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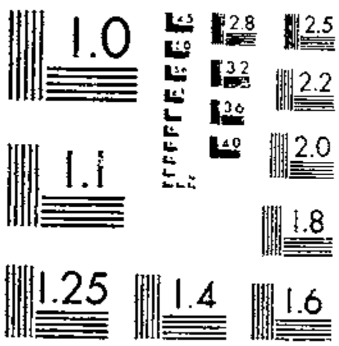

MICROCOPY RESOLUTION TEST CHART
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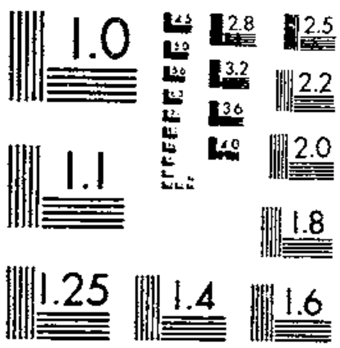

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Effect of Homogenization on the Curd Tension, Digestibility, and Keeping Quality of Milk[1]

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INTRODUCTION

The use of homogenized milk is increasing rapidly in the United States. One reason is that many consumers prefer milk in which the fat is evenly dispersed; another is that some consumers also find the homogenized milk more palatable than unhomogenized milk; and furthermore, milk distributors have promoted the use of homogenized milk on the basis of its soft-curd properties. Some authorities contend that soft-curd milk is more readily digested than hard-curd milk.

Weisberg, Johnson, and McCollum (*36*);[2] Wallace (*34*) and Washburn (*35*) were among the first to report that homogenization changes the character of the curd of milk. Hill (*15*), however, reported that the results of his work did not justify the use of the homogenizer for the production of soft-curd milk. More recently Doan and Welch (*11*); Tracy (*28*); Theophilus, Hansen, and Spencer (*26*); Wolman (*37*); Babcock (*2*); and others have shown that soft-curd milk can be produced by homogenization.

[1] Received for publication April 27, 1942.

[2] Italic numbers in parentheses refer to Literature Cited, p. 21.

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Table 1 also shows that, from a curd-tension standpoint, the maximum pressure of homogenization need not be greater than 2,500 pounds. Only a slightly greater reduction in curd tension is obtained at higher pressures. This is in agreement with work of Caulfield and Martin (*4*), who concluded that homogenizing pressures in excess of 2,500 pounds appear to be of little practical value in reducing the curd tension of milk. Tracy (*29*) also states that a pressure of 2,500 pounds is sufficiently great for all practical purposes as there is little to be gained, as far as reduction in curd tension is concerned, by increasing the pressure to 3,000 pounds.

HOMOGENIZING TEMPERATURE

The temperature at which milk is homogenized at any given pressure affects the curd tension of the milk. As a rule, the higher the temperature of homogenization the lower the curd tension. (See table 2.)

TABLE 2.—*Effect of homogenizing temperature on the curd tension of milk (homogenized at 2,000 pounds pressure)*

Homogenizing temperature	Curd tension: Unpasteurized milk	Curd tension: Milk pasteurized after homogenizing	Curd tension: Milk pasteurized before homogenizing	Homogenizing temperature	Curd tension: Unpasteurized milk	Curd tension: Milk pasteurized after homogenizing	Curd tension: Milk pasteurized before homogenizing
°F.	*Grams*	*Grams*	*Grams*	*°F.*	*Grams*	*Grams*	*Grams*
120	26	24	22	160	19	17	15
130	25	22	23	170	15	14	13
140	23	21	24	180	15	13	12
150	21	20	18				

Table 2 shows that when unpasteurized milk is homogenized the higher the temperature of homogenization the lower its curd tension. When homogenized milk is pasteurized the same normal reduction in curd tension occurs. When homogenization takes place after pasteurization, however, slightly lower curd tensions result at both the lower and higher homogenizing temperatures. This was also found to be true at homogenizing pressures of 1,000, 1,500, 2,500, and 3,000 pounds. It agrees with the results of Tracy (*29*), who reported that when homogenization occurs after pasteurization somewhat lower curd tensions result at the lower homogenizing temperature. The greater reductions in curd tension at the higher temperatures of homogenization are probably caused, as concluded by Caulfield and Martin (*4*) by the combined effects of heat treatment and homogenization. The average curd tension of the pasteurized milk used in this work was 56 gm. Momentarily heating this milk to 180° F. reduced the curd tension to 38 gm. Tracy (*29*) has also presented data which show that heating raw milk to 180° F. reduces the curd tension from 58 gm. to 40 gm.

SINGLE-STAGE AND TWO-STAGE HOMOGENIZATION

To determine the effect of one- and two-stage homogenization on the curd tension of milk, a pressure of 3,000 pounds on the first stage of a two-stage homogenizer was gradually transferred to the second stage. The average results are shown in table 3.

TABLE 3.—*Effect of transferring the homogenizing pressure from the first to the second stage of the homogenizer on the curd tension of milk*

Homogenizing pressure		Curd tension	Homogenizing pressure		Curd tension
First stage	Second stage		First stage	Second stage	
Pounds	*Pounds*	*Grams*	*Pounds*	*Pounds*	*Grams*
3,000	0	12.0	1,000	2,000	13.5
2,500	500	13.0	500	2,500	14.0
2,000	1,000	12.5	0	3,000	11.5
1,500	1,500	13.5			

The effect of two-stage as compared with that of single-stage homogenization on the curd tension of milk was also determined by using various pressures on one stage and then dividing the pressures used equally between the first and second stage. The average results obtained by this procedure are shown in table 4.

