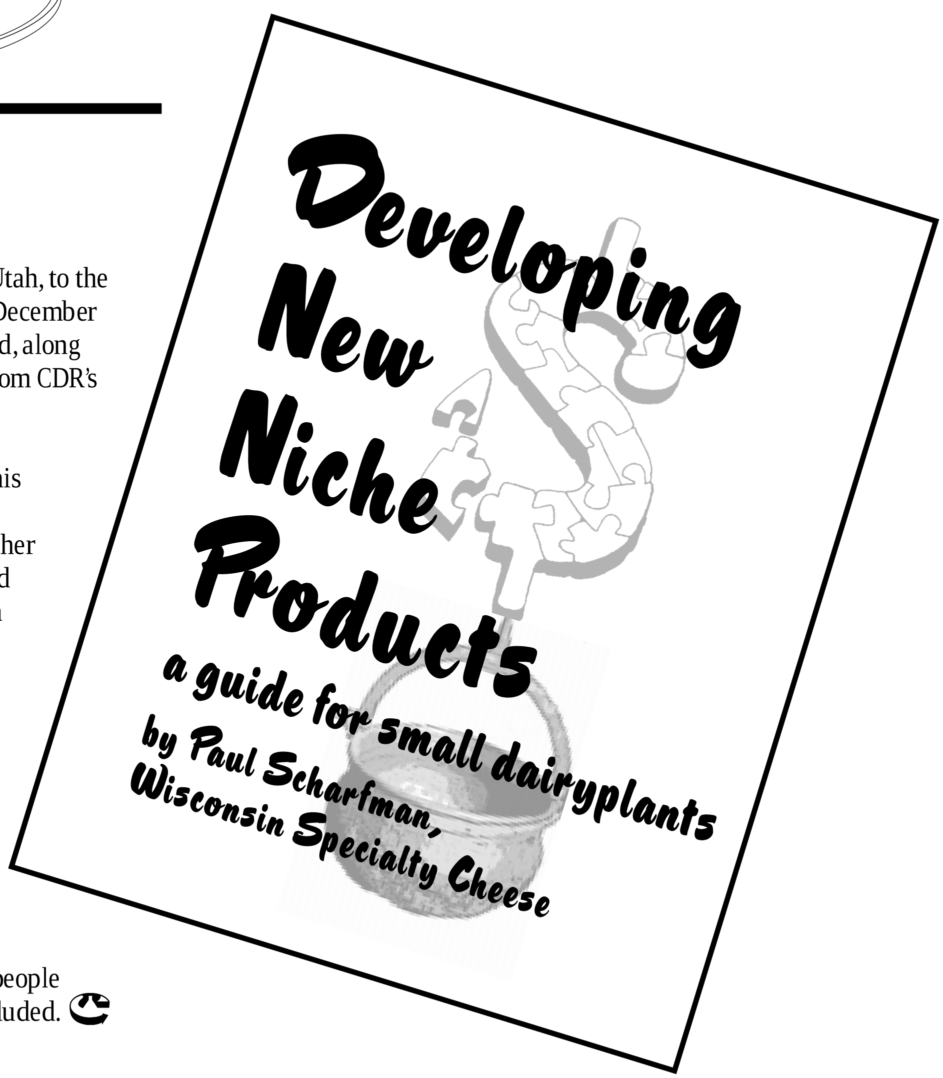
1. Food Marketing Institute, 1997. Consumer Attitudes and the Super Market.
2. Bishop, J. R. 1989. A Simple Shelf Life Estimation Method as an Integral Part of a Total Dairy Quality Assurance Program. Dairy Food Env. San. Dec. 698-701.
3. Bell, C., Bowles, C., Toszeghy, M., and Neaves, P. 1996. Development of a hygiene standard for raw milk based on the Lumac ATP-bioluminescence method. International Dairy Journal. 6: 709-713
4. Griffiths, M.. 1993. Applications of bioluminescence in the dairy industry. Journal of Dairy Science. 76: 3118-3125.
5. Kearns, J. 1995. A practical approach to milk testing. International Food Hygiene. 6: 5,7.
6. Bishop, J.R. and C.H. White. 1986 Assessment of Dairy Product Quality and Potential Shelf Life – A Review J. Food Prot. Sept. 739-753.
7. Byrne, R., Bishop, J., and Boling J. 1989. Estimation of potential shelf-life of pasteurized fluid milk utilizing a selective preliminary incubation. Journal of Food Protection. 52: 805-807.

