Prediction of Mozzarella Cheese Yield from Milk Composition

Hamzah M. Abu-Tarboush

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PREDICTION OF MOZZARELLA CHEESE
YIELD FROM MILK COMPOSITION

by

Hamzah M. Abu-Tarboush

A thesis submitted in partial fulfillment of the requirements for the degree
of
MASTER OF SCIENCE
in
Nutrition and Food Sciences

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I would like also to express my thanks to all my family members, and to all my friends for their support.

Hamzah M. Abu-Tarboush
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>ii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>v</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>vi</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>REVIEW OF LITERATURE</td>
<td>3</td>
</tr>
<tr>
<td>Cheese Making</td>
<td>3</td>
</tr>
<tr>
<td>Mozzarella Cheese</td>
<td>4</td>
</tr>
<tr>
<td>Factors Affecting Cheese Yields</td>
<td>5</td>
</tr>
<tr>
<td>Factors Affecting Milk Composition</td>
<td>5</td>
</tr>
<tr>
<td>The Relationship of Fat and Casein to Yield of Cheese</td>
<td>21</td>
</tr>
<tr>
<td>Relation of Water to Cheese Yield</td>
<td>22</td>
</tr>
<tr>
<td>Predicting Cheese Yields</td>
<td>22</td>
</tr>
<tr>
<td>METHODS AND PROCEDURES</td>
<td>26</td>
</tr>
<tr>
<td>Milk and Cheese Source</td>
<td>26</td>
</tr>
<tr>
<td>Cheese Making Procedure</td>
<td>26</td>
</tr>
<tr>
<td>Milk Analysis</td>
<td>27</td>
</tr>
<tr>
<td>Cheese Analysis</td>
<td>28</td>
</tr>
<tr>
<td>Statistical Analysis</td>
<td>28</td>
</tr>
<tr>
<td>RESULTS</td>
<td>31</td>
</tr>
<tr>
<td>Model 1</td>
<td>31</td>
</tr>
<tr>
<td>Model 2</td>
<td>31</td>
</tr>
<tr>
<td>Model 3</td>
<td>31</td>
</tr>
<tr>
<td>DISCUSSION AND CONCLUSIONS</td>
<td>39</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>42</td>
</tr>
<tr>
<td>APPENDIX</td>
<td>46</td>
</tr>
</tbody>
</table>
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Milk constituents and their distribution in cheese and whey</td>
<td>3</td>
</tr>
<tr>
<td>2.</td>
<td>Standards of identity for Mozzarella cheese</td>
<td>4</td>
</tr>
<tr>
<td>3.</td>
<td>Average gross composition of cows’ milk</td>
<td>10</td>
</tr>
<tr>
<td>4.</td>
<td>Fat, protein, casein and lactose in milk from different breeds of cows</td>
<td>18</td>
</tr>
<tr>
<td>5.</td>
<td>Correlation coefficients (r) between actual and predicted yields and residual sums of squares (RSS) of the three models</td>
<td>32</td>
</tr>
<tr>
<td>Figure</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>1. United States cheese production in 1980</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>2. Per capita consumption of Italian and American cheese in the United States, 1972-1979</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>4. Correlation between cheese yield and milk fat plus protein content in Eastern Ontario in 1972</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>5. Regression of yield predicted by the equation $Y_1 = \frac{[0.88F + (0.78P-0.02)]1.12}{1 - W}$ versus measured yield</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>6. Regression of yield predicted by the equation $Y_2 = \frac{(0.86F + 0.97P)}{1 - W}$ versus measured yield</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>7. Regression of yield predicted by the equation $Y_3 = \frac{(0.89)(1.24)F + 0.78P}{1 - W}$ versus measured yield</td>
<td>38</td>
<td></td>
</tr>
</tbody>
</table>
This study was conducted to develop and evaluate several formulas which predict Mozzarella cheese yield from fat and protein content of milk and moisture content of cheese. During a one month period, 107 samples of milk and cheese were collected at Olympia Cheese Company, Olympia, Washington. Milk samples were analyzed for fat and protein content. Cheese samples were analyzed for fat, protein and moisture content.

