Abstract
Whipping properties of various whey preparations were studied by measuring overrun and stability of foams produced in a Hobart mixer. Presence of heat-labile whey proteins resulted in poor whip-pability, poor foam stability, and low overruns. Removal of the heat-acid coagulated proteins greatly improved whip-pability, and foams resembled whipped egg whites with overruns of more than 2,500%. Increasing total solids by evaporation of the acid supernatant or by addition of sucrose or soluble starch decreased the overrun but increased foam stability. Air uptake and overrun were negatively affected by calcium hydroxide. Foams from dialyzed supernatants with addition of sucrose were successfully baked into meringues.

Introduction
Industrial fractionation of cheese whey has advanced considerably with the development of several new processes (8). Commercial success of these processes depends on unique functional properties of the final products. Whippability is one of the attractive properties of the whey protein fraction, and use of whey proteins in place of egg whites in baking applications has been of interest for some time (7, 11, 16). Numerous whipping studies with various whey protein products have been reported (2, 3, 5, 8, 14). All of these investigations were with preparations containing most of the individual whey proteins.

In related work, excessive foaming was noticed in cheese wheys from which heat-acid precipitable protein fractions were removed. This conforms with observations of Potter and Williams (13), who showed that incorporation of whey, and especially of the deproteinated supernatant to sherbets, increased the overrun. Heat-acid deproteination process is often used prior to lactose crystallization (9), and a continuous process was patented recently (12). However, the heat-acid process removes only about 60% of the nitrogenous material from the whey (6, 15).

This study was to investigate factors affecting whip-pability and stability of foams produced from various cheese whey preparations. The objectives were: (1) to determine the whippability of cheese whey before and after the heat-acid protein coagulation treatment; (2) to evaluate the effects of total solids (TS), adjusted by evaporation and/or by addition of sugar or starch, and the effect of pH adjustment on whipping characteristics of heat-acid deproteinated whey; and (3) to evaluate the possibility of using these foams in baking meringues.

Materials and Methods
Source of material. Cheese wheys were secured from local sources. In preliminary studies, whey preparations from commercial whey concentrate, processed at or below 75 C, or from samples of cottage cheese whey were used. Colby cheese whey, defatted by centrifugation without preliminary heating, was used for most of the experimental work.

Sample preparation. Preparatory treatment (Fig. 1) with the cottage and Colby cheese whey involved removing the heat-acid coagulable proteins by heating (95 C or above) and acidification (pH 4.5 to 4.8) as described (6), condensing the supernatant to 40% TS or more in a pilot plant vacuum pan (Rogers Co., Detroit, Michigan), and crystallizing some of the lactose by holding the concentrated supernatant in about 4 C for several days. The decanted mother liquor was stored at 4 C until used in the whipping trials.

A portion of the Colby whey mother liquor was dialyzed against tap and deionized water for 18 h and recondensed in a rotary glass evaporator Buchi (Rinco Co., Greenville, Illinois). These samples were used mainly for meringue preparations in the baking trials.

The preparatory procedure was reversed with the 50% TS whey concentrate. Lactose crystallization was accomplished first, followed by centrifugal separation of lactose crystals,
heat-acid deproteination of the 1:1 diluted supernatant, filtration through No. 4 Whatman filter paper, and recondensation in the Rinco evaporator. The partially delactosed, viscous concentrate was diluted prior to the deproteination step to avoid burning and to accomplish effective heat denaturation (10).

Experimental procedures. Unless specified otherwise, weighed 100-ml samples were whipped at room temperature for 10 min in a 4.7-liter Hobart Mixer at the highest speed. The percent overruns were determined, using a 100 ml tared beaker, as (wt mix-wt whipped mix) X 100%/wt whipped mix.

Immediately after whipping, foams were transferred into a glass funnel, and foam stability was evaluated by recording the time elapsing before a first drop appeared in the funnel stem.

Air uptake rates were determined by evaluating overruns in 1 or 2-min intervals. Whipping was stopped during weighing, and weighed samples were returned to the bowl.

Colby whey mother liquor was a base used for most experiments. To adjust to the desired TS, the base was diluted with appropriate amounts of tap water; further condensed in the glass evaporator; or mixed with appropriate amounts of food grade sucrose or soluble starch (Fisher certified). The sucrose was dissolved before the whipping trials, and the syrups were usually extremely viscous. The starch addition resulted in formation of a suspension or of a paste at the highest concentration. When needed, pH was adjusted by 5N-Ca(OH)₂.

The foams for baking the meringues were prepared from the dialyzed recondensed samples (pH 8.5) in which appropriate amounts of sugar were dissolved before whipping. The foams were baked in a household oven at approximately 95 C for 4 to 5 h.

Analytical procedures. Total solids were determined by the AOAC procedure for dairy products (1). Lactose was measured by the phenol-sulphuric acid method of Dubois et al. (4). Total nitrogen content was determined by Kjeldahl and expressed as % protein (N × 6.38) without differentiating between the true protein and the non-protein nitrogen. Compositions of the Colby whey preparations are summarized in Table 1.