News from CDR

CDR sent a contingent to Salt Lake City, Utah, to the Dry Milk and Whey Technology Forum, December 7-8. Rusty Bishop, CDR's director attended, along with K. J. Burrington and Karen Smith, from CDR's Whey program.

Sponsored by Dairy Management, Inc., this forum brought academics and industry, including end-users and producers, together to discuss the present and future uses and needs. Day one focused on dry milk, then second day was devoted to whey.

Developing New Niche Products, a compilation of articles by Paul Scharfman, and previously published in the Dairy Pipeline will be available in a bound booklet in January. If you are interested, or have questions about purchasing the booklet, call Tim Hogensen at (608) 265-2133. The cost is $15 for Wisconsin residents and $20 for people outside WI. Shipping and handling is included.



Thermal Cycling—Could it Save You Money?

A team of university researchers, sponsored by the Energy Center of Wisconsin, has pioneered the use of a storage technique that could save cheese plants thousands of dollars in annual energy costs.

This storage technique takes advantage of thermal storage—using cooling equipment at night during off-peak hours and "storing" the energy. Stephen Zehr started this series of experiments when he earned a Master degree in Mechanical Engineering by examining methods of improving energy efficiency in Wisconsin cheese plants. He explored the idea of using cheese as thermal storage medium in refrigerated warehouses. Essentially, cheese was sub-cooled at night and then it gradually returned to normal storage temperature during the day. In a conventional cheese warehouse, the temperature stays at 40-45° F for 24 hours/day. In this thermal storage model, the refrigeration system lowers the off-peak temperature to 30°F for 12 hours, and then the system is shut off. Zehr analyzed energy use in a cheese warehouse and concluded that a large plant could save almost 15,000$/year using this technique.

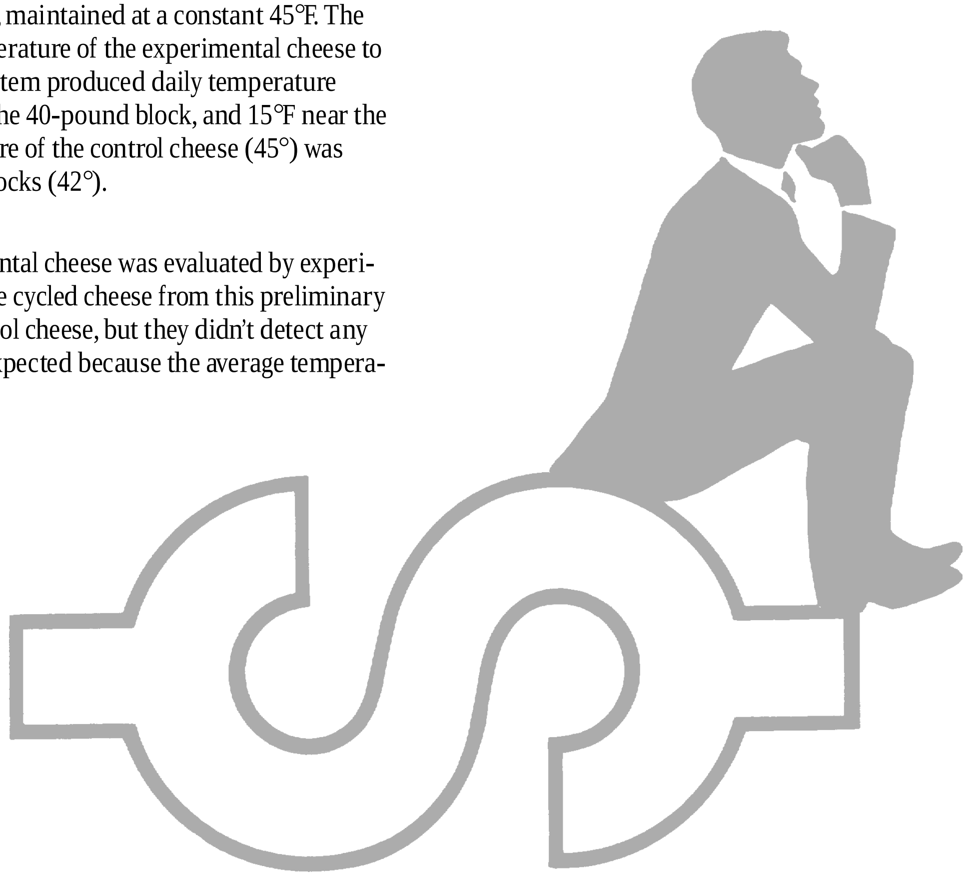
Does it affect quality?