TABLE 4.—*The effect of 2-stage homogenization on the curd tension of milk*

Single-stage homogenization		Two-stage homogenization			
Pressure	Curd tension	Pressure			Curd tension
		First stage	Second stage	Total	
Pounds	*Grams*	*Pounds*	*Pounds*	*Pounds*	*Grams*
500	34.5	250	250	500	36.0
1,000	19.0	500	500	1,000	20.0
1,500	16.0	750	750	1,500	17.5
2,000	14.0	1,000	1,000	2,000	15.0
2,500	13.0	1,250	1,250	2,500	14.0
3,000	12.0	1,500	1,500	3,000	12.5

Tables 3 and 4 show that there is no advantage from a curd-tension standpoint in using a two-stage homogenizer instead of a single-stage homogenizer. These results are in agreement with those of other investigators. Theophilus, Hansen, and Spencer (*26*) concluded that single-stage and two-stage homogenizers were equally effective in reducing the curd tension of milk. The data obtained by Tracy (*28*) indicated that single and double homogenization at the same total pressure have comparable effects on curd tension. Caulfield and Martin (*4*) concluded that the curd tension of homogenized milk was not materially changed by rehomogenization.

EFFECT OF FAT CONTENT

Tracy (*30, p. 576*) reported that as the butterfat content of the milk is increased, the curd tension is reduced unless at the same time there is an increase in the percentage of serum solids. Hill (*14*) also presented data which show that the removal of the fat from milk causes an increase in curd tension, but that the concentration of fat in a milk is not an index to the curd character. The author, using milk obtained by standardizing skim milk and cream, found that the higher the fat content the lower the curd tension of the milk. (See table 5.)

TABLE 5.—*Effect of butterfat content on curd tension (standardized skim milk and cream)*

Butterfat content	Curd tension		Butterfat content	Curd tension	
	Unhomogenized milk	Milk homogenized at 2,000 pounds		Unhomogenized milk	Milk homogenized at 2,000 pounds
Percent	*Grams*	*Grams*	*Percent*	*Grams*	*Grams*
0.02	66	64	3.0	50	21
1.0	58	31	4.0	48	18
2.0	56	28	5.0	45	16

Table 5 shows that as the butterfat content of the milk was increased the curd tension was lowered. It further shows that the effect of butterfat content on curd tension was greater in homogenized milk than in unhomogenized milk. Homogenization at 2,000 pounds pressure had practically no effect on the curd tension of skim milk. The addition of 1 percent of butterfat, however, caused a marked reduction in the curd tension of the homogenized milk as compared with that of the unhomogenized milk. This reduction in curd tension for homogenized milk as compared with the unhomogenized milk became more marked as the butterfat content of the milk was increased above 1 percent. In determining the effect of butterfat content on the curd tension of milk, no material change in the results was obtained by using a two-stage homogenizer as compared with the results obtained by using the single-stage homogenizer.

The fact that the butterfat content had a more marked effect on the curd tension of homogenized milk than on that of unhomogenized milk, supports the finding of Weisberg, Johnson, and McCollum (*36*) that the concentration and manner of dispersion of the fat are important in influencing the curd character, and the finding of Chambers (*5*) that a direct relationship exists between degree of fat dispersion and degree of curd-tension reduction.

EFFECT OF MIXING HOMOGENIZED MILK WITH UNHOMOGENIZED MILK

The curd tension of milk is lowered by the addition of a softer-curd milk. Smith (*24*) mixed 4 parts by volume of normal whole (market) milk having a curd tension of approximately 40 gm., with 1 part of similar milk which was treated by homogenization to reduce its curd tension to approximately 19 gm., and obtained a resulting milk with a curd tension of about 28.

In this investigation unhomogenized milk, having an average curd tension of 48 gm., was mixed with homogenized milk having an average curd tension of approximately 12. The following results were obtained: When the mixture consisted of 25 percent homogenized and

75 percent unhomogenized milk, the average curd tension of the mixture was 31.2 gm. or approximately 35 percent lower than that of the unhomogenized milk.

When the homogenized and unhomogenized milks were mixed on a 50-50 basis, the average curd tension of the mixture was 22.3 gm., or approximately 53.5 percent lower than that of the unhomogenized milk.

A mixture of 75 percent of homogenized and 25 percent of unhomogenized milk gave a milk with an average curd tension of 16.4 gm., or approximately 66.5 percent lower than that of the unhomogenized milk.

These results show that the curd tension of milk is lowered by the addition of milk in which the curd tension has been lowered by homogenization. To obtain a soft-curd milk it is necessary, however, to add homogenized milk in such a proportion that the resultant mixture will not have a normal cream line.

Effect of Partial Freezing

In cold climates milk frequently becomes partly frozen. To determine the effect of partial freezing on the curd tension of milk, bottled milk was held for 4 hours at 0° F., then slowly thawed at room temperature and compared with duplicate samples that had been held at 45°. The pasteurized milk that had been partly frozen had an average curd tension of 63.3 gm. as compared with 63.8 gm. for the unfrozen samples. Homogenized milk had an average curd tension of 22 gm. for both the frozen and unfrozen samples. These results show that the curd tension of milk is not affected by partial freezing. This is contrary to the findings of Berry (*4*), who worked with completely and partly frozen milks, and concluded that the freezing of milk had a hardening effect upon the curd. Tracy (*28*), while not reporting on the effect of freezing on curd tension, concluded, however, from his work that there is less churning of fat in milk that has been frozen and thawed if the milk is previously homogenized. He also states that milk homogenized at 2,000–3,000 pounds and then frozen will have a normal appearance when melted.

