CHARACTERISTICS OF CHEDDAR CHEESE COOLED AT DIFFERENT RATES DURING EARLY CURING STAGES

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ABSTRACT

Sixteen lots of Cheddar cheese were made from manufacturing-grade and grade-A milk by using commercial starters and cultures reported to give fruity and bitter-flavored cheese. Curd blocks were pressed for 4 and 20 h, then cooled to 7.5 C in brine or in air. There were no statistically significant differences in total, enterococcus, and Violet red bile agar counts, or proteolysis and judging scores among different pressing or cooling treatments. Significantly greater amounts of lactose, glucose, and galactose were present in brine-cooled cheese. Lactose persisted beyond 3 months. Air-cooled cheese had a significantly higher lactic-acid content, more free fatty acids, and more color variation. Air-cooled cheese was more severely criticized for flavor defects. Brine cooling produced uniform flavor, body, and color, and six of the seven judges preferred brine-cooled cheese.

Even though the effects of different curing temperatures on cheese characteristics have been carefully documented, there is virtually no literature on the influence of temperature *during the early part of curing* on subsequent Cheddar-cheese maturation. Conochie and Sutherland *(5)* have cited a particular instance in which differences between blocks from the same vat could be attributed to the block stacking of warm cheese on pallets and block stacking of pallets. Reinbold *(25)*, in more general terms, noted that cheese graders sometimes encounter flavor differences between blocks from the same vat. Wilson and Reinbold *(34)* stated that the openness in texture in Cheddar cheese cured at high temperatures has been related to the fermentation of residual carbohydrate, suggesting prompt and efficient cooling before curing.

Before the early 1900's, Cheddar cheese was cured at room temperature *(30)*. It was found later that cheese ripened below 7.2 C has more uniform flavor, body, and texture *(1, 24)*. A sizeable amount of commercial Cheddar cheese is still criticized, however, for lack of flavor, high acidity, defective body and texture, and off-flavors.

Temperature of cheese blocks when taken out of the press may range between 21 and 35 C and the length of press may range between 2.5 and 17 h *(33)*. In large commercial operations making thousands of pounds of cheese daily, blocks are sometimes stacked close together in the curing room, with no effort made to hasten cooling.

Our study explored the effect of temperatures used during *the early stages* of Cheddar-cheese curing on the physical, chemical, and bacteriological changes during ripening and on the finished cheese.

EXPERIMENTAL METHODS

Manufacture and treatment of cheese

The experimental treatments used represent curd-handling procedures currently employed in 20 commercial plants surveyed in Iowa, Wisconsin, New York, and South Dakota *(33)*. Details of the manufacturing treatments are presented in Table 1. Make procedures were essentially those recommended by Wilson and Reinbold *(34)*; starter cultures, milk source, and other factors, however, were selected and adjusted to produce the kinds of cheese listed in Table 1. Pressing time and early-curing temperature variations were then introduced. After 4-h pressing, two sets of blocks were wrapped in foil-cellofoil wrappers (Marathon, Division of American Can Company, Neenah, Wisc.) and sealed with a Flexpress (Model R.L. 100. D. L. Manufacturing Company, W. De Pere, Wisc.). One set was immersed in a 4 C brine tank for rapid cooling to 7.5 C, and the other was stacked on a pallet in the curing room at 7.5 C for conventional air cooling. After 20 h, two more sets of blocks were removed from the press and were treated in the same way.

Sampling, tests, and cheese analysis

Table 2 lists the tests and testing schedule used for analysis. All cheeses, except lot A, were judged organoleptically after 3 and 6 months of curing by a panel of seven experienced judges using the American Dairy Science Association Intercollegiate Scorecard. Lot A was abnormally acid and bitter at 3 months; flavor scores were, therefore, rejected. Because it had somehow improved by 6 months, results were then included with data from the other lots. In addition, paired comparisons *(15)* were made among the four treatments (4- or 20-h press, followed by brine or air cooling) after 3 months of curing. Samples representing the four treatments were combined into the six possible pairs. These pairs were

