Real-time evaluation of milk quality as reflected by clotting parameters of individual cow’s milk during the milking session, between day-to-day and during lactation

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Real-time analysis of milk coagulation properties as performed by the AfiLab™ milk spectrometer introduces new opportunities for the dairy industry. The study evaluated the performance of the AfiLab™ in a milking parlor of a commercial farm to provide real-time analysis of milk-clotting parameters –Afi-CF for cheese manufacture and determine its repeatability in time for individual cows. The AfiLab™ in a parlor, equipped with two parallel milk lines, enables to divert the milk on-line into two bulk milk tanks (A and B). Three commercial dairy herds of 220 to 320 Israeli Holstein cows producing ≈11 500 l during 305 days were selected for the study. The Afi-CF repeatability during time was found significant (P < 0.001) for cows. The statistic model succeeded in explaining 83.5% of the variance between Afi-CF and cows, and no significant variance was found between the mean weekly repeated recordings. Days in milk and log somatic cell count (SCC) had no significant effect. Fat, protein and lactose significantly affected Afi-CF and the empirical van Slyke equation. Real-time simulations were performed for different cutoff levels of coagulation properties where the milk of high Afi-CF cutoff value was channeled to tank A and the lower into tank B. The simulations showed that milk coagulation properties of an individual cow are not uniform, as most cows contributed milk to both tanks. Proportions of the individual cow’s milk in each tank depended on the selected Afi-CF cutoff. The assessment of the major causative factors of a cow producing low-quality milk for cheese production was evaluated for the group that produced the low 10% quality milk. The largest number of cows in those groups at the three farms was found to be cows with post-intramammary infection with Escherichia coli and subclinical infections with streptococci or coagulase-negative staphylococci (~30%), although the SCC of these cows was not significantly different. Early time in lactation together with high milk yield >50 l/day, and late in lactation together with low milk yield <15 l/day and estrous (0 to 5 days) were also important influencing factors for low-quality milk. However, ~50% of the tested variables did not explain any of the factors responsible for the cow producing milk in the low – 10% Afi-CF.

Keywords: milk clotting parameters, real-time evaluation, cheese yield

Implications

The present work demonstrates the potential of the AfiLab™ to assess on-line milk-clotting parameters and to divert the milk into two bulk milk tanks A and B through two parallel milk lines. Simulated segregation of milk according to clotting parameters revealed that the cow’s milk was diverted according to varying quality parameters for cheese production on a daily basis, as well as during the milking session. The major factors responsible for low-quality milk for cheese making were post-udder infection by various bacteria and the combination of the cow’s status of days in milk and level of milk production.

Introduction

In modern dairy farming operations, at any given time, the animals in the herd differ in the stage of lactation, physiological conditions, hormone levels, health status, etc. These differences have implications on the milk properties of each individual animal. Consequently, the bulk milk represents an
average milk of all the individual milked animals. Differentiation between animals producing low- or high-quality milk is an economical goal for the cheese industry.

Present appraisal of individual cow’s milk potential for cheese manufacturing can be predicted by using the AfiLab™ milk spectrometer (Afimilk, Afikim, Israel), which provides the coagulation properties of the milk – Afi-CF value of curd firmness on-line (Leitner et al., 2011 and 2012). Such a device, when installed in a milking parlor equipped with two parallel milk lines and two bulk milk tanks, has the potential of controlling the milk properties in two bulk milk tanks A and B, on the basis of its on-line properties for cheese making and for other milk products and fluid milk.

The cheese yield formula of van Slyke has long been used by the dairy industry and scientists alike for calculating predicted cheese yields (Fenelon and Guinee, 1999; Verdier-Metz et al., 2001; Brito et al., 2002; Emmons and Modler, 2010). The equation takes into account that, during coagulation, fat loss is lower than CP loss, and that casein loss is a fixed value of 0.1 (Emmons et al., 1993 and 2003; Emmons and Modler, 2010). Although this equation is effective in calculating bulk milk cheese yield, applying the equation to an individual animal is not accurate, particularly regarding animals that are in the margin of their normal milking curve, that is, beginning and late lactation, suffering from udder infection (clinical and/or subclinical), etc. Van Slyke’s equation relies on consistent incorporation of milk constituents in cheese per liter milk used. However, as milk fat and protein are not uniform for all animals during the entire lactation (Čandek-Potokar et al., 2006; Quist et al., 2008; Forsbäck et al., 2009) and vary from day to day (Forsbäck et al., 2010), neither is component loss. Moreover, van Slyke’s formula assumes that casein loss is fixed, when in reality this is not the case, and the coagulation process is much more complex than simply aggregating fixed proteins and fat molecules (Fleminger et al., 2011).