To study the effect of thermal cycling on cheese quality, Doug Reinemann, John Mitchell, Aaron Hade, and Jeannie Leggett (Dept. of Biological Systems Engineering and the Solar Energy Laboratory, University of Wisconsin-Madison) took the modeling one step further. They prepared an experimental chamber designed to simulate the effects of thermal storage. They stored two 40-pound blocks of cheese in their chamber and placed a third block from the same cheese batch in a control chamber, maintained at a constant 45°F. The researchers measured the internal temperature of the experimental cheese to monitor variation. This refrigeration system produced daily temperature variations of about 6°F at the center of the 40-pound block, and 15°F near the exposed surface. The average temperature of the control cheese (45°) was slightly higher than the experimental blocks (42°).

After 90 days, the flavor of the experimental cheese was evaluated by experienced cheese tasters. They noted that the cycled cheese from this preliminary experiment tasted milder than the control cheese, but they didn't detect any cheese defects. This milder flavor was expected because the average temperature was higher.

The Energy Center of Wisconsin is a private nonprofit organization dedicated to improving energy efficiency in Wisconsin. With support from Wisconsin's energy utilities, the Center provides energy-efficiency programs, research, and education to residents, businesses, and governments. Contact them for more information about thermal cycling.

Ruth Urban, Energy Center of Wisconsin
595 Science Dr.
Madison, WI 53711
608-238-8276, ext 17
rurban@ecw.org



Annual Wisconsin Dairy Field Reps Conference

February 2-3, 1999
Crown Plaza Hotel - Madison East

Tuesday, Feb. 2
Morning

Quality Milk Production in Wisconsin

Moderator – Denny Zimmer

10:00 State of the Wisconsin Dairy Industry
- Ron Tauchen, WI Ag. Statistic Serv.

10:25 International Milk Quality Standards
- Morten Dam Rasmussen, Danish Inst. Of Ag. Sciences

10:50 Updated UWEX Milk Quality Program
- Pamela Ruegg, DVM, UW-Dairy Science

11:30 Growing Wisconsin's Dairy Industry
- Ron Caldwell, WDATCP

12:00 Lunch

Future Role of Dairy Plant Field Reps

Moderator - Dan Belk

Afternoon

1:15 Panel Discussion – "The Changing Roles of the Dairy Plant Field Rep"

Equipment Supplier - Kris Kanak, Central Ag. Supply
Veterinarian – David Reid, DVM, Practitioner, Hazel Green
Dairy Producer – Pete Kappleman, Prof. Dairyman's Assn.
Field Rep – Ray Cherry, Land O'Lakes
Milk Hauler - Steve Setterland, WI Milk Haulers Assn.

Milk Pricing Issues

Moderator – Jim Glaeser

3:40 Volume Premiums in Wisconsin
- Ben Brancel, WDATCP

4:30 Business Meeting

5:30 Social Conference

Wednesday, Feb. 3
Morning
7:30-8:30 Breakfast

Critical Regulatory Issues for Quality Milk

Moderator – Bob Bradley

9:00 Impact of Codex on the Wisconsin Dairy Industry
- Bill Wendorff, UW-Food Science