Three models were derived to predict the yield of Mozzarella cheese. The three models were statistically fitted to the data by applying the Gauss-Newton non-linear least squares method of iteration. The differences among the three models in predicting cheese yield were insignificant. Any of the three formulas can predict yield of Mozzarella cheese reasonably well.
INTRODUCTION

Cheese yield is defined as the amount of cheese manufactured from a given weight of milk. Cheese yield is of great interest to milk producers, cheese makers and dairy economists (18). The influence of milk fat and casein on the amount of cheese produced suggests using fat and casein as a base for milk payment by the cheese industry.

In 1948, and again in 1952, Van Slyke and Price published a formula for predicting Cheddar cheese yields from milk on the basis of its fat and casein content (45). A number of other yield formulas that have been proposed by many workers are listed by Davis (12), but the Van Slyke formula (45) has received the widest acceptance.

The Van Slyke formula is:

\[ Y = \frac{[0.93F + (C - 0.1)] 1.09}{1 - W} \]

where:

\( Y \) = Kg Cheddar cheese per 100 Kg milk.
\( F \) = Percent fat in the milk.
\( C \) = Percent Casein in the milk.
\( W \) = Kg moisture per Kg cheese.

This formula assumes that 93% of milk fat is recovered in the cheese, 0.1 Kg of milk casein per 100 Kg of milk is lost in the whey, other milk solids (not fat and casein) plus salt added represent 9% of cheese fat and casein.

The Van Slyke formula is the basis of the program suggested by Ernstrom (14) which uses the Cheddar cheese yielding capacity of milk.
as a means of payment. It is possible to derive a yield formula for any varieties of cheese which fits the form of the Van Slyke formula. However, the factors 0.93, 0.1 and 1.09 will differ from cheese to cheese (18).

The objective of this study was to develop a formula to predict Mozzarella cheese yield based on milk compositions. This formula could then be used to determine the value of milk for making Mozzarella cheese.
REVIEW OF LITERATURE

Cheese Making

In the conversion of milk to cheese curd, a partition of milk constituents occurs which is dependent upon the characteristics of each component (27, 45). During milk clotting, casein, which exists as a suspension of micelles in milk, aggregates and forms a network that entraps some of the water and most of the milk fat. Fat globules are held within the protein network (12, 27, 45). Table 1 shows the typical separation of milk constituents into cheese and whey (45).

Table 1. Milk constituents and their distribution in cheese and whey (45).

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Milk (Kg)</th>
<th>Cheese (Kg)</th>
<th>Whey (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>87.0</td>
<td>3.90</td>
<td>83.10</td>
</tr>
<tr>
<td>Lactose</td>
<td>5.1</td>
<td>0.20</td>
<td>4.90</td>
</tr>
<tr>
<td>Fat</td>
<td>4.0</td>
<td>3.70</td>
<td>0.30</td>
</tr>
<tr>
<td>Casein</td>
<td>2.5</td>
<td>2.40</td>
<td>0.10</td>
</tr>
<tr>
<td>Whey protein</td>
<td>0.7</td>
<td>0.05</td>
<td>0.65</td>
</tr>
<tr>
<td>Mineral</td>
<td>0.7</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>10.60</td>
<td>89.40</td>
</tr>
</tbody>
</table>
Mozzarella Cheese

Mozzarella cheese belongs to the pasta filata or pulled curd category. Mozzarella cheese originated in Italy where it was made from the high fat milk of the water buffalo. People in southern Italy still use the milk of water buffalo to manufacture this kind of cheese while in northern Italy cows' milk has been used to produce Mozzarella cheese (18, 31).

Four types of Mozzarella cheese are recognized by the United States Food and Drug Administration. Table 2 shows fat and moisture levels required for each type to meet the standard of identity (15).

<table>
<thead>
<tr>
<th>Type of Cheese</th>
<th>Fat* (%)</th>
<th>Moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mozzarella cheese</td>
<td>$F \geq 45$</td>
<td>$52 &lt; W \leq 60$</td>
</tr>
<tr>
<td>Part skim Mozzarella cheese</td>
<td>$30 \leq F &lt; 45$</td>
<td>$52 &lt; W \leq 60$</td>
</tr>
<tr>
<td>Low moisture Mozzarella cheese</td>
<td>$F \geq 45$</td>
<td>$45 &lt; W \leq 52$</td>
</tr>
<tr>
<td>Low moisture part skim Mozzarella cheese</td>
<td>$30 \leq F &lt; 45$</td>
<td>$45 &lt; W \leq 52$</td>
</tr>
</tbody>
</table>

*Calculated on the solid basis.
The popularity of Italian cheese in the United States began in 1952, and is still increasing (18). Total cheese production in the United States in 1980 increased seven percent over the previous year. Mozzarella registered the second largest increase in production in 1980, behind only Cheddar cheese. Production of Italian varieties of cheese increased six percent above 1979 production, and Mozzarella alone accounted for 70% of the Italian varieties (39, 44). Figure 1 shows cheese production in the United States in 1980.