The objectives of the present study were (i) to evaluate the performance of the AfiLab™ equipment installed in a milking parlor of commercial farms to provide real-time analysis of milk-clotting parameters – Afi-CF – for cheese manufacture and determine its repeatability in time for individual cows, and (ii) to assess the major causative factors of a cow producing milk, influencing the quality of the milk for cheese production.

Material and methods

Study layout

Three commercial dairy herds of 220 to 320 Israeli Holstein cows producing ~11 500 l during 305 days were selected for the study. The cows were milked three times daily (0500, 1300 and 2000 h) and were fed a typical Israeli total mixed ration containing 65% concentrate and 35% forage (17% protein). Food was offered ad libitum in mangers located in the sheds. The milking parlor was a double-sided herringbone equipped with Afimilk on-line milking stations. Cow’s data included: lactation (L), days in milk (DIM), days in pregnancy (DIP) and milk yield (kg/day). Fat, protein, lactose, somatic cell count (SCC) and history of health were taken from the Israeli Herd Book. Daily on-line data including milk yield, fat, protein, conductivity and Afi-CF were also taken from the Afimilk on-line data recording system (Leitner et al., 2012).

In herd 1, three analyses were performed:

1. The on-line data were monitored during 100 days, and the weekly average was used to calculate the fluctuation of cow’s Afi-CF (Leitner et al., 2011 and 2012). The data were also used to calculate cheese yield (for Cheddar cheese) using the empirical equation of van Slyke ([% fat × 0.93] + [% protein × 0.78 − 0.1]) × 1.09/[1 − (moisture in cheese)]. During this period, cows were inseminated and others were dried off, so that each cow was introduced into the analysis only after she had at least three measurements.

2. At one time point of each of the three daily milkings, the AfiLab™ was set to simulate segregation of the milk into each of the bulk milk tanks A and B by diverting pulses of 200 ml as ‘analyzed’ on-line. During milking and depending on the cow daily milk yield, 15 to 35 pulses of milk were recorded for each cow. The Afi-CF cutoff level was set according to the desired volume of milk required in each of the bulk tanks A and B, to the possible needs of the dairy on the processing day. The study was conducted using the following combinations: 90 : 10; 70 : 30; 50 : 50; 30 : 70 and 10 : 90 (percent milk diverted to tanks A : B).

3. Two independent measurements were taken (in June and August) to determine the effects influencing Afi-CF and its repeatability using the Israeli Herd Book data. The correlations of gross milk composition (fat, protein and lactose), SCC and Afi-CF and the main factors influencing these parameters were calculated using results of herd 1, with additions of the other two herds monitored for 1 week.

Bacteriology testing

Bacterial identification were based on pretrial quarter fore-milk samples of 5 ml, taken aseptically two or three times at 2-week intervals during the morning milking, and tested at the laboratory within 1 h for bacteriology according to accepted microbiological procedures of the US National Mastitis Council (Oliver et al., 2004).

Statistical analyses

All statistical analyses were performed using JMP software (SAS Institute, 2000). Three analyses were performed: (1) Afi-CF repeatability, (2) milk segregation and (3) factors effecting Afi-CF and the empirical van Slyke equation.