RELATIVE DIGESTIBILITY OF HOMOGENIZED AND UNHOMOGENIZED MILK

Considerable work, as reviewed by Doan (*9*), has been done which shows that soft-curd milk is more easily digested and therefore more suitable for infant feeding than hard-curd milk. Only a few of these studies, however, deal with homogenized milk. Hull (*18*) reported digestion studies which showed that homogenized milk run at 1,500 and 2,500 pounds pressure at a temperature of 130° F., gave almost duplicate results with those of regular milk. Doan and Flora (*10*) concluded that homogenization of milk lowers curd tension considerably but apparently improves digestibility very slightly, if at all. Wolman (*38*), however, in reporting on an extensive study with 840 normal infants in Philadelphia, concluded that pasteurization and homogenization of whole milk under the conditions of the study, results in a milk product possessing soft-curd properties and small-curd characteristics, features that he regarded as much to be desired in the artificial feeding of infants. In a later report (*39*) he also states that milk pasteurized and homogenized under the conditions of the study proved to be as satisfactory for the feeding of healthy infants as was pasteurized milk boiled for 5 minutes in the home. The experimental milks were fed unboiled.

It is impossible to measure digestion accurately in vitro, because the conditions of the stomach cannot be accurately simulated, but indication of digestibility can be obtained. Using the procedure previously outlined (p. 2), comparisons were obtained, by measuring the rate of proteolysis in:

(1) Raw milk and boiled milk. The raw milk used had an average curd tension of 60 gm., and after the milk was boiled the average curd tension was 9 gm.

(2) Unpasteurized milk and pasteurized homogenized milk. The unpasteurized milk, with a curd tension of 50 gm., was pasteurized and homogenized at 2,500 pounds pressure, which lowered the curd tension to an average of 16 gm.

(3) Unpasteurized milk and milk pasteurized and then homogenized at 1,000 pounds pressure. The unpasteurized milk had an average curd tension of 58 gm., which was lowered to 29 by pasteurizing and homogenizing.

(4) Pasteurized milk and pasteurized homogenized milk. The pasteurized milk, with an average curd tension of 46 gm., was homogenized at 2,500 pounds pressure, reducing the curd tension to 7 gm.

The first, second, and third comparisons were made by adding sufficient of the acid-pepsin digestant to the milk so that proteolysis took place at pH 3.5, and the last comparison at pH 2.0. In the latter the milk was coagulated by adding N/10 HCl-pepsin solution and placing in a water bath at 37° C. for 10 minutes prior to digestion at pH 2.0 (p. 2).

The results with boiled milk as compared to raw milk, are presented in figure 1, *A*. These show that proteolysis took place much more rapidly in the boiled milk than in the raw milk during the first 15 minutes of digestion, but the difference in rate of proteolysis decreased after this time and at the end of 5 hours was practically the same in both milks. During the first 15 minutes an average of 76.5 percent more proteolysis had taken place in the boiled milk than in the raw milk. After the first 15 minutes, the average difference in the amount of proteolysis that had occurred in the raw and boiled milks decreased, the difference in favor of the latter being 34.8, 25.0, 17.2, 10.3, 8.5, 1.6, and 0.4 percent, respectively, at 30- and 45-minute and 1-, 2-, 3-, 4-, and 5-hour intervals.

The digestion results for unpasteurized milk and corresponding milk when pasteurized and then homogenized at 2,500 pounds, are shown in figure 1, *B*. These also indicate that the soft-curd (homogenized) milk begins to digest more rapidly than the hard-curd (raw) milk. The difference in rate of digestion was 56.5, 40.5, 30.1, 22.2, 15.4, 9.3, 4.9, and 0.8 percent, respectively, at the end of the 15-, 30-, and 45-minute, and 1-, 2-, 3-, 4-, and 5-hour intervals, respectively.

Comparison of figures 1, *B*, and 1, *A*, shows that proteolysis in homogenized milk was very similar to that in boiled milk. During the first 15-minute interval, digestion did not proceed as rapidly in

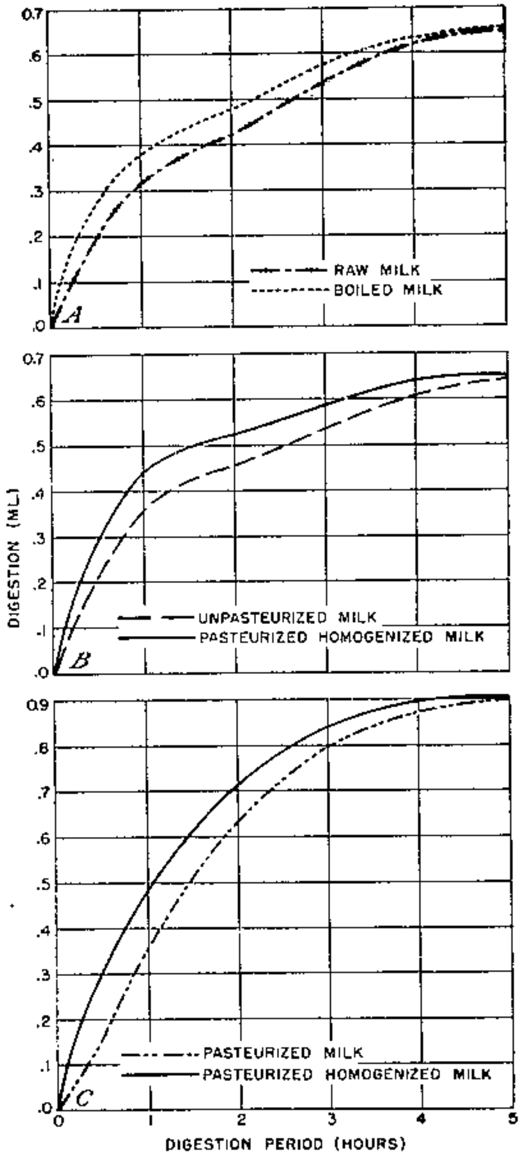

FIGURE 1.—Relative digestion, as shown by formol titration, of: *A*, Raw milk and boiled milk; *B*, unpasteurized milk and pasteurized homogenized milk; and *C*, pasteurized milk and pasteurized homogenized milk. In *A* and *B*, digestion took place at pH 3.5, and in *C*, at pH 2.0.