Results and Discussion

Effect of all whey proteins on whippability. The results with the partially delactosed whey concentrate and with the cottage cheese whey mother liquor are summarized in Table 2. Apparently, the presence of undenatured, heat-acid coagulable proteins was detrimental to both overrun and foam stability. Without heat treatment of the delactosed concentrate,

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![Diagram](image)

**Fig. 1.** Preparatory treatment of the Colby cheese whey in whipping studies.

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Table 1. Composition of various Colby whey preparations used in whipping studies.

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Sample identification</th>
<th>Total solids (%)</th>
<th>Protein (%)</th>
<th>Lactose (%)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Separated Colby cheese whey</td>
<td>5.8</td>
<td>81</td>
<td>4.5</td>
<td>5.5</td>
</tr>
<tr>
<td>2</td>
<td>Separated Colby cheese whey, deproteinated</td>
<td>5.4</td>
<td>.41</td>
<td>4.4</td>
<td>4.8</td>
</tr>
<tr>
<td>3</td>
<td>Mother liquor after lactose crystallization</td>
<td>29.75</td>
<td>2.35</td>
<td>21.4</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>Dialyzed mother liquor, recondensed</td>
<td>10.05</td>
<td>6.87</td>
<td>2.93</td>
<td>8.5</td>
</tr>
</tbody>
</table>

a As shown in Fig. 1.
foams, if obtained at all, were highly unstable. After heat treatment the delactosed whey concentrate foamed much better even without removal of the heavy coagulum. After removing the coagulum and concentrating the filtrate to 34% TS, overrun, stability, and appearance of the foams were comparable to those produced from egg whites. Similar results were obtained with heat-acid deproteinated cottage cheese mother liquor at 42% TS.

The detrimental effect of heat coagulable protein fractions on whippability was confirmed with unheated Colby cheese whey at 5.8 and 15% TS. Without heating to 100°C these whey samples failed to produce solid foams. After the heat treatment and removal of coagulum solid, although unstable, foams were produced. These observations agree with a report (13) on excessive overruns in sherbets with heat-acid deproteinated whey. Consequently, further experiments were carried out with the heat-acid deproteinated Colby cheese whey mother liquor. It should be noted that Weichers (16) considered only the γ-globulin fraction detrimental to whipping properties of whey proteins and recommended mild heat treatment, e.g., pasteurization, as sufficient to prevent its interference.

Effect of TS content. Fig. 2 shows the effects of TS concentration in the Colby whey base on percent overrun and stability of the resulting foams. Diluting the base from the initial 30% TS substantially decreased foam stability, while the overrun actually increased at 22.5% TS followed by a decrease at lower TS. Concentration to 38% TS decreased overrun, but stability was remarkably increased. The arbitrarily selected measure of foam stability does not correspond to actual breakdown of the foam, nor does it mean that there was no change during the stable period. This is illus-

![Graph of effect of total solids on overrun and stability](image)

**Fig. 2.** Effect of total solids in the Colby whey mother liquor (base) on percent overrun and foam stability.

### Table 2

<table>
<thead>
<tr>
<th>Sample</th>
<th>Treatment</th>
<th>Total solids</th>
<th>Overrun</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partially delactosed</td>
<td>Centrifuged to remove lactose crystals A, heated to 90°C</td>
<td>33</td>
<td>17.5</td>
<td>Good</td>
</tr>
<tr>
<td>remnant whey concentrate</td>
<td>A, water added</td>
<td>33</td>
<td>17.5</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>C, heated to 90°C</td>
<td>14</td>
<td>34</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>D, coagulum removed by filtration</td>
<td>42</td>
<td>42</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>E, filtrate condensed</td>
<td>42</td>
<td>42</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>F, Lactose crystals removed by sedimentation</td>
<td>42</td>
<td>42</td>
<td>Good</td>
</tr>
</tbody>
</table>

**Table 2.** Results of whipping trials showing the detrimental effect of heat-coagulable whey protein fractions.
trated in Fig. 3 where a freshly prepared foam from the 30% TS base (A) is compared with a 1-h old foam of identical composition (B). The 1st drop stability of sample B was about 20 min.

Increasing the TS content of the base by addition of sucrose or soluble starch had a similar effect as increasing TS by evaporation (Fig. 4); the foam stability increased while overrun decreased. The appearance of fresh foam prepared from 60 g sucrose/100 g base mix (Fig. 5, A) was not appreciably different from that of a 1-h old foam of the same composition (B). Foams with the highest sucrose or starch additions remained stable for several days; e.g. the appearance of a 24-h foam from the highest sucrose formulation (80 g/100 g base) is shown in Fig. 6. Comparison of fresh foams with and without sucrose (Fig. 3, A and Fig. 5, A) demonstrates the decrease in overrun resulting from the increase in TS of the mix. Thus, within the desirable foam quality limits, stability cannot be increased without lowering overrun when using the base.

The protein concentration, together with the TS concentration, may affect the overall foam quality, i.e., overrun and stability. However, the ease of whipping and high overrun, even in the very dilute stage (Fig. 2), proves that a small amount of the whippable protein fraction ensures sufficient overrun.