Per capita consumption of cheese in the United States has also increased for both American and Italian cheese. During the period of 1969 to 1979 per capita consumption of cheese increased by 60% (40, 41, 42, 43). Figure 2 shows per capita consumption of Italian and American cheese in the United States between 1972 and 1979 (41).

Factors Affecting Cheese Yields

Four main factors determine the yield of all types of cheese (12, 18, 45):

1. Composition of the milk
2. Amounts of milk constituents lost in the whey
3. Amount of salt added in the cheese making process
4. Amount of water retained in the cheese

Factors Affecting Milk Composition

Table 3 shows the average gross composition of cows' milk (17).
Figure 1. United States cheese production in 1980 (39).
Figure 2. Per capita consumption of Italian and American cheese in the United States, 1972-1979 (42).
Per capita consumption (kg) over years 1972 to 1979 for various types of cheese:

- BRICK
- CHEDDAR
- HARD ITALIAN CHEESE
- SWISS
- MOZZARELLA
- BLUE

The graph shows an increasing trend in consumption for all types of cheese over the years.
Table 3. Average gross composition of cows' milk (17).

<table>
<thead>
<tr>
<th>Milk Constituent</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>87.2</td>
</tr>
<tr>
<td>Fat</td>
<td>3.7</td>
</tr>
<tr>
<td>Protein</td>
<td>3.5</td>
</tr>
<tr>
<td>Lactose</td>
<td>4.9</td>
</tr>
<tr>
<td>Ash</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Many workers have reported factors which may affect the composition of milk. These factors are:

1. Season of year (12, 16, 17, 23, 27, 35, 37, 47).
2. Age of cow (4, 6, 17, 47, 49).
3. Breed of cow (7, 10, 11, 21).
4. Feeding (11, 12, 21, 29, 36).
5. Stage of lactation (4, 8, 20, 21, 49).
6. Disease (32, 47, 48).
8. Cheese manufacturing (12, 27, 46).

**Season of year**

Irvine (16), in studying the composition of milk in Ontario, Canada, indicated that milk fat reached a minimum in August and a maximum in October. He found that variation in protein content paralleled that of fat except for an unexpected increase in June. The Canadian study showed that the concentration of lactose varied also
and appeared to compensate for variations in protein since the level of solid-not-fat was fairly stable throughout the entire period (Figure 3).

Irvine also indicated that cheese yield varied directly with deviations in the amounts of fat and protein according to seasonal variation. However, the relationship was not consistent at certain times of the year (Figure 4). Olson (27) attributed these yield changes to the variation of milk protein.

Steinsholt and Ystgaard (37) found that the smallest yield was from May to August, but they excluded June because during this period the milk had the lowest content of fat, total solids and casein nitrogen. Waite, et al. (47), in studying the effect of season of the year on milk composition, concluded that seasonal variations caused the yield of milk to increase from January to the May-June period, and then decrease to a minimum during October-November. Fat content decreased to a minimum in June, then increased to a maximum in October. Crude protein and casein contents rose to a peak in May-June and again in September while the lowest values were observed from January to March.

The range of variation in the values for lactose was less than those for protein and fat. Davis (12) indicated that there is a relationship of fat and casein in milk with cheese yield. Maximum cheese yield occurs during the period from October to December when fat and solids-not-fat in milk reach their maximum. Minimum cheese yield occurs from March to April when fat and solids-not-fat in milk decrease to their minimum. However, he indicated that maximum and minimum yield may be obtained at other times of the year. Szijarto, et al. (38) found an
Figure 3. Seasonal trends in Ontario milk composition in 1972 (16).
Figure 4. Correlation between cheese yield and milk fat plus protein content in Eastern Ontario in 1972 (16).
increase in percent casein in milk during May, June and July and a decrease during August, September and October. Johnson (17) indicated that the percentage of total solids in milk decrease sharply from May to June. He attributed this to change in feed or temperature. Schinckel (35) observed that seasonal variation affects the amount of cheese which can be manufactured from a given quantity of milk. They noticed a decline in the cheese yield during the late summer period.