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the homogenized milk as in the boiled milk. At the end of this period 56.5 percent more proteolysis had taken place in the homogenized milk than in the raw milk (fig. 1, *B*) as compared with 76.5 percent more for boiled than in the raw milk (fig. 1, *A*). The rate of digestion, however, did not decrease so rapidly in the homogenized as it did in the boiled milk. At the end of 2 hours the difference in rate of digestion was 15.4 percent more for homogenized than for raw milk, whereas the rate for the boiled milk was only 10.3 percent greater than in the raw milk. At the end of a 5-hour interval, there was no significant difference in the homogenized and unpasteurized milks.

With unpasteurized milk and corresponding milk pasteurized and then homogenized at 1,000 pounds pressure, the average digestion of the two milks was very similar in trend to that shown when the milk was homogenized at 2,500 pounds. The difference in amount of proteolysis between milk homogenized at 1,000 pounds and unpasteurized milk, was considerably less than the difference between the milk homogenized at 2,500 pounds and the unpasteurized milk (pH 3.5). At the end of 15 minutes of digestion the milk homogenized at 1,000 pounds showed only 27.2 percent more proteolysis, whereas that homogenized at 2,500 pounds showed 56.5 percent more than the corresponding unpasteurized milk. The rate of proteolysis in milk homogenized at 1,000 pounds was 27.2, 26.8, 7.8, 3.8, 3.1, 0.8, 0.8, and 0.0 percent more at 15-, 30-, and 45-minute, and 1-, 2-, 3-, 4-, and 5-hour intervals, than with the unpasteurized milk. There was practically no difference in the amount of proteolysis that had taken place in the milk homogenized at 1,000 pounds and in the unpasteurized milk, at the end of 3 hours of digestion, whereas with milk homogenized at 2,500 pounds pressure the proteolysis in the two milks did not become equalized until 5 hours of digestion had taken place.

Results for samples of pasteurized milk, as compared to corresponding milk when homogenized at 2,500 pounds, are shown in figure 1, *C*. This comparison was made with proteolysis taking place at pH 2.0. Figure 1, *C*, as compared with figure 1, *A* and *B*, shows that lowering the pH at which digestion took place, from 3.5 to 2.0 greatly accelerated the rate of proteolysis.

With digestion taking place at pH 2.0 (fig. 1, *C*) in 15 minutes the pasteurized homogenized milk showed 171 percent more proteolysis than the pasteurized milk. As was the case when proteolysis took place at pH 3.5, after 15 minutes the difference in the amount of proteolysis between the two milks decreased and at the end of 5 hours the extent of proteolysis was practically the same for both milks. The difference in rate of proteolysis was 93.5, 54.0, 38.5, 13.5, 5.7, 2.2, and 0.5 percent at 30- and 45-minute, and 1-, 2-, 3-, 4-, and 5-hour intervals, in favor of the homogenized milk.

The rate of proteolysis in raw and pasteurized milk was also compared. Proteolysis took place at pH 3.5. The data are not oresented as there was no definite difference in the rate of proteolysis between these two milks. The individual determinations made at different periods of digestion showed that at times slightly less, and at other times slightly more, proteolysis had taken place in the pasteurized milk than in the raw milk. The largest average variation in the amount of proteolysis obtained at the end of any digestive period was 0.9 percent.

CURD AREA

Wolman (*37*) was probably the first to stress the correlation between curd size and digestibility of milk. Using an artificial stomach, he found that the average curd size was determined by the initial curd tension and ran directly proportional to it, regardless of the type of milk employed, so long as foreign substances are not present. Regarding homogenized milk, he states that the curds obtained were always much finer than the curds of prepared formulas derived from identical specimens of milk pasteurized but not homogenized.

Storrs (*25*), however, found that within individual types of commercially modified milks there appears to be no significant correlation between curd tension and curd surface area. He suggests that these are independent characteristics of milk, and that each may be influenced or determined by factors not closely related.

In this investigation, curd area measurements were made by using a technique similar to that of Wolman (*37*), but with the changes mentioned herein under procedure (p. 3). On comparing these values with the curd-tension measurements, it was found that the curd area cannot always be correlated with curd tension. This is especially true where the variations in curd tension are small. When a number of determinations are averaged, however, there appears to be a rather definite correlation between curd area and curd tension. This is shown in table 6.

TABLE 6. *Relation of curd area to the curd tension of milk*

Character of milk	Average curd area	Average curd tension
	Cm.²	*Grams*
Raw	1,300	51
Pasteurized	1,600	40
Homogenized at a pressure of—		
1,000 pounds	4,200	22
1,500 pounds	4,600	17
2,000 pounds	5,400	13.5
2,500 pounds	6,300	11.0
3,000 pounds	8,800	10.5

Table 6 shows that, on the average, as the curd tension of milk is lowered by homogenization the surface area of the curds increases. The increase in curd surface is probably not significant from a digestive standpoint until the milk is homogenized at a pressure of 2,000 pounds or more. The smaller the curds that are formed the more readily they would probably leave the stomach, and theoretically the greater the curd area the more readily they would be attacked by the digestive juices. The fact that homogenized milk forms smaller curds with a greater curd area than raw or pasteurized milk, indicates that it is more easily digested.