9:25 Critical Issues from NCIMS
- Randy Daggs, DHFS

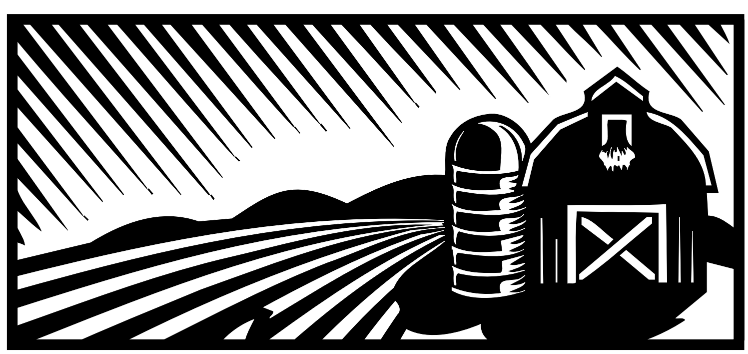
9:55 Current Concerns from WDATCP
- Tom Leitzke, WDATCP

10:55 Summary

Adjournment

For more information

Call Bill Wendorff at (608) 263-2015.



Curd Clinic

Q: Most of the time I make a very good Gouda cheese. Sometimes, though, I find that the body is too short and gritty. What can I do to get a smoother cheese with a longer body?

A: I can suggest a few things for you to try that will help you solve the problem of producing a Gouda cheese with a short texture. This problem is caused by too much acid in your cheese (or a pH that is too low). Before I give you the short answer, I'd like to caution you to keep this problem in context. You really need to understand how it fits in the total picture of standardizing your cheesemaking process and controlling the rate of acid development. (See the Spring 1998 curd clinic in the Dairy Pipeline for a discussion of moisture, pH and cheese quality.)

Take a look at the processing chart included in this issue of the Pipeline. Developed back in 1969 by the Danish Government Research Institute for the Dairy Industry, this chart is still current today. As you review the techniques, keep in mind that this chart focuses on manufacturing semi-soft eyed cheeses, like Gouda. I mentioned that a high acid content is causing your texture problems. Look over the lower left section of the processing chart for some tips that will help you produce cheese with less acid. Factors listed in the upper right quadrant are changes that produce a softer cheese.

Add water to cheese milk (Factor 2)

Adding water to cheese milk dilutes the sugar, or lactose, concentration. There will be less acid produced because of this lowered lactose level. Coagulation is slightly slower and the coagulum becomes loose and less cohesive as more water is added. The table below describes the relationship between added water, pH, and coagulation time.

Adding water—How it affects coagulation time and pH

% Water Added	pH	Coagulation time seconds
2	6.58	510
4	6.58	520
6	6.62	535
8	6.62	555
10	6.63	570
15	6.65	610

Curd Clinic Doctor for this issue is J. M. Buch Kristensen, M.sc.
Dalum Technical College
Denmark

Questions for the Curd Clinic?
Write to:
CDR, *UW Dairy Pipeline*
1605 Linden Dr.
Madison, WI 53706
FAX: 608/262-1578
e-mail: Paulus@cdr.wisc.edu

Use (more) water during scalding (Factor 8)

Depending on how much water you add, this factor can increase the pH of the cheese. (After 24 hours). Adding water also influences calcium content, since the amount of dissolved calcium increases as water increases. You will see fewer and smaller holes after adding lots of water.

Cooling by adding water 15 minutes before ending the stirring (Factor 14)

The pH of the cheese will fall if you cool the cheese before collecting the curds. (If you cool without adding water to the whey the final pH will be lower.)

Decrease addition of starter (Factor 4)

You can regulate the acidification of your cheese by changing the amount of starter, although you shouldn't change this by more than .25% at a time. The acidification in the cheese vat is reduced, less phosphate and calcium is removed and you will have greater buffering capacity in your cheese.