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TABLE 1. CHEESE MANUFACTURING DATA AND TESTING PROCEDURES

Lot	Milk grade	Heat treatment	Culture	Milling acidity (% titratable acidity)	General description	Tests[a]
A	Mfg.[b]	62.8 C/17 sec	CL[c]	0.60	Slightly high acid	All
B	Mfg.	62.8 C/17 sec	CL	0.68	High acid	All
C	Mfg.	62.8 C/17 sec	CL	0.70	High acid	All
D	Mfg.	62.8 C/17 sec	CL	0.56	Nomal	All
E	Mfg.	Raw	CL	0.60	Raw milk	All
F	Mfg.	62.8 C/17 sec	CL	0.50	Normal	All
G	A	62.8 C/17 sec	Fruity[d]	0.55	Fruity	All
H	A	62.8 C/17 sec	Fruity	0.54	Fruity	All
I	A	62.8 C/17 sec	Fruity	0.56	Fruity	All
J	A	62.8 C/17 sec	CL	0.53	Good	Organo.
K	A	62.8 C/17 sec	CL	0.58	Good	Organo.
L	A	62.8 C/17 sec	CL	0.59	Good	Organo.
M	A	62.8 C/17 sec	Bitter[e]	0.51	Bitter	Organo.
N	A	62.8 C/17 sec	Bitter	0.54	Bitter	Organo.
O	A	62.8 C/17 sec	Bitter	0.64	Bitter	Organo.
P	A	71.7 C/17 sec	1% CL 0.5% Coliform	0.58	Gassy	Organo.

[a]The bacteriological, chemical, and color measurements listed in Table 2, unless otherwise noted, were made during the first 3 months of curing. Organoleptic determinations were made after 3 and 6 months of curing.
[b]Iowa grading law for milk manufacturing purposes, Chapter 194, Iowa Department of Agriculture.
[c]The symbol CL indicates the use of 1% commercial lactic starter.
[d]See reference 31 and 32.
[e]Provided by Dr. D. B. Emmons, Canadian Department of Agriculture, Ottawa.

presented to the judges in randomized order. The judges were asked to determine if there were differences in flavor, body and texture, and color within each pair and to indicate their preferences within each pair. A sample received 1 point each time it was preferred over the other in the pair. If no preference was indicated within a pair, it was allotted 0.5 point. The number of points for each sample in the six pairs was added and multiplied by 2 to remove half points. This provided a means to determine each judge's paired-comparison score on each treatment for that cheese lot. Statistical analyses were made only on the basis of preference with each pair.

Statistical analysis

Results from samples collected from lots A through I after 12 days and after 1, 2, and 3 months of curing were used for statistical analyses. Statistical significance was determined by comparing F values with critical values given by Steel and Torrie *(28)*.

RESULTS AND DISCUSSION

Statistical significance of the effects of pressing times and cooling rates on the bacteriological, chemical, physical, and organoleptic tests are in Table 3. Specific results are given for the cheese of lot D because it is similar to typical commercial Cheddar cheese.

To simplify the presentation, results are furnished only for samples collected after milling, 4-h pressing, 12 days, and after 1, 2, and 3 months of curing. Detailed results for all the lots are presented elsewhere *(19)*.

Bacterial counts of the manufacturing-grade milk and the curd for lot D cheese are presented in Table 4. Counts are presented for curd pressed 4 h and then brine-cooled. Although air-cooled curd required considerably more time than did brine-cooled curd to reach 8 C or below *(20)*, no corresponding significant differences were observed in the total enterococcus, or Violet red bile count. Nor did pressing times have a significant effect on the counts.

With reference to other cheese lots, enterococci were present in large numbers only in cheese made from manufacturing-grade milk. For example, the enterococcus count of lot E was 18×10^6/g at milling; it reached a high of 52×10^6/g at 1 month of curing; at 3 months, the count was 52×10^4/g. Lot H, made from grade-A milk, contained 10×10^1 enterococci/g at milling, 30×10^1/g at 1 month of curing, and 40×10^1/g at 3 months. Both these cheeses were made from curd pressed 4 h and brine-cooled. The greater number of enterococci in manufacturing-grade milk cheese curd was not unexpected because Clark and Reinbold *(4)* have reported frequent occurrence of enterococci in young commercial Cheddar cheese.

Lactic-acid content of cheese from lot D is presented in Fig. 1. Statistical analysis showed that the lactic-acid concentration in air-cooled cheese was significantly higher than in brine-cooled cheese and in 20-h- over 4-h-pressed cheese ($P < 0.01$). The higher acidity in the air-cooled and longer-pressed cheese probably resulted from more rapid growth and metabolism of starter organisms during cooling of the curd to curing-room temperature. Since the

TABLE 2. TESTS AND TESTING SCHEDULE

Product and test period	Tests: Bacteriological[a]	Chemical[b]	Organoleptic and color[c]
Milk			
Raw	+		
After heating	+		
Cheese			
4-h press	+	+	
20-h press	+	+	
4 days	+	+[d]	
8 days	+	+[d]	
12 days	+	+[d]	
21 days	+	+[d]	
1 month	+	+	
3 months	+	+	+
6 months	+		+

[a]Bacteriological tests included: Total counts—Eugonagar *(2)*, 21, 21 C for 7 days; Enterococcus counts—Citrate azide agar *(26)*, 37 C for 72 h; Violet red bile counts—Violet red bile agar, 32 C for 18-20 h. Samples were collected and analyzed immediately.