KEEPING QUALITY

It has been reported by Babcock (*1*) and others (*7*, *17*, *19*) that homogenized milk is as palatable or more so than unhomogenized milk. In order to determine whether or not homogenized milk retains its palatability as well as unhomogenized milk, comparative studies were made of the keeping quality of the two milks.

SUSCEPTIBILITY TO COPPER-INDUCED OXIDIZED FLAVOR

Holm et al. (*16*) showed that homogenization of milk prior to drying improved the keepability of the powder as far as the development of tallowiness was concerned. Tracy, Ramsey, and Ruehe (*31*) found that when a copper salt was added to the milk at the rate of 2.6 parts per million, the homogenized milk remained free from tallowiness after 24 hours of incubation. The control milk, and milk with copper added and passed through the machine without pressure, however, were strongly tallowy.

Homogenization at pressures as low as 500 pounds, according to Thurston, Brown, and Dustman (*27*), either reduced the intensity of the oxidized flavor resulting after the addition of copper or prevented it altogether. In no case was oxidized flavor developed in milks containing 2.6 p. p. m. of added copper when the homogenizing pressure was 3,000 pounds or more. Ross (*23*) presented data showing that homogenization at a pressure of 1,500 pounds prevented the development of oxidized flavor, whether the milk was contaminated with copper before or after homogenization.

Trout and Gould (*33*) also presented data showing that a pressure of 1,500 pounds has a marked effect in stabilizing the flavor of copper-contaminated milk. They found, however, that a pressure of 2,000 pounds was more effective, and that pressures of 2,500 and 3,000 pounds were sufficient to inhibit the development of the oxidized flavor when the copper was added at the rate of 5.0 p. p. m. prior to homogenization. When the milk was contaminated after homogenization, a pressure of 3,000 pounds inhibited oxidized flavor development in milk contaminated with 2.5 p. m., but this pressure was ineffective when 5.0 p. p. m. of copper were similarly added.

Larsen, Gould, and Trout (*20*) stated that homogenization tends to stabilize the milk against oxidation, but has no influence on changes in the oxidation-reduction potentials. Trends in Eh were similar regardless of homogenization.

Results obtained in work by the author also show that homogenization retards or inhibits the development of copper-induced oxidized flavor in milk. When copper was added prior to homogenization at 3,000 pounds, none of the milk used developed the flavor from the use of 3 p. p. m. of copper. The addition of 4 p. p. m. of copper prior to homogenization, however, produced an oxidized flavor in milk homogenized at 3,000 pounds when the milk before homogenization developed the flavor on the addition of 0.1 and 0.2 p. p. m. of copper. As the susceptibility of the milk toward oxidation decreased, the quantity of copper that could be added prior to homogenization without causing an oxidized flavor increased. Milk which required the addition of copper at the rate of 1.0 p. p. m. to produce an oxidized flavor did not develop the flavor after homogenization at 3,000 pounds, even though 5.0 p. p. m. of copper were added prior to homogenization. No milk was obtained, however, to which 6.0 p. p. m. of copper could be added prior to homogenization without the development of an oxidized flavor in the homogenized milk.

Homogenized milk is much less susceptible to the development of a copper-induced oxidized flavor than unhomogenized milk. (See table 7.)

TABLE 7.—*The effect of homogenization on the development of an oxidized flavor [1] in milk from contamination with copper*

Source of milk [2]	Unhomogenized milk with a copper addition (p. p. m) of—																			
	0.2				0.3				0.4				0.5				0.6			
	At 24 hours	At 48 hours	At 72 hours	At 96 hours	At 24 hours	At 48 hours	At 72 hours	At 96 hours	At 24 hours	At 48 hours	At 72 hours	At 96 hours	At 24 hours	At 48 hours	At 72 hours	At 96 hours	At 24 hours	At 48 hours	At 72 hours	At 96 hours
A	+	++	++++	++++	++	++++	++++	++++	++++	++++	++++	++++	++++	++++	++++	++++	...	...	...	...
B	−	+	++	++	+	++	++	++++	+++	+++	++++	++++	++++	++++	++++	++++	...	...	...	...
C	−	−	−	−	−	−	−	−	−	+	+	++	−	+	+	++	+	+	++	++
D	−	−	−	−	−	−	−	−	−	−	+	+	−	+	+	++	−	+	+	+++
E	−	−	−	−	−	−	−	−	−	−	−	+	−	+	++	++	−	+	+	+++
F	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	+	+

Source of milk [2]	Homogenized milk [3] with a copper addition (p. p. m.) of—																			
	2.0				3.0				4.0				5.0				6.0			
	At 24 hours	At 48 hours	At 72 hours	At 96 hours	At 24 hours	At 48 hours	At 72 hours	At 96 hours	At 24 hours	At 48 hours	At 72 hours	At 96 hours	At 24 hours	At 48 hours	At 72 hours	At 96 hours	At 24 hours	At 48 hours	At 72 hours	At 96 hours
A	−	+	++	++	+	++	+++	+++	+++	++++	++++	++++	+++	++++	++++	++++	...	...	...	...
B	−	−	−	+	−	+	++	++	+	++	+++	+++	++	++++	++++	++++	...	...	...	...
C	−	−	−	−	−	+	+	++	+	++	++	++	+	++	+++	++++	+	+++	++++	++++
D	−	−	−	−	−	−	−	−	−	+	+	+	−	++	++	+++	+	+++	+++	+++
E	−	−	−	−	−	−	−	−	−	−	+	++	−	−	−	++	−	+	+	+++
F	−	−	−	−	−	−	−	−	−	−	−	+	−	−	+	+	−	+	+	++

[1] Minus sign (—) indicates no oxidized flavor; += very slight ozidized flavor; ++= slight oxidized flavor; +++= oxidized flavor; ++++= strong oxidized flavor.
[2] Each milk represents an average of 3 different samples.
[3] Homogenized at 3,000 pounds pressure.