**Age of cow**

Johnson (17) found that both average fat and solids-not-fat percentages of milk decline with the age of cow, but lactose and casein are affected most. Bartlett (6) showed that age of the cow has an influence on the lactation curve. Many workers have indicated that there is a decline in solids-not-fat percentages with the age of a cow or advancing lactation which is almost twice the magnitude of the decline in fat percentage (4, 6, 47, 49). They reported declines in solids-not-fat from 0.21 to 0.45% during the first seven years of lactation. Most of this decrease was due to a decline in lactose content. While the crude protein did not change much with age, the casein percentage declined during the first seven lactations almost as much as the lactose, suggesting that the whey protein and non-protein nitrogen fractions increased with advancing lactation number.

**Breed of cow**

Cerbulis and Farrell (10) stated that cheese should be made from milk which has high casein content without concern for whey protein and lactose content because casein is the principal protein component
of cheese. They also indicated that yield of cheese depends directly on the amount of casein in milk. In a study involving 26 Holstein, 25 Jersey, 24 Guernsey, 25 Ayrshire, 33 Brown Swiss and 18 Milking Shorthorn cows, they found that the largest protein percentage is in milk from Jersey and Brown Swiss cows and the lowest is in milk from Holstein and Milking Shorthorn cows. The percent casein (as percent of protein) is highest in Jersey and Brown Swiss milk while lowest in Holstein and Guernsey milk (Table 4). Therefore, milk from Jersey or Ayrshire cows would be better for cheese making than milk from other breeds. Chapman (11) claimed that Ayrshire milk is most suitable for cheese making due to its small even-sized fat globules. Blake et al. (7) found that the percent casein (as percent of protein) is higher in Jersey's milk than in Holstein's milk. Armstrong (2) found that the highest fat content was in Jersey milk.

Legates (21) indicated that breed affects milk composition and that fat content varies more than any other constituent. He also indicated that there is a variation in solids-not-fat due to breed of cow and that most of the variation in solids-not-fat is accounted for by variation in protein content.

Feeding

Davis (12) claimed that prolonged feeding of cows without green fodder of any kind may lead to the cows secreting a milk which clots poorly with rennet or even not at all. He thought that grass, hay, dried grass and silage may have a special significance for the cheese making farmer. He said that some feed like linseed cake and sunflower seed cake may adversely affect milk for cheese making when fed in large
Table 4. Fat, protein, casein and lactose in milk from different breeds of cows (10).

<table>
<thead>
<tr>
<th>Breed</th>
<th>Fat (%)</th>
<th>Protein (%)</th>
<th>Casein (%)</th>
<th>Lactose (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holstein</td>
<td>3.73</td>
<td>3.22</td>
<td>2.53</td>
<td>4.93</td>
</tr>
<tr>
<td>Jersey</td>
<td>5.42</td>
<td>4.22</td>
<td>3.39</td>
<td>4.99</td>
</tr>
<tr>
<td>Guernsey</td>
<td>4.76</td>
<td>3.70</td>
<td>2.88</td>
<td>4.66</td>
</tr>
<tr>
<td>Ayrshire</td>
<td>4.12</td>
<td>3.47</td>
<td>2.73</td>
<td>4.67</td>
</tr>
<tr>
<td>Brown Swiss</td>
<td>4.28</td>
<td>4.05</td>
<td>3.14</td>
<td>5.15</td>
</tr>
<tr>
<td>Milking Shorthorn</td>
<td>3.58</td>
<td>3.42</td>
<td>2.56</td>
<td>4.80</td>
</tr>
</tbody>
</table>

quantities. Chapman (11), however, indicated that the high nutritional value of spring grass causes a rise in milk solids-not-fat and a decrease in fat when compared to winter feed.

Schingoethe et al. (36) concluded that adding dried whole whey to the grain ration of cows may prevent the drop in milk fat tests which is experienced on high-grain rations. He attributed that to the minerals in the whey as well as lactose. Banks, et al. (5) reported that the addition of fat to a fat-deficient diet may result in milk with a different protein to fat ratio.

Legates (21) indicated that a decrease in solids-not-fat occurs when cows are fed rations with 25% less than normal energy requirements and most of this change is due to protein. Patchell (29) and Rook, et al. (33) found that underfeeding may decrease the solids-not-fat percentage by 0.3 to 0.4%. The decrease in protein content is somewhat more than the decrease in the lactose content.
Stage of lactation

Legates (21) indicated that after the first test of a cow's lactation total solids, solids-not-fat and protein drop to reach a low value by the second month of lactation. Lactose content is highest at the beginning of the lactation and declines linearly during the remainder of the lactation while solids-not-fat rises toward the end of lactation.