[b]Chemical tests included: Lactic acid *(13, 19)*; Proteolysis *(12)*; Total free fatty acids *(14)*; Reducing sugars *(19)*. Samples were analyzed immediately whenever possible, otherwise, they were stored at −10 C until tested.

[c]All cheeses were subjected to organoleptic tests after 3 and 6 months of curing. Color measurements were made at 3 months by using a Beckman DK-2A ratio recording spectrophotometer for reflectance measurements at 400-700 nm. The reflectance data taken at the absorption maxima of 465 nm were statistically analyzed.

[d]Proteolysis and total free fatty acids tests not done.

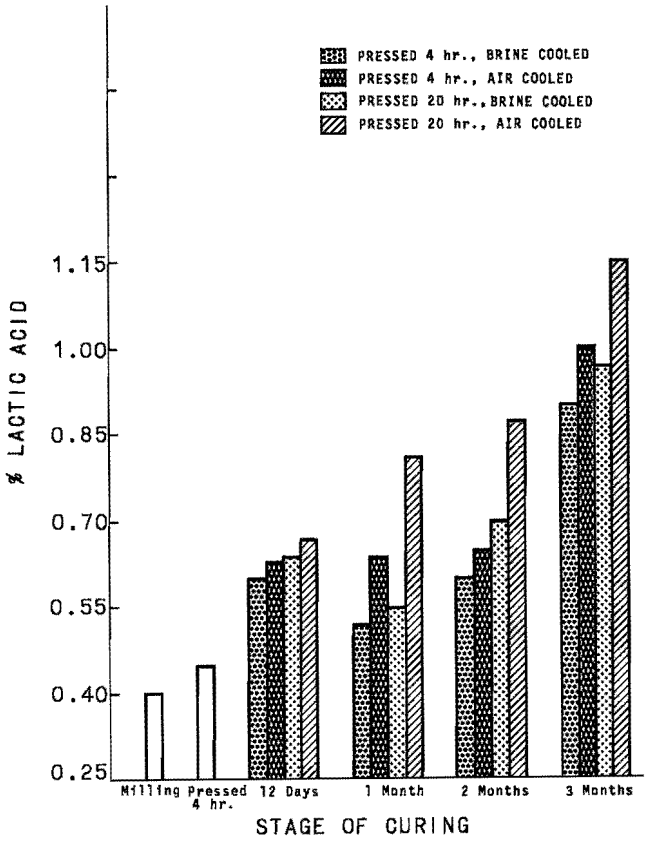

Figure 1. Lactic acid content of Cheddar cheese from lot D (manufacturing-grade milk) during curing.

TABLE 3. STATISTICAL SIGNIFICANCE[a] OF EFFECTS OF PRESSING TIMES AND COOLING RATES OF CHEESE CURD ON BACTERIOLOGICAL, CHEMICAL, PHYSICAL, AND ORGANOLEPTIC TESTS ON COMMERCIAL CHEDDAR CHEESE (LOT D)

Pressing time[b]	
Significant	Not significant
Lactose	Total count
Galactose	Enterococcus count
Lactic acid	Violet red bile count
Free fatty acids	Glucose
	Proteolysis
	Reflectance
	Judging score
	Flavor
Cooling rate[c]	
Significant	Not significant
Lactose	Total count
Glucose	Enterococcus count
Galactose	Violet red bile count
Lactic acid	Proteolysis
Free fatty acids	Judging score
Reflectance	Flavor

[a]$P < 0.05$.

[b]Curd was pressed for 4 and 20 h.

[c]Curd was cooled in 4.4-7.2 C brine and in 7.2 C air to 7.5 C.

treatments did not produce a significant difference in bacterial counts at the test intervals, it is possible that the temperature affected the metabolic rate, but did not change the bacterial population. Changes in total number between 4 and 20 h of pressing were not determined. It is possible, although not likely, that other groups of microorganisms not enumerated in this experiment could have converted the available sugar to lactic acid.