An examination of table 7 shows that the susceptibility of homogenized milk to the development of a copper-induced oxidized flavor is also related to the susceptibility of the milk before homogenization. As a rule, it required the addition of approximately 10 times as much copper to homogenized milk to produce an oxidized flavor, as was required to produce a similar flavor in the same milk before homogenization.

Susceptibility to Sunlight-Induced Oxidized Flavor

Hammer and Cordes (*13*), Frazier (*12*), Tracy and Ruehe (*32*), Doan (*8*), and others have reported that sunlight may cause a tallowy or oxidized flavor in milk. Davies (*6*) stated that homogenized milk is more susceptible to the action of light than the corresponding raw milk. Hood and White [3] found that direct sunlight induces the development of a characteristic "cappy" or "cardboard" flavor in homogenized milk, whereas in pasteurized milk the flavor produced is more of a tallowy nature.

The author found that homogenized milk is much more susceptible to the action of sunlight than the corresponding pasteurized milk. When the sunlight is sufficiently intense to produce an oxidized flavor in homogenized milk upon exposure for one-half hour, the flavor does not appear in the pasteurized milk until it has been exposed to the same light for 1 hour. The same relation held true when the intensity of the light was such that it produced the flavor in homogenized milk after exposures for 1 and 2 hours. Under these conditions the flavor did not appear in the pasteurized milk before it was exposed for 2 and 4 hours, respectively. These results indicate that homogenized milk is twice as susceptible to the action of sunlight as pasteurized milk.

Flavor Developments During Storage

The flavor developments in both homogenized and pasteurized milk during storage depend primarily on the quality of the milk prior to storage and the temperature of storage (see table 8).

[3] Hood, E. G., and White, A. H. HOMOGENIZATION OF MARKET MILK. [Canada] Dept. Agr. Mimeograph No. 25, 14 pp. 1934. [Processed.]

TABLE 8.—*Comparison of flavor developments in pasteurized and homogenized milks after storage at different temperatures*

Storage temperature and storage period	Flavor of milk from source—					
	A		B		C	
	Pasteurized	Homogenized	Pasteurized	Homogenized	Pasteurized	Homogenized
Prestorage	Good	Good	Slight cooked, slight feed.	Slight cooked, slight feed.	Good	Good.
37° C. (98° F.) for 24 hours	Sour, curdled	Sour, wheyed off	Sour, partly wheyed off	Sour, wheyed off		
32° C. (90° F.) for 24 hours					Mild acid, slight whey	Yeasty acid, whey, gas.
20° C. (68° F.) for—						
24 hours	Good	Good	Slight feed	Slight feed	Good	Good.
2 days	do	do	Slight feed, slight old	Very slight acid	High acid	Sour, curdled.
3 days	High acid, slight unclean.	Sour, unclean	High acid, unclean	Sour, putrid	Clean acid, curdled	Fairly clean acid, curdled.
6.7° C. (44° F.) for—						
2 days						
4 days						
6 days						
8 days						
10 days						
13 days						
21 days						
0° C. (32° F.) for—						
2 days	Good	Good	Slight feed	Slight feed		
4 days	do	do	Slight unclean	do		
7 days					Good	Good.
8 days						
9 days	Very slight old	Very slight old	Slight old, slight musty	Slight old, feed		
13 days					Very slight old	Very slight old.
16 days	Very slight old	Very slight old	Old, oxidized	Old		
21 days						
33 days					Old	Old, unclean.
35 days						
43 days						

TABLE 8.—*Comparison of flavor developments in pasteurized and homogenized milks after storage at different temperatures*—Con.

Storage temperature and storage period	Flavor of milk from source—					
	D		E		F	
	Pasteurized	Homogenized	Pasteurized	Homogenized	Pasteurized	Homogenized
Prestorage	Good	Good	Good	Good	Cowy, slight feed	Cowy, slight feed.
37° C. (98° F.) for 24 hours						
32° C. (90° F.) for 24 hours	Clean acid, slight whey	Clean acid, whey				
20° C. (68° F.) for—						
24 hours	Good	Good				
2 days	Slight acid	High acid				
3 days	Clean acid, slight whey	Clean acid, whey				
6.7° C. (44° F.) for—						
2 days			Good	Good	Cowy	Cowy, slight bitter.
4 days			do	do	Slight oxidized	Do.
6 days			do	do	do	Slight unclean, slight bitter.
8 days			do	do	Oxidized	Bitter, unclean.
10 days			Very slight old	Very slight old	do	Do.
13 days			Slight old	Slight old	do	Do.
21 days			Old	Slight acid, putrid	Putrid, oxidized	Putrid, bitter.
0° C. (32° F.) for—						
2 days						
4 days						
7 days	Good	Good				
8 days			Good	Good	Slight oxidized	Feed, unclean.
9 days						
13 days	Slight oxidized	Very slight old	Good	Good	Slight oxidized	Unclean.
16 days						
21 days	Oxidized	Slight old	Very slight old	Very slight old	Oxidized	Old, unclean.
33 days	Oxidized, moldy	Old				
35 days			Old	Old	Strong oxidized	Old, unclean.
43 days			do	do	do	Do.