1. Afi-CF repeatability: cows were measured 3 to 14 times for Afi-CF during 100 days. The differences between repeats were determined by a one-way ANOVA model in ‘blocks’ design using the repeat (3 to 14) as the main effect and the cows as ‘blocks’. The statistical model was

\[ Y_{ijk} = \mu + B_i + \alpha_j + e_{ij}. \]

where \( \mu \) = mean of all data, \( B_i \) = the variance between cows (blocks), \( \alpha_j \) = the difference between the mean of
repeat i from the trial mean and $e_{ij} = $ residual variance between measurements (random error). Multiple comparisons between repeated measurements were made by Student's t-test.

2. Milk segregation: correlations between all the continuous variables and the analyzed parameters were determined for all data and for each lactation separately (first or second or third and higher). The ANOVA model included the lactation (first or second or third and higher) as a fixed effect and the continuous variables as co-variance for each cutoff level separately. Interactions between the lactation and the continuous variables were also included in the model. Owing to the registration of DIP only at 45 days, the two similar models were used, one with DIP, therefore including only ~60% of the cows, and the second without DIP, including all the cows. Only model 2 is presented, which included all the continuous variables, except DIP:

Model 2 : $Y_{ijklmnopq} = \mu + x_i + \beta_j + \delta_l + e_{im} + z_n + \eta_o + \theta_p + \kappa_q + \lambda_r + \pi_s + x_{ij} + x_{im} + x_{ln} + x_{in} + x_{io} + x_{ip} + x_{iq} + x_{ir} + x_{is} + \epsilon_{ijklmnopq}$

where $\mu$ is the grand mean; $a_i$ represents the fixed effect of lactation; $b_j$ represents the co-variance of DIM; $\delta_l$ represents the co-variance of total milk; $e_{im}$ represents the residual variance of Afi fat; $z_n$ represents the co-variance of Afi protein; $\eta_o$ represents the co-variance of Afi lactose; $\theta_p$ represents the co-variance of milk yield (kg); $\kappa_q$ represents the co-variance of cond.; $\lambda_r$ represents the co-variance of SCC; $\pi_s$ represents the co-variance of urea; $\alpha_{ij}$ represents the lactation $\times$ DIM interaction; $\alpha_{ij}$ represents the lactation $\times$ total milk interaction; $\alpha_{ij}$ represents the lactation $\times$ Afi fat interaction; $\alpha_{ij}$ represents the lactation $\times$ Afi lactose protein interaction; $\alpha_{ij}$ represents the lactation $\times$ Afi lactose interaction; $\alpha_{ij}$ represents the lactation $\times$ conductivity interaction; $\alpha_{ij}$ represents the lactation $\times$ SCC interaction; $\alpha_{ij}$ represents the lactation $\times$ urea interaction; and $\epsilon_{ijklmnopq}$ represent the residual variance between measurements (random error).

3. Factors effecting Afi-CF and the empirical van Slyke equation: two independent measurements were taken (in June and August) to determine the repeatability of the results. In each study, one sample of milk was taken from the cows, and the milk yield (milk), Log SCC, percent fat (fat), percent protein (protein), percent lactose (lactose), Afi-CF and van Slyke were determined. On the milk sampling day, the cow’s lactation, DIM and DIP were recorded. For each study separately, the continuous variables (DIM, DIP, milk, Log SCC, fat, protein and lactose) were included in an ANOVA model in a random design using the lactation (first, second or third and fourth or more) as fixed effects and the continuous variables as co-variance.

No interactions were included in the model. The statistical model was

Model 3 : $Y_{ijklmnop} = \mu + x_i + \beta_j + \gamma_k + \delta_l + e_{im} + z_n + \eta_o + \theta_p + \epsilon_{ijklmnop}$

where $\mu$ is the grand mean; $a_i$ represents the fixed effect of the lactation; $b_j$ represents the co-variance of DIM; $\gamma_k$ represents the co-variance of DIP; $\delta_l$ represents the co-variance of milk; $e_{im}$ represents the co-variance of Log SCC; $z_n$ represents the co-variance of fat; $\eta_o$ represents the co-variance of protein; $\theta_p$ represents the co-variance of lactose; and $\epsilon_{ijklmnop} = $ residual variance between measurements (random error).