A substantial amount of lactose was still present after 3 months of curing (Fig. 2). This contradicts earlier belief that, in hard cheeses, lactose is completely utilized within the first 2 weeks of curing *(21, 23, 27)*. Many other research workers *(9, 11, 18, 29, 30)* have reported that lactose is utilized early in the ripening of Cheddar cheese. Methods used by earlier investigators for detecting lactose were less sensitive. In 1956, Mabbitt and Zielinska *(17)* detected lactose in Cheddar cheese after 4 months of ripening. In our study, cheese pressed 20 h and then air-cooled contained 0.34% lactose after 3 months of curing. Pressing intervals and cooling rates showed a significant difference ($P < 0.01$) in the amount of lactose present during curing. The shorter pressing time and faster cooling rate resulted in greater amounts of residual lactose in the cheese.

TABLE 4. BACTERIAL COUNTS OF MANUFACTURING-GRADE MILK (PER ML) AND CURD (PER GRAM) FOR LOT D CHEESE[a]

Sample	Total count × 10^6	Enterococcus count × 10^3	Violet red bile count × 10^1
Milk			
Raw	61	180	290,000
Heat treated	15	64	36
Curd			
Milling	1,500	2,900	9,100
4-h pressing	920	2,700	7,800
12 days	68	24,000	1,500
1 month	600	32,000	5,900
2 months	110	6,600	1,600
3 months	42	530	<10

[a]Curd was pressed 4 h and brine-cooled.

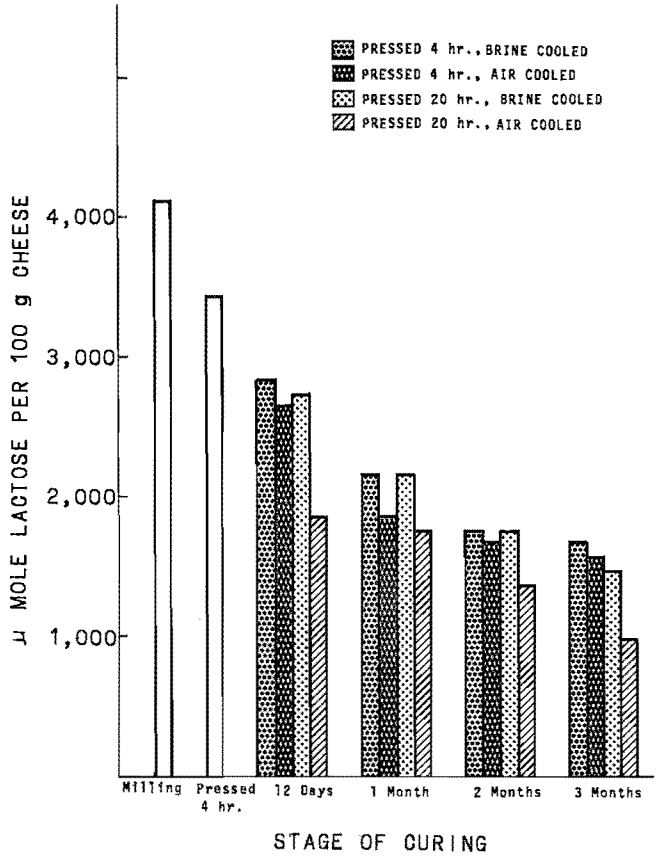

Figure 2. Lactose content of Cheddar cheese from lot D (manufacturing-grade milk) during curing.

The amount of glucose present in the brine-cooled cheese was significantly higher ($P < 0.05$) than in the air-cooled cheese. Pressing time, however, did not have a significant effect on the glucose level. These statements are based on average glucose content of all cheeses but are not apparent in the data given in Fig. 3.

Disappearance of galactose followed a pattern similar to that of glucose. Brine-cooled cheese contained significantly higher amounts of galactose than did the air-cooled cheese ($P < 0.01$). Even though there was more lactose hydrolysis in air-cooled cheese, the glucose level was considerably lower than that of galactose during the first 12 days of curing. This probably was due to preferential utilization. Figure 4 gives the pattern of galactose disappearance in lot D cheese. Unfortunately, the same anomalous results as with glucose disappearance in Fig. 3 are apparent in this figure, however, as indicated previously, for purposes of continuity, all specific data shown pertain to lot D cheese.