Table 8 shows that storage had practically the same effect on the flavor of both pasteurized milk and homogenized milk. It should be noted, however, that the homogenized milk had a tendency to deteriorate slightly more rapidly than the pasteurized milk, especially when stored at the higher temperatures. It should be noted also that an oxidized flavor did not appear in the homogenized milk upon storage even when the milk was pasteurized in equipment containing exposed copper, as was the case with the milk from source F and to a lesser extent with that from sources B and D.

Table 8 further shows that when either pasteurized or homogenized milk is of good flavor prior to storage, it can be stored at usual storage temperatures without deterioration in flavor for longer periods than are usually required for market milk.

Comparisons of Bacterial Growth and Acid Development [4]

Tracy (*29*) has presented data showing that homogenization increases the bacterial count of milk. No attempt was made, however, to determine the rate of bacterial growth or acid development in the two milks.

To determine whether bacteria multiply faster and acid develops more rapidly in homogenized milk than in the corresponding pasteurized milk, samples were obtained from various sources, before and after homogenization, and stored at different temperatures. The initial bacterial count, acidity, and pH value were determined prior to placing the milks in storage. After different storage periods, these determinations were repeated. The results are given in table 9.

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[4] The bacteriological work was done by J. Frank Cone, associate market-milk specialist, and the chemical work by H. S. Haller, assistant chemist, Division of Market-Milk Investigations.

TABLE 9. *Bacterial growth and acid development in pasteurized and homogenized milks*

Storage temperature and storage period	Bacteria per milliliter											
	A		B		C		D		E		F	
	Pasteurized	Homogenized	Pasteurized	Homogenized	Pasteurized	Homogenized	Pasteurized	Homogenized	Pasteurized	Homogenized	Pasteurized	Homogenized
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Prestorage	[1] 10,000	[1] 10,000	3,800	13,400	6,100	7,600	21,000	70,000	1,800	9,700	4,600	8,600
37° C. (98° F.) for 24 hours	325,000,000											
32° C. (90° F.) for 24 hours												
20° C. (68° F.) for—												
24 hours	[2] 6,000,000	113,000	630,000	3,260,000	155,000	10,000	2,400,000	590,000				
2 days	71,000,000	134,000,000	3,700,000	32,000,000	2,100,000	2,550,000	61,000,000	500,000				
3 days	111,000,000	163,000,000	31,100,000	191,000,000								
6.7° C. (44° F.) for—												
2 days									6,700	9,200	2,400	6,600
4 days									125,000	42,500	7,700	12,800
6 days									1,020,000	1,550,000	41,000	1,000
8 days									13,400,000	6,000,000	107,000	3,000
10 days									17,500,000	14,500,000	110,000	10,500
13 days									11,000,000	3,000,000	170,000	63,000
21 days									120,000,000	88,000,000	300,000	3,800,000
0° C. (32° F.) for—												
2 days	10,500	15,500	4,500	12,000								
4 days	15,000	16,000	9,000	15,000								
7 days					4,500	7,600	17,500	77,000				
8 days									16,500	11,000	2,000	1,000
9 days	5,500	16,500	3,000	16,500								
13 days					8,000	13,000	27,000	270,000	1,360,000	152,000	3,100	9,200
16 days	1,960,000	375,000	4,500	210,000								
21 days									10,200,000	1,550,000	4,000	7,000
33 days					2,500,000	2,500,000	2,000,000	1,500,000				
35 days									43,000,000	4,700,000	10,000	5,000
45 days									104,000,000	62,000,000	400	900

pH

	A Pasteurized	A Homogenized	B Pasteurized	B Homogenized	C Pasteurized	C Homogenized	D Pasteurized	D Homogenized	E Pasteurized	E Homogenized	F Pasteurized	F Homogenized
Prestorage	6.54	6.58	6.53	6.58	6.72	6.72	6.68	6.68	6.57	6.58	6.65	6.57
37° C. (98° F.) for 24 hours	4.52	4.73	5.16	4.38								
32° C. (90° F.) for 24 hours					5.73	5.54	5.10	4.92				
20° C. (68° F.) for												
24 hours	6.53	6.64	6.52	6.54	6.61	6.62	6.60	6.60				
2 days	6.43	6.27	6.51	6.42	6.42	6.41	6.37	4.34				
3 days	6.26	4.82	6.22	5.92	6.77	5.94	6.07	4.28				
6.7° C. (44° F.) for—												
2 days									6.53	6.53	6.55	6.55
4 days									6.52	6.52	6.58	6.57
6 days									6.58	6.58	6.54	6.58
8 days									6.52	6.51	6.48	6.58
10 days									6.55	6.47	6.48	6.48
13 days									6.58		6.48	6.49
21 days									6.32	6.23	6.49	6.45
0° C. (32° F.) for—												
2 days	6.57	6.67	6.45	6.57								
4 days	6.55	6.59	6.56	6.57								
7 days					6.65	6.61	6.62	6.62				
8 days									6.55	6.53	6.55	6.58
9 days	6.53	6.57	6.52	6.53								
13 days					6.62	6.59	6.58	6.58	6.55	6.55	6.55	6.54
16 days	6.60	6.62	6.58	6.62								
21 days					6.52	6.50	6.52	6.52	6.54	6.52	6.52	6.52
33 days					6.53	6.58	6.58	6.62				
35 days									6.58	6.52	6.52	6.58
43 days									6.48	6.30	6.53	6.45