Whipping characteristics of the base mother liquor were compared with those of a sample from which additional lactose was removed by further evaporation, crystallization, and centrifugation, and with a dialyzed partially recondensed sample (Table 3). Increased protein did not increase stability (sam-
Effect of pH. Hansen and Black (5) reported that adjustment of whey protein- CM CMC complex solution to pH 9.5 improved whipping performance. On the contrary, increasing the pH of the Colby whey base had a minor negative effect on the percent overrun (Fig. 7) while the foam stability was not affected. A whitish precipitate, formed in increasing quantities as pH was increased, may have affected the overrun.

Although flavor evaluation was not a part of this study, it was noted that the slightly objectionable sensation of saltiness, enhanced by the acidity of the unadjusted base, was diminished at higher pH. However, at or above neutrality an increasingly objectionable soapy flavor developed; thus, no whipping trials were continued above pH 7.

Further observations. Adjustment of pH than TS content (samples C vs. D). It is conceivable that an optimum TS to protein ratio could maximize foam stability without drastically decreasing overruns.

TABLE 3. Effect of total solids (TS) and protein content of various Colby whey preparations on overrun and foam stability.

<table>
<thead>
<tr>
<th>Code</th>
<th>Sample</th>
<th>TS (%)</th>
<th>Protein (%)</th>
<th>Overrun</th>
<th>Time to 1st drop (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Control base</td>
<td>29.8</td>
<td>2.35</td>
<td>2,450</td>
<td>20</td>
</tr>
<tr>
<td>B</td>
<td>A, dialyzed and partially recondensed</td>
<td>7.6</td>
<td>4.74</td>
<td>3,050</td>
<td>15</td>
</tr>
<tr>
<td>C</td>
<td>A, recondensed and more lactose crystals removed</td>
<td>34.0</td>
<td>4.02</td>
<td>2,100</td>
<td>60</td>
</tr>
<tr>
<td>D</td>
<td>B, sucrose added</td>
<td>53.7</td>
<td>2.37</td>
<td>900</td>
<td>60</td>
</tr>
</tbody>
</table>
with Ca(OH)$_2$ resulted in a retardation of the air uptake (Fig. 8). Whipping time required for the maximum overrun, and the maximum overrun itself were negatively affected by neutralization of the base (initial pH 4.6). Without neutralization the maximum overrun was achieved in 4 to 6 min with or without sugar addition. Continued whipping of the high sugar formulations did not improve the overrun; in fact, a distinctive maximum was observed with addition of both 40 and 80 g sucrose per 100 g base.

This effect cannot be explained by heat evolution during whipping (maximum increase in temperature was 2 C), since temperature was an indifferent variable regarding whipping performance. A sample of the base was heated to 100 C and immediately whipped, with essentially the same results as in unheated control. Likewise, freezing and thawing of the dialyzed sample had no effect on the whippability.

Stabilization of the whey foam by admixing sucrose after the whipping, as suggested by Hansen and Black (5), was less desirable than dissolving the same amount of sugar in the mix before whipping. Sucrose addition to the foam resulted in lower final overrun as compared to the whipped base-sucrose solution, and stability was not improved.

**Baking trials.** Meringues prepared from the base with or without sucrose addition did not bake well. Even after prolonged baking at 95 C the foams remained moist and tacky and did not dry at room temperature after several days. Baking at higher temperatures caused rapid browning of the foams.

Baking trials with the dialyzed sample (Table 1) were more successful. Foams of 900% overrun, prepared from 80 g dialyzed sample and 80 g sugar, were baked at 95 C for 4 h into a white crusty meringue of a light consistency. Meringues from 60 g sample and 120 g sugar (370% overrun) were of much heavier consistency and closely resembled those prepared from egg white-sucrose mixtures of similar formulation.

Replacement of 20 g sucrose by 20 g lactose powder in the latter formulation did not have an effect on overrun or stability of the whipped foam; however, baking was more difficult than with the sucrose alone due to prolonged tackiness. After additional time in the oven or at room temperature, the meringue dried and was indistinguishable from that produced without added lactose. Thus, the presence of lactose is only partly responsible for the tackiness with the foams from the whey base. No discoloration took place during the 4 to 5 h of baking at 95 C; at 175 C all meringues, regardless of formulation, browned rapidly.

**Conclusions**

Substantial improvement in whipping characteristics by heat-acid deproteination of cheese whey suggests that the whipping properties of whey protein preparations are due to the heat-acid stable fraction.

Foams of 2,500% overrun were produced from heat-acid deproteinated concentrated whey. The stability of these foams was mainly a function of total solids content.

Adjustment of pH by Ca(OH)$_2$ had a slight negative effect on overrun and on air uptake rate. Without Ca(OH)$_2$ addition, the maximum obtainable overrun was reached in 4 to 6 min regardless of TS content.

The heat-acid stable fraction is not dialyzable. Excellent foams can be produced from dialyzed deproteinated concentrated wheys. The stability of these foams was mainly a function of total solids content.

References

proteins. 33rd Annu. IFT Meeting, Paper No. 112.