The free fatty acid content of cheese from lot D is presented in Fig. 5. Air-cooled cheese contained significantly larger amounts of free fatty acids than did brine-cooled cheese. Greater amounts of fatty acids in air-cooled cheese probably resulted from the increased activity of bacterial flora during the early stage of ripening. Pressing also had a highly significant effect on the amount of fatty acids, 20-h pressed cheese containing more than did 4-h pressed cheese. Cheese sampled at 3 months from lot B (high-acid cheese) pressed 4 h and then brine-cooled required only 6.91 ml of 0.01 N alcoholic KOH, compared with 10.47 ml for cheese from lot D. Higher amounts of free fatty acids found in normal cheese relative to high-acid cheese suggest that lipoly-

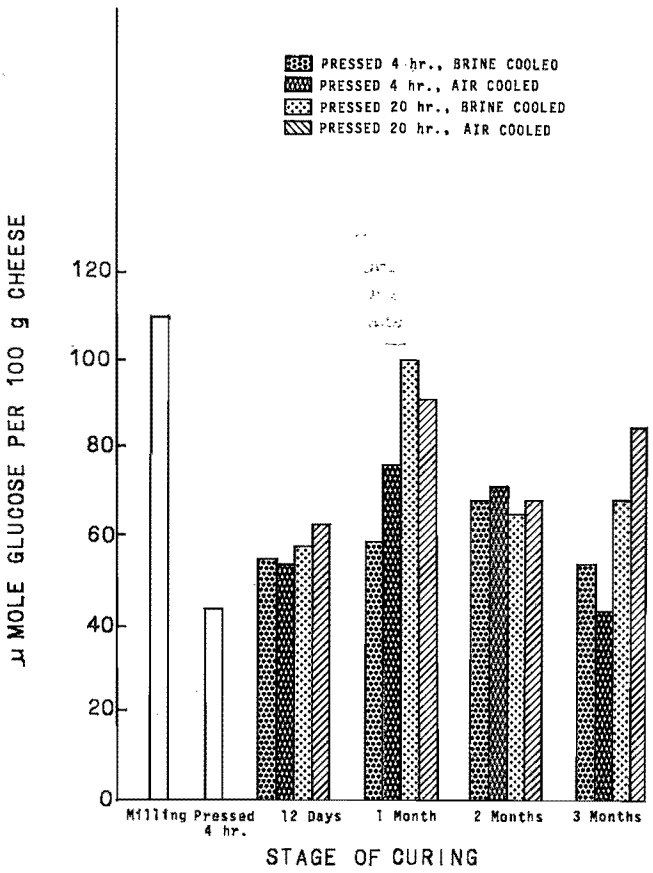

Figure 3. Glucose content of Cheddar from lot D (manufacturing-grade milk) during curing.

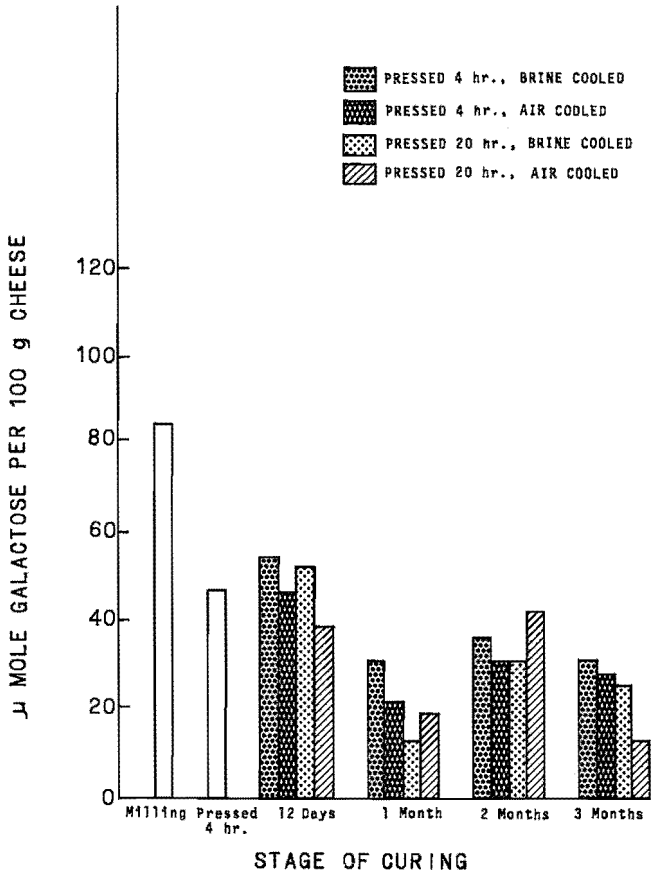

Figure 4. Galactose content of Cheddar cheese from lot D (manufacturing-grade milk) during curing.

tic activity is diminished at low pH. Irrespective of press and cooling treatment, the high-acid cheeses required an average of 6.66 ml of 0.01 N alcoholic KOH per 5 g cheese. Cheeses made at normal acid levels required 10.63 ml for neutralization of the fatty acids per 5 g cheese.