The combination of the data from the two studies were analyzed in an ANOVA model in a ‘blocks’ design, using the study as ‘blocks’ (random effect), the lactation (first, second or third and fourth or more) as fixed effect and the continuous variables (DIM, DIP, milk, Log SCC, % fat, % protein and % lactose) as co-variance. The statistical model was

Model 4 : $Y_{ijklmnop} = \mu + B_q + x_i + \beta_j + \gamma_k + \delta_l + e_{im} + z_n + \eta_o + \theta_p + \epsilon_{ijklmnop}$

where $\mu$ is the grand mean; $B_q$ represented the variance between studies; $a_i$ represents the fixed effect of the lactation; $b_j$ represents the co-variance of DIM; $\gamma_k$ represents the co-variance of DIP; $\delta_l$ represents the co-variance of milk; $e_{im}$ represents the co-variance of Log SCC; $z_n$ represents the co-variance of % fat; $\eta_o$ represents the co-variance of % protein; $\theta_p$ represents the co-variance of % lactose; and $\epsilon_{ijklmnop} = $ residual variance between measurements (random error). The same models (3 and 4) were used to analyze the cows of each of the three farms, which produced the low 10% Afi-CF. In the model, instead of two independent studies, three farms were used, and in model (4) the combination of the three farms was the co-variance. In the ANOVA models, the multiple compressions between lactations were carried out by Tukey–HSD t-test. Correlation ($R^2$) between individual Afi-CF and fat, protein, lactose and SCC was also performed.

Results

Evaluation of the AfiLab™ on-line milk separation performance for cheese manufacturing and its repeatability in time for an individual cow

Afi-CF repeatability during time. The one-way ANOVA model (1) using the cows as ‘blocks’ was found significant ($P < 0.001$) for cows. The model succeeded in explaining 83.5% ($R^2 = 0.849$) of the variance between Afi-CF and cow. No significant variance was found between the means of the weekly repeated recordings. Figure 1 illustrates the distribution of Afi-CF values measured within cows (average of 10 measurements of 50 representative cows) and its mean value.
Milk segregation. At every selected target segregation level, milk from most cows was diverted into both bulk milk tanks, A and B. The proportion of milk diverted from each cow to one of the tanks depended on the selected target level. The amount that flowed into bulk tank A (higher Afi-CF) as a percent of the whole milk volume was higher when Afi-CF cutoff level was lower. As a result, as Afi-CF cutoff level increased, lower proportions of milk from fewer cows was diverted into bulk tank A (Figure 2). Dichotomies means and standard error of milk flow for each Afi-CF cutoff level on the cow level are summarized in Table 1. The dichotomy decision of grouping was made arbitrarily, depending on the volume of milk diverted to each bulk tank A or B. Lactation, pregnancy, DIP and DIM had no significant effect on milk distribution, even though at some cutoff levels there were significant differences ($P < 0.05$) in DIM. Daily milk yield was also not a major factor, although at cutoff level $>30:70$, cows with low daily milk production contributed a significantly higher proportion of the milk to tank A. Of the milk components, lactose and SCC, as well as conductivity, did not affect the milk flow. Fat and protein were the major milk constituents that were significantly different with lower amounts in tank B (Table 1).

In general, regardless of the Afi-CF cutoff level, most cows contributed milk to both tanks. At a cutoff level 90:10, the intention was to divert non-coagulating milk (Afi-CF $< 3$) out of tank A; thus, part of the milk of only about 15% of the cows was diverted into tank B. Similar results of

![Figure 1 Distribution of Afi-CF values measured among 50 representative cows (open circles – mean weekly measured values; solid circles – mean of the cow’s measured values).](https://doi.org/10.1017/S1751731113000542)

![Figure 2 Distribution of cows according to the milk diverted into bulk milk tank A. Each figure represents a different Afi-CF cutoff level.](https://doi.org/10.1017/S1751731113000542)
Table 1 Means of lactation, DIM, DIP, daily milk yield and composition, SCC, conductivity and Afi-CF of milk in tank A or B for five cutoff levels (90: 10, 70: 30, 50: 50, 30: 70 and 10: 90) during 1 day of three milkings. Each cutoff level was analyzed separately using statistical model (2).