Titratable acidity

	A Pasteurized	A Homogenized	B Pasteurized	B Homogenized	C Pasteurized	C Homogenized	D Pasteurized	D Homogenized	E Pasteurized	E Homogenized	F Pasteurized	F Homogenized
Prestorage	0.11	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.12	0.14	0.14
37° C. (98° F.) for 24 hours	.29	.34	.46	.51								
32° C. (90° F.) for 24 hours					.33	.45	.58	.50				
20° C. (68° F.) for												
24 hours	.14	.14	.13	.13	.13	.13	.13	.13				
2 days	.15	.17	.13	.15	.23	.24	.20	.05				
3 days	.18	.55	.18	.25	.31	.34	.23	.71				
6.7° C. (44° F.) for—												
2 days									.12	.12	.14	.14
4 days									.12	.12	.14	.14
6 days									.12	.12	.14	.14
8 days									.12	.12	.14	.14
10 days									.13	.13	.14	.14
13 days									.12	.12	.14	.14
21 days									.17	.20	.15	.14
0° C. (32° F.) for—												
2 days	.13	.14	.13	.13								
4 days	.13	.13	.11	.14								
7 days					.13	.13	.13	.13				
8 days									.12	.12	.14	.14
9 days	.13	.13	.13	.13								
13 days	.14	.14	.13	.13					.12	.12	.14	.14
16 days	.14	.14	.13	.14								
21 days					.13	.14	.13	.13	.12	.12	.14	.14
33 days					.13	.13	.14	.13				
35 days									.13	.13	.14	.14
43 days									.14	.17	.14	.14

[1] Estimated. [2] Approximate.

Table 9 shows that with the exception of the milk from source A, the initial bacterial counts of the homogenized milk were higher than those of the corresponding unhomogenized milk. The difference was quite pronounced in the milk from source D. These differences, however, were not consistently reflected in the counts made after the various periods of storage. This indicates that from a bacteriological standpoint there is no significant difference between homogenized and unhomogenized milks of good quality.

After the plates were counted, they were flooded with a 0.5-percent solution of p-aminodimethylaniline monohydrochloride to determine whether any oxidase-producing colonies were present. Positive reactions were found occasionally in the case of samples that had been stored at 0° C. (32° F.) for long periods of time. None of the milks, however, in which oxidase-producing bacteria were found developed an oxidized flavor.

Table 9 also indicates that as a rule there was no significant difference in the development of acid, as shown by titratable acidity and pH determinations, in the homogenized and the unhomogenized milk. The only exception to this rule was that after acid development started, it apparently developed more rapidly in the homogenized milk than in the unhomogenized milk. This was shown by the determinations on those samples held at the higher temperatures. The samples held at 0° C. (32° F.) showed practically no change in acidity even though stored over long periods.

CONCLUSIONS

The degree to which the curd tension of milk is lowered by homogenization depends primarily on the pressure of homogenization. A pressure of 2,500 pounds gives almost the maximum reduction obtainable.

When milk is homogenized before it is pasteurized, the higher the temperature of homogenization the lower the curd tension. When homogenization follows pasteurization, homogenization at the pasteurization temperature causes a slightly higher curd tension than homogenization at temperatures either below or above the pasteurizing temperature.

There is no advantage from a curd-tension standpoint in using a two-stage homogenizer instead of a single-stage machine.

As the butterfat content of milk is increased, the curd tension is lowered, the reduction being much greater with homogenized milk than with unhomogenized milk.

When homogenized soft-curd milk is mixed with unhomogenized milk in any proportion, the curd tension of the mixture is only slightly lower than the theoretical average curd tension for that particular combination of the two milks.

The curd tension of homogenized and unhomogenized milk is not materially affected by partial freezing.

By digestion in vitro, according to the procedure employed in this investigation, the rate of proteolysis is very similar for boiled milk and for homogenized milk. Proteolysis takes place much more rapidly in either boiled milk or homogenized milk than in raw milk. The amount of proteolysis that has taken place is practically the same for all three milks after 4 or 5 hours. This indicates that boiled milk and homogenized milk are more readily but not more completely digested than raw milk.

Homogenized milk forms smaller curds than unhomogenized milk in the presence of artificial gastric juice in an artificial stomach. The smaller curds afford a greater surface area for contact with digestive juices, which would seem to make the homogenized milk more readily digested than the unhomogenized milk.

Homogenization retards or inhibits the development of copper-induced oxidized flavor in milk. This is true when the copper contamination occurs either before or after homogenization. The degree to which homogenization will inhibit or retard the development of an oxidized flavor in copper-contaminated milk, and the susceptibility of homogenized milk to copper-induced oxidized flavor, depend on the susceptibility of the milk before homogenization. It requires the addition of approximately 10 times as much copper to produce an oxidized flavor in homogenized milk as is required to produce a similar flavor in the same milk before homogenization.

Homogenized milk is much more susceptible to the action of sunlight than the corresponding unhomogenized milk. Homogenized milk requires approximately half as long an exposure to sunlight as unhomogenized milk to produce a sunlight-induced oxidized flavor.

The flavor changes in homogenized milk during storage are similar to those in pasteurized unhomogenized milk. From a flavor standpoint the two milks are equal in keeping quality when stored at low temperatures.

From a bacteriological standpoint, as determined by plate count, there is no significant difference between homogenized and unhomogenized milk.

There is no significant difference in the development of acid, as shown by titratable acidity and pH determinations, in homogenized and unhomogenized milk.

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