Vedamuthu et al. *(31, 32)* reported that fruity-flavor defects could be caused by high amounts of aldehydes and other carbonyl compounds produced by certain starter organisms. One of these cultures was used for the fruity cheese lots. Fatty acids in these cheeses were significantly less than in the other cheese lots. One of the reasons for the flavor defects could be the formation of esters from alcohol and fatty acids. Mabbitt *(16)* suggested that residual sugar fermentation by heterofermentative bacteria produced acetic acid, ethanol, glycerol, and mannitol. If these are produced in excessive quantities, their reaction with fatty acids would produce detectable levels of esters. Bills et al. *(3)* found that excess fatty esters caused fruity flavor in Cheddar cheese. In this experiment, only one lot of the cheeses made with a fruity-flavor culture developed a characteristic fruity taste. The defect did occur casually in a few other lots of cheese, usually where slow cooling had been used. But, there were not enough instances for proper evaluation; therefore, the effect of press time and cooling rate cannot be reported. With this experience, however, it seems reasonable to expect that slowly cooled cheese would more readily develop this defect. This conjecture should be thoroughly tested.

There was no statistically significant difference in the amount of proteolysis due to the pressing period or cooling rate. Naturally, the amount of proteolysis increased during curing. As an example of this increase, cheese from lot D had proteolysis indexes of 13.0, 21.9, and 26.9% at 1, 3, and 6 months, respectively.

Use of rapid cooling did not improve the flavor of cheese made with the bitter culture. Development of bitter flavor in cheese has been attributed to insufficient breakdown of proteins and polypeptides to amino acids *(6, 8)*. Raadsveld *(22)* isolated substances with a polypeptide structure from bitter cheese, but similar products also were obtained from nonbitter cheese. He concluded that bitter taste resulted with certain combinations of odoriferous compounds. Emmons et al. *(7)* found that the development of bitter flavor in Cheddar cheese was more dependent on the starter strains used than on the manufacturing procedure.

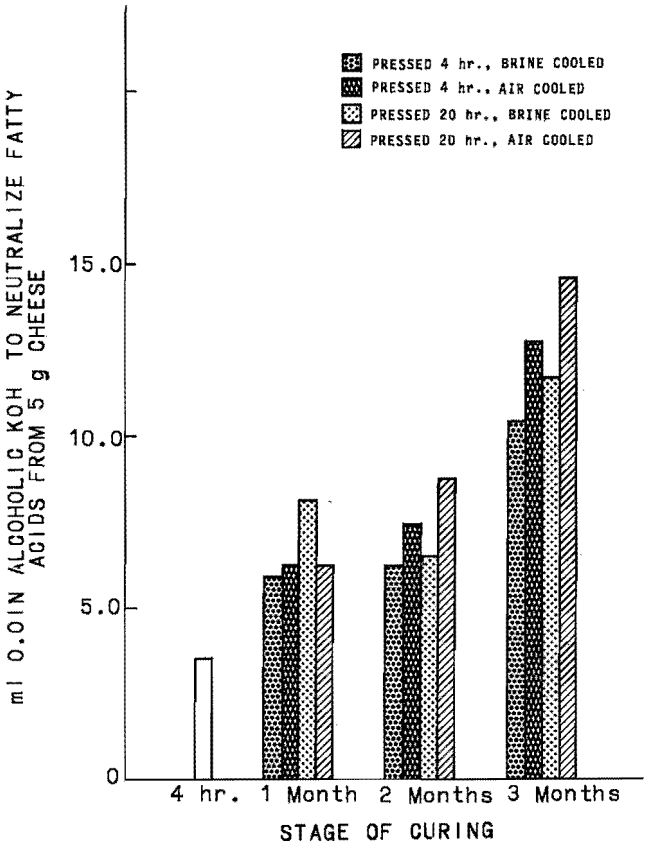

Figure 5. Free fatty acid content of Cheddar cheese from lot D (manufacturing-grade milk) during curing.