<table>
<thead>
<tr>
<th>Target tank</th>
<th>Milk volume (%)</th>
<th>Cutoff level (Afi-CF)</th>
<th>No. of cows (% cows)</th>
<th>% Milk diverted</th>
<th>Lactation</th>
<th>DIP (&gt;45 days)</th>
<th>Milk (g/day)</th>
<th>Fat (g/l)</th>
<th>Protein (g/l)</th>
<th>SCC (&gt;10^5)</th>
<th>Conductivity</th>
<th>Afi-CF</th>
<th>Van Slyke</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>90</td>
<td>&gt;9.99</td>
<td>94 (84.7)</td>
<td>86–100</td>
<td>2.52</td>
<td>139.03</td>
<td>33.0 ± 0.8</td>
<td>43.0 ± 0.5</td>
<td>46.0 ± 0.7</td>
<td>243 ± 157</td>
<td>12.4 ± 0.0</td>
<td>10.42</td>
<td>0.04</td>
</tr>
<tr>
<td>B</td>
<td>90</td>
<td>&gt;9.99</td>
<td>95 (84.7)</td>
<td>30–83</td>
<td>2.65</td>
<td>159.03</td>
<td>34.9 ± 1.5</td>
<td>44.0 ± 1.0</td>
<td>46.1 ± 0.2</td>
<td>199 ± 89</td>
<td>10.78 ± 0.2</td>
<td>7.06</td>
<td>0.04</td>
</tr>
<tr>
<td>A</td>
<td>70</td>
<td>&gt;9.89</td>
<td>95 (84.7)</td>
<td>43–100</td>
<td>2.75</td>
<td>159.03</td>
<td>32.9 ± 0.9</td>
<td>43.3 ± 1.0</td>
<td>46.0 ± 0.2</td>
<td>271 ± 89</td>
<td>10.51 ± 0.1</td>
<td>10.5</td>
<td>0.04</td>
</tr>
<tr>
<td>B</td>
<td>70</td>
<td>&gt;9.89</td>
<td>95 (84.7)</td>
<td>0–40</td>
<td>2.67</td>
<td>159.03</td>
<td>32.3 ± 0.9</td>
<td>43.2 ± 0.5</td>
<td>46.0 ± 0.2</td>
<td>178 ± 75</td>
<td>10.51 ± 0.1</td>
<td>10.5</td>
<td>0.04</td>
</tr>
<tr>
<td>A</td>
<td>50</td>
<td>&gt;12.46</td>
<td>82 (73.8)</td>
<td>28–100</td>
<td>2.57</td>
<td>163 ± 0.9</td>
<td>35.2 ± 1.7</td>
<td>43.1 ± 0.4</td>
<td>46.3 ± 0.2</td>
<td>321 ± 77</td>
<td>10.51 ± 0.1</td>
<td>10.5</td>
<td>0.04</td>
</tr>
<tr>
<td>B</td>
<td>50</td>
<td>&gt;12.46</td>
<td>44 (39.6)</td>
<td>0–26</td>
<td>2.45</td>
<td>165 ± 0.8</td>
<td>36.1 ± 1.3</td>
<td>43.5 ± 0.9</td>
<td>46.7 ± 0.3</td>
<td>352 ± 100</td>
<td>10.51 ± 0.1</td>
<td>10.5</td>
<td>0.04</td>
</tr>
<tr>
<td>A</td>
<td>30</td>
<td>&gt;14.92</td>
<td>41 (100)</td>
<td>41–100</td>
<td>2.56</td>
<td>117 ± 8.4</td>
<td>30.3 ± 1.2</td>
<td>45.4 ± 0.7</td>
<td>46.7 ± 0.2</td>
<td>195 ± 39</td>
<td>10.51 ± 0.1</td>
<td>10.5</td>
<td>0.04</td>
</tr>
<tr>
<td>B</td>
<td>30</td>
<td>&gt;14.92</td>
<td>67 (60.4)</td>
<td>0–40</td>
<td>2.26</td>
<td>115 ± 5.2</td>
<td>35.4 ± 0.4a</td>
<td>34.6 ± 0.8b</td>
<td>46.7 ± 0.2</td>
<td>6.88 ± 0.3b</td>
<td>7.06 ± 0.04</td>
<td>10.51</td>
<td>0.04</td>
</tr>
<tr>
<td>A</td>
<td>10</td>
<td>&gt;18.42</td>
<td>29 (26.1)</td>
<td>15–100</td>
<td>2.52</td>
<td>176 ± 6.5</td>
<td>28.8 ± 1.6</td>
<td>34.8 ± 0.9</td>
<td>46.7 ± 0.2</td>
<td>13.7 ± 0.2</td>
<td>7.06 ± 0.04</td>
<td>10.51</td>
<td>0.04</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>&gt;18.42</td>
<td>82 (73.9)</td>
<td>0–15</td>
<td>2.59</td>
<td>121 ± 5.2</td>
<td>34.8 ± 0.9</td>
<td>46.7 ± 0.2</td>
<td>46.7 ± 0.2</td>
<td>17.4 ± 0.5b</td>
<td>7.06 ± 0.04</td>
<td>10.51</td>
<td>0.04</td>
</tr>
</tbody>
</table>