Shorter time for preripening (Factor 7)

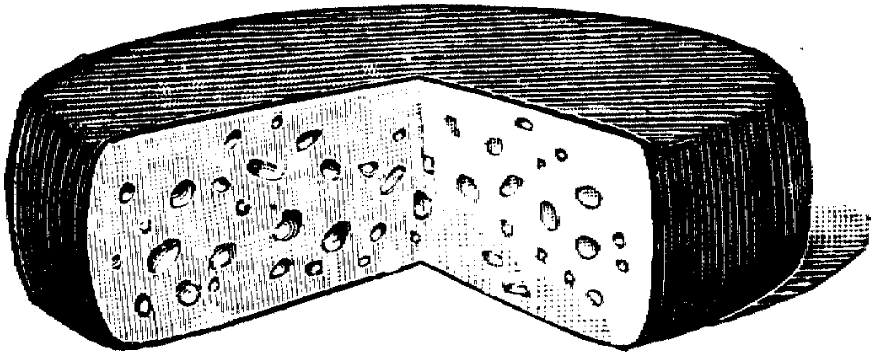
You can reduce the acid in your cheese by starting to cook earlier—shortening the pre-stirring time. Moisture is expelled earlier and at a higher pH, which influences the buffering capacity.

Raise the temperature for scalding (Factor 9)

The cooking temperature is one of the most important factors influencing the acidification of the cheese because a higher temperature produces a higher pH in the cheese. The pH falls at a slower rate and the buffering capacity also increases since the calcium and phospate content is higher in the cheese. Keep in mind that you may need to adjust other facets of your process at the same time you change the temperaure.

These factors influence the pH of your cheese through two pathways. They either decrease the concentration of lactose thus limiting lactic acid formation. Or, they influence the buffering capacity of cheese—which is particularly important when the concentration of lactic acid is high. Remember that these factors do affect each other, the chart should help you track the direction of changes.

These factors influence the pH of your cheese through two pathways. They either decrease the concentration of lactose thus limiting lactic acid formation. Or, they influence the buffering capacity of cheese—which is particularly important when the concentration of lactic acid is high.



Calendar

Feb. 2-3 Wisconsin Dairy Field Reps Conference. Madison, WI. Call Bill Wendorff at (608) 263-2015.

Feb. 23-24 Wisconsin Process Cheese Short Course. Madison, WI. Call Jim Path at (608) 262-2253 or Bill Wendorff at (608) 263-2015 for more details.

Mar. 9 Wisconsin CIP Workshop, Madison, WI. Call Bill Wendorff at (608) 263-2015.

Mar. 10 Dairy HACCP Workshop, Madison, WI. Call Marianne Smukowski at (608) 265-6346.

Mar. 22-26 Wisconsin Cheese Technology Short Course, Madison, WI Call Bill Wendorff at (608) 263-2015.

Apr. 13-14 Wisconsin Cheese Industry Conference, La Crosse, WI. For information, call Judy Keller at (608) 255-2027.

Apr. 20-23 Basic Cheesemaker's License Short Course, River Falls, WI. Call Ranee May for further info at (715) 425-3150.

Apr. 21-22 Introduction to Dairy Microbiology Workshop
, Madison, WI. Call Steve Ingham at (608) 265-4801.

May 4-5 Dairy Plant Water and Waste Management Short Course, Madison, WI. Call Bill Wendorff at (608) 263-2015.

CDR Dairy Pipeline

To subscribe to the Pipeline simply phone, fax, or e-mail your request to CDR. We welcome your questions and comments. Send them to:

The Dairy Pipeline
Center for Dairy Research
1605 Linden Dr.
Madison, WI 53706
phone: 608/262-5970
fax: 608/262-1578

Karen Paulus, Editor
e-mail: Paulus@cdr.wisc.edu
phone: 608/262-8015

Technical Reviewers:
Mark Johnson, CDR
Norman Olson, Dept. of Food Science
Jim Path, CDR
Marianne Smukowski, CDR
Tom Szalkucki, CDR
Bill Wendorff, Dept. of Food Science

You can also find the Dairy Pipeline on our website: www.cdr.wisc.edu

The *Dairy Pipeline* is published by the Center for Dairy Research and funded by the Wisconsin Milk Marketing Board.

CDR
***Wisconsin* Center for Dairy Research**
University of Wisconsin-Madison
1605 Linden Drive
Madison, Wisconsin 53706-1565

ADDRESS CORRECTION REQUESTED

Nonprofit Org.
U.S. Postage
PAID
Madison, WI
Permit No. 658