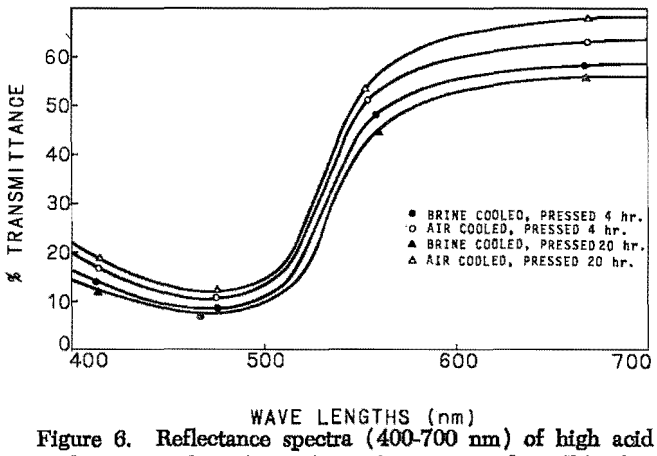

Figure 6. Reflectance spectra (400-700 nm) of high acid Cheddar cheese from lot B (manufacturing-grade milk) after 3-months curing.

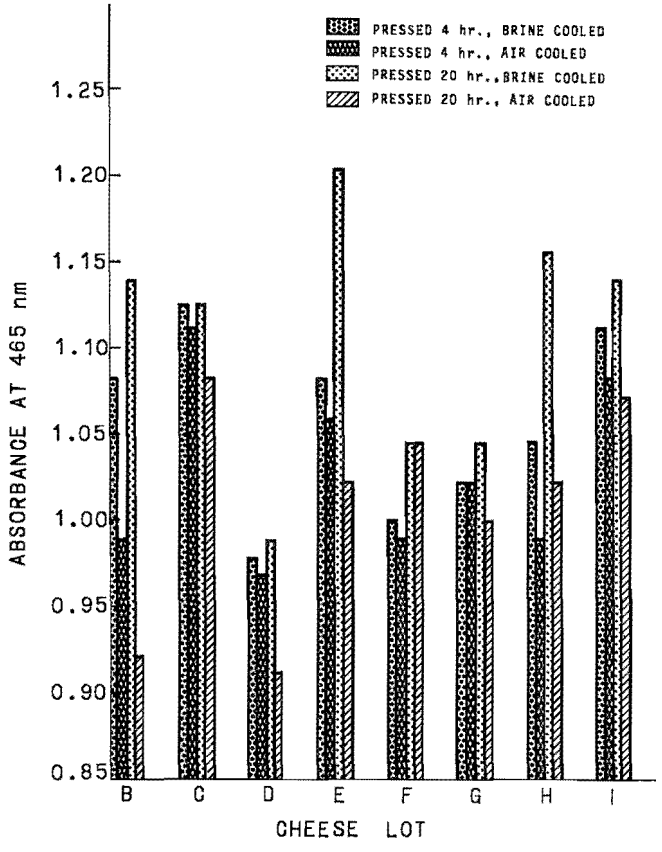

Figure 7. Intensity of Cheddar cheese color measured by reflectance at 465 nm after 3-months curing.

A reflectance spectra of cheese from lot B, performed after 3 months of curing, is shown in Fig. 6. Color differences between cheeses subjected to the various pressing and cooling treatments were greater in high-acid cheese. Figure 7 shows absorbance values for samples of 3-month-old cheese from eight of the lots that received the four treatments. Brine-cooled cheese showed more intense color than did air-cooled cheese. These differences were highly significant ($P < 0.01$). Color differences are explainable in light of sugar breakdown and acidity. There were, however, no significant differences in color because of differences in pressing time.

Judging results were consistent with results of the chemical tests. Brine-cooled cheese, which contained higher concentrations of sugar, less lactic acid, and less fatty acids, received higher flavor scores. Thus, differences in the cooling rate of cheese blocks can attribute serious problems in cheese flavor as suggested by Conochie and Sutherland *(5)*. With poor-quality milk containing millions of adventitious bacteria, the organisms, if the temperature is suitable, could produce unbalanced fermentations leading to serious defects. Bacterial flora in cheese made from poor-quality milk can be controlled to some extent if cooled rapidly to curing-room temperature (7.5 C) after pressing.