DIM = days in milk; DIP = day in pregnancy; SCC = somatic cell count.

*% of cows milk diverted to bulk tank A.

Parameters within row for each set of cutoff level with no common superscript differ significantly (P < 0.05).

Factors effecting Afi-CF and the empirical van Slyke equation. The effects of lactation, DIM, DIP, daily milk yield and composition, SCC, conductivity and Afi-CF of milk in tank A or B for five cutoff levels (90: 10, 70: 30, 50: 50, 30: 70 and 10: 90) during 1 day of three milkings. Each cutoff level was analyzed separately using statistical model (2).
Assessment of the major causative factors of a cow producing milk of low quality for cheese production. The cows in the three farms were divided into two categories: Low – 10% Afi-CF and the rest High – 90% Afi-CF (Table 3). For all three farms, fat, protein, lactose and Afi-CF were significantly lower in the 10% group. The level of SCC was not significantly different among groups. The cows in the 10% group were further analyzed for possible causes responsible for producing low-quality milk for cheese manufacturing. The largest numbers of cows in all three farms (~30%) were found to be those with post-inframammary infection with *Escherichia coli* and subclinical infections with streptococci or coagulase-negative staphylococci (CNS; Table 4). Early time in lactation, together with high milk yield, >50 l/day, and late time in lactation together with low milk yield, <15 l/day and estrous (0 to 5 days) were additional factors influencing low-quality milk, probably temporary to the time of measurement. However, ~50% of the tested variables did not explain any of the factors responsible for the cow producing milk in the low – 10% Afi-CF.

**Table 2** The effects of lactation, DIM, DIP, Log SCC, milk yield and composition on Afi-CF and the empirical van Slyke equation determined by ANOVA (model (4)) from the two independent measurements (in June and August) in farm 1

<table>
<thead>
<tr>
<th></th>
<th>Afi-CF (R² &gt; 0.91)</th>
<th>van Slyke (R² &gt; 0.99)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variance between studies</td>
<td>(4.8%) (P = 0.003)</td>
<td>ns</td>
</tr>
<tr>
<td>Lactation</td>
<td>First &gt; second, third &gt; fourth or higher (P = 0.009)</td>
<td>ns</td>
</tr>
<tr>
<td>DIM</td>
<td>b = −0.02 (P = 0.947)</td>
<td>ns</td>
</tr>
<tr>
<td>DIP</td>
<td>b = 0.344 (P = 0.020)</td>
<td>ns</td>
</tr>
<tr>
<td>Log SCC</td>
<td>b = 1.67 (P &lt; 0.001)</td>
<td>b = 1.45 (P &lt; 0.001)</td>
</tr>
<tr>
<td>Milk yield</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Fat</td>
<td>b = 12.19 (P &lt; 0.001)</td>
<td>b = 1.37 (P &lt; 0.001)</td>
</tr>
<tr>
<td>Protein</td>
<td>b = 0.98 (P &lt; 0.001)</td>
<td>ns</td>
</tr>
<tr>
<td>Lactose</td>
<td>b = 10.12 (P &lt; 0.001)</td>
<td>ns</td>
</tr>
</tbody>
</table>

DIM = days in milk; DIP = day in pregnancy; SCC = somatic cell count; ns = not significant.
b = slope of regression line.