There was great variation among judges in the scoring of cheeses subjected to the different treatments. No statistically significant difference was observed between the different treatments. There was

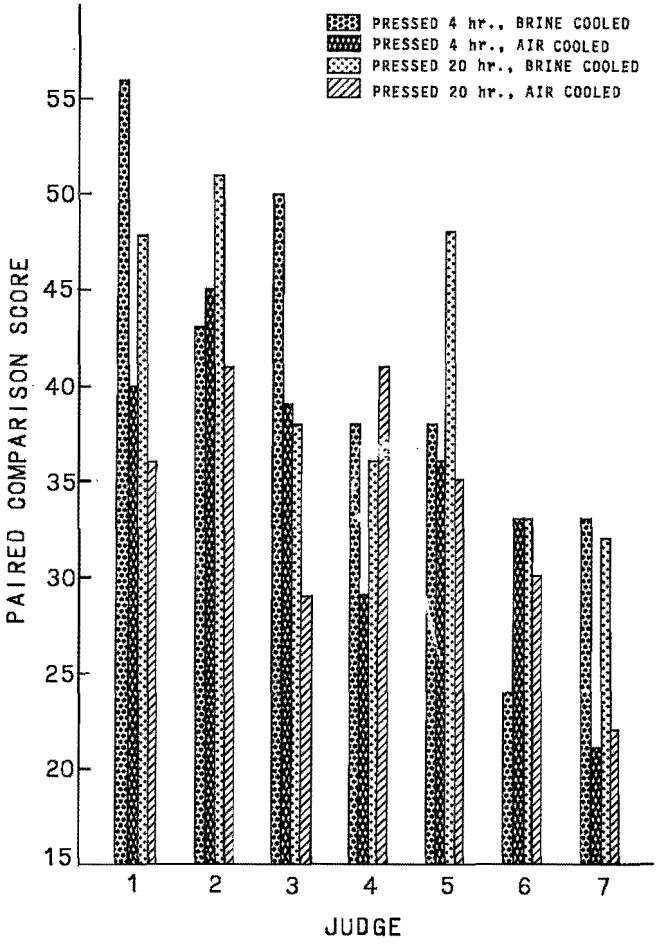

Figure 8. Paired comparison scores for each judge on 15 lots of Cheddar cheese which received four pressing and cooling treatments.

a significant difference ($P < 0.01$) in body and texture scores among normal-acid cheese (D, E, F), fruity cheese, (G, H, I), the three lots manufactured with recommended procedures, and the three lots manufactured with a culture that produced bitter flavor. Cheese made under "ideal conditions" and cheese made with the bitter culture had a firmer and smoother body than the normal-acid and fruity cheese. Each type of cheese had a significantly higher flavor and body score at 6 months than at 3 months of curing.

Figure 8 shows the paired comparison scores of each judge on individual treatments over 15 lots of cheese. Brine-cooled cheese had higher total scores in most instances. The preference of only one judge was statistically significant ($P < 0.01$); he preferred 4-h pressed, brine-cooled cheese. Six of the seven judges preferred the 4-h pressed cheese, and three judges preferred the 20-h pressed cheese. Although one judge preferred 20-h pressed, air-cooled cheese, four judges did not prefer the cheese receiving this treatment. Most judges noted a slight-to-moderate difference in flavor and body within a pair composed of air- and brine-cooled cheeses. Differences between 4- and 20-h pressing were insignificant.

On the basis of the criticisms marked on the score-cards, an attempt was made to categorize the defects of the cheese. Five of six judges criticized the air-cooled, high-acid cheese (A, B, C), for high acid and bitter flavor. The brine-cooled cheeses were not criticized for such defects by three judges; three others described the acid or bitter flavor in these cheeses as being slight when compared with the air-cooled cheese.

Two lots of the normal-acid cheese (D, E, F) were criticized by four judges for high acid and by three judges for fruity-flavor defects at 6 months of curing. Air-cooled cheese was severely criticized by all judges for high-acid and fruity-flavor defects, but brine-cooled cheese did not receive these criticisms. Of the three lots of cheese made with recommended procdures, the air-cooled cheese was criticized for high-acid flavor.

None of the cheeses (G, H, I) made with the fruity culture was criticized for fruity flavor at 3 months of curing. At 6 months, only lot I had developed an appreciable amount of fruity flavor. Because of this, the effect of press time and cooling time and cooling rate could not be properly measured. The brine-cooled cheese, however, did not receive criticism for high-acid flavor.

When the bitter culture was used, both brine- and air-cooled cheese was criticized for bitter flavor. The lot of cheese made with added coliform organisms received low scores for all treatments and had a gassy, weak, and pasty body. Five of six judges, however, considered the brine-cooled cheeses of this lot flat rather than high-acid flavored. On the other hand, four of six judges criticized the air-cooled cheese for having a high-acid taste, and two of them detected fruity flavor.

From the foregoing, it is evident that high-quality milk, desirable starters, and rapid curd cooling are necessary for the manufacture of uniformly high-quality Cheddar cheese.

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