**Figure 3** Effect of percent milk protein on the recorded Afi-CF curd firmness (squares; a = 12.68; R² = 0.76) and van Slyke calculated cheese yield (circles; a = 3.10; R² = 0.75).

**Discussion**

In the previous studies (Leitner *et al.*, 2011 and 2012), it was shown that the parameter Afi-CF determined by the AfiLab™ is suitable for assessing milk quality according to its clotting parameters, which cannot be assessed by merely measuring fat and protein content on either the gland or the cow level.

The dairy industry refers to the bulk milk as its ultimate raw material, as it has neither control nor information on the individual animal’s milk flow into the bulk milk tank. Upon reception of milk for processing, it is graded according to the constituent’s level and SCC. The milk is accepted for processing unless individual cows cause an increase of SCC, which results in total withdrawal of the milk or reduction of its price. Therefore, upon purchasing of the milk by a dairy, the maximal effective cheese yield of that milk is already determined by its origin. Under these conditions, van Slyke’s formula could be suitable for predicting cheese yield, although the prediction is not always accurate. The reasons for such inaccuracies lie in the assumptions of constant values of incorporation of fat and protein in the curd, and the constant loss of casein (~0.1) included in the formula, while ignoring the complexity and availability of the protein for curdling. Owing to these limitations, many suggestions for modifying the van Slyke equation have been published (Banks *et al.*, 1984; Emmons *et al.*, 1993; Emmons and Modler, 2010), although they did not refer to the problem of the quality and origin of the raw milk, as fat and protein contents were always blamed for the inaccuracies (Fenelon and Guinee, 1999). Moreover, inferior milk clotting was blamed among many factors on some causatives such as bacterial udder infection (Barbano *et al.*, 1991; Leitner *et al.*, 2006 and 2011), stage of lactation (Lawrence, 1991; Sapru *et al.*, 1997), nutrition (Lawrence, 1991; Coulon *et al.*, 1998), genetic variability (Ikonen *et al.*, 2004; Malacarne *et al.*, 2006; Vallas *et al.*, 2010) relative composition of caseins (Wedholm *et al.*, 2006; Penasa *et al.*, 2010) and other unknown reasons (Ikonen *et al.*, 1999 and 2004).

As the above-mentioned factors, whether temporary and/or permanent, cannot be controlled at the level of the bulk milk...
tank, they need to be controlled at the milking parlor. Moreover, to control the milk flow into the bulk tank, it is crucial to understand the complexity of the incorporation of milk proteins and fat into the curd and to identify the milk involved/responsible for low cheese yield during manufacturing on the gland or animal level. The AfiLab™ was calibrated by comparing measured curd firmness by the Optigraph as a reference value and deliberating a dimensionless value of curd firmness – Afi-CF, by testing milk of hundreds of individual glands/cows (Leitner et al., 2011). Although this calibration does not provide a better understanding of the complexity of curd formation, it showed a major deviation from van Slyke’s equation that was expressed by the different values resulting from the statistical analysis assigned to fat and protein. As can be seen in Table 2 and Figure 3, Afi-CF infers lower weight to fat than to protein – the major factor in curd formation, as presented by the differences in the slopes for protein in the figure. This difference should be further investigated because in the dairy industry, fat is the factor that is constantly being changed according to the product, in contrast to protein in the bulk milk, which is at a fixed level, although it might vary between batches, which is also accompanied by a lower percent of casein.

The other important finding for the cheese-making industry lies in the varying values of Afi-CF for cows within a herd. Therefore, segregation of milk according to its mean Afi-CF is suitable for improving the milk quality for cheese making. However, it has various limitations owing to: (i) changes of milk properties of individual cows of similar features such as DIM, milk yield, milk composition, etc. during lactation, (ii) short-time changes in Afi-CF owing to udder infection, disease, estrus, stress, etc. and (iii) varying milk quality of each individual cow at any given time during the milking session. Thus, during every milking, different proportions of milk of most of the cows was diverted to each of the tanks A or B.

Post-intramammary infection with E. coli and subclinical infection with streptococci or CNS resulted in, 30% lower Afi-CF values, which are long-term influences and are consistent with the findings of the present study (Leitner et al., 2012). These results are of utmost importance for dairies that manufacture long-time ripening cheese, as defects related to these lingering effects will be noted at a late stage when the damage cannot be corrected.

The results also indicated that 10% to 15% of the low Afi-CF milk is temporarily due to estrus, new illness or infection, including intramammary infection. Thus, the daily information provided by the AfiLab™ can be used by the farmer to detect animal health status and may add to the identification of estrus. Moreover, if the milking parlor is equipped with two milk lines, on those days the on-line sensor can divert this milk to a ‘low Afi-CF’ tank. The repeatability analysis indicated that ~50% of the low Afi-CF milk as well as the high Afi-CF milk (data not shown) had no explained relation to the cows or their behavioral or physiological conditions.

### Table 3

<table>
<thead>
<tr>
<th>Farm</th>
<th>No. of cows</th>
<th>Fat (g/kg)</th>
<th>Protein (g/kg)</th>
<th>Lactose (g/kg)</th>
<th>SCC (10^3)</th>
<th>Afi-CF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>199</td>
<td>31.9a</td>
<td>34.0a</td>
<td>48.6a</td>
<td>228</td>
<td>27.1a</td>
</tr>
<tr>
<td>2</td>
<td>21</td>
<td>29.7b</td>
<td>27.0b</td>
<td>47.7b</td>
<td>173</td>
<td>18.3b</td>
</tr>
<tr>
<td>3</td>
<td>286</td>
<td>38.9a</td>
<td>34.0a</td>
<td>47.2a</td>
<td>318</td>
<td>22.0a</td>
</tr>
<tr>
<td>3</td>
<td>32</td>
<td>32.2b</td>
<td>30.5b</td>
<td>46.9b</td>
<td>472</td>
<td>14.8b</td>
</tr>
<tr>
<td>3</td>
<td>220</td>
<td>34.3a</td>
<td>32.5a</td>
<td>48.2a</td>
<td>123</td>
<td>15.2a</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>31.5b</td>
<td>31.1b</td>
<td>47.3b</td>
<td>203</td>
<td>14.5b</td>
</tr>
</tbody>
</table>

SCC = somatic cell count; ns = not significant.

### Table 4

<table>
<thead>
<tr>
<th>Farm</th>
<th>Number cows</th>
<th>Post-intra mammary infection with <em>Escherichia coli</em> and subclinical infections with streptococci or CNS</th>
<th>Estrous (0 to 5 days)</th>
<th>Early in lactation and high milk yield &gt;50 l/day</th>
<th>End of lactation and low milk yield &lt;15 l/day</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21</td>
<td>37.1</td>
<td>6.3</td>
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<td>3.2</td>
<td>47.1</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>28.1</td>
<td>9.4</td>
<td>28.1</td>
<td>9.4</td>
<td>25.0</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>36.4</td>
<td>13.6</td>
<td>–</td>
<td>4.5</td>
<td>55.6</td>
</tr>
</tbody>
</table>

CNS = coagulase-negative staphylococci.
Leitner, Merin, Jacoby, Bezman, Lemberskiy-Kuzin and Katz

Thus, in future, this value could be used as a factor to be implemented in the evaluation for protein productivity, although this point requires further studies.

Conclusion

The AfiLab™ instrument when installed on-line in a milking parlor, which is equipped with two milk lines and two bulk milk tanks, provides an opportunity to divert 200 ml resolution pulses of milk into tank A or B, according to its suitability for cheese production. In the present study, it was shown that milk suitability for cheese making according to predetermined values changes between days, between milking sessions and even during the milking session. Low-quality milk for cheese manufacturing was blamed on post-intramammary infection, DIM, stage of lactation, estrus and other unknown variables.

Acknowledgment

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References