Many workers (4, 8, 20, 21, 22, 24, 28, 30, 49) have indicated that stage of lactation influences milk components. The percentage of fat and protein are high in colostrum, drop to a low around the second month, then rise at slightly different rates, increasing most rapidly at the end of lactation. Lactose is low in colostrum then rises to normal in the first week and remains steady until mid-lactation. Then it decreases slowly at first and then more rapidly at the end of lactation. They have also concluded that there is a small increase in protein and solids-not-fat after the sixth month of lactation due to pregnancy.

Disease

Weaver and Kroger (48) found that as somatic cell count in milk increases, total protein content is also increased. The increase in total protein is due to the leak of serum albumin and immunoglobulins from damaged cells into the milk. However, they also found that as the somatic cell count increases casein content in the milk decreases.

Waite, et al. (47) observed a decrease in lactose and solids-not-fat by 0.38% and 0.25%, respectively, as the total leucocyte count
increased to 500,000 per ml. They also observed a negative correlation between casein and cell counts.

The Wisconsin Dairies study as shown by Rhodes (32) attributed the losses in yield of cheese made from mastitic milk to its low casein content and alkaline pH. Moreover, the increase in sodium chloride and pH adversely affect rennet coagulation and cause losses of casein in the whey. Rhodes also concluded that a loss of 0.31 Kg of cheese per 100 Kg of milk was observed above 640,000 cells per ml.

Heat treatment of milk

El-Sadek and Motteleb (13) found that pasteurization of buffalo milk increased the yield of cheese over that made from raw milk. They found that heating milk to 170°C for 15 minutes before making the cheese resulted in a higher yield when compared to the yield of cheese made from raw milk. Angevine (1) indicated that higher temperature or longer holding (or a combination of both) can affect the yield of Cottage cheese. He also concluded that higher temperature may incorporate some of soluble protein into the cheese curd. Narasimhan (25) found that the yield of Cottage cheese was increased by 15.6% when the heat treatment temperature of skim milk was increased from 61.8° to 79.4°C for 30 minutes due to the retention of whey proteins in the curd.

Cheese manufacturing

Olson (27) mentioned that loss of fat and casein may occur at any stage during cheese making. Pumping with inadequately sized pumps and cutting prior to the formation of a good coagulum are examples of things which cause fat and casein loss. Davis (12) attributed the
loss of fat and casein to violent agitation of milk and curd and the
temperature employed.

Van Slyke and Publow (46) indicated that loss of fat in the
manufacture of Cheddar cheese may occur due to the failure to keep fat
well distributed in milk, cutting the curd when it is too soft, heating
the curd too rapidly or to too high temperatures, excessive piling of
curd and putting curd into the press while still too warm. Loss of
casein is due to violence in cutting the curd, agitation while removing
the whey from the curd and any condition which interferes with the com­
plete coagulation of the milk casein by rennet.

The Relationship of Fat and Casein
to Yield of Cheese

There is a relationship between fat and casein percentages in
milk as found by Van Slyke and Price (45). Van Slyke and Publow (46)
also reported a positive correlation between fat and casein. An increase
in fat content of 1% is accompanied by an increase in casein of 0.4%.
However, this relationship is reliable only for an average of a very
large number of cows and is not reliable for predicting the relation­
ship between fat and casein in milk from individual cows or herds.
Van Slyke and Price (45) also found an increase in the yield of cheese
in proportion to the increase of fat and casein. They observed that
50% of milk solids were recovered in the cheese, and the remainder
went into the whey. They also indicated that 90% of cheese solids are
fat and casein.

Many workers have mentioned the relationship between yield of
cheese and milk fat and casein (12, 16, 27, 45, 46). Olson (27)
indicated that there was a direct linear relationship between the amount of fat and casein in milk and the yield of Cheddar cheese. Mickelsen (24) found that cheese yield depends on fat as well as casein of the milk. Steinsholt and Ystgaard (37) concluded that there is a positive correlation between the yield of cheese and the casein fraction, fat content and total solids of milk.

**Relation of Water to Cheese Yield**

Van Slyke and Price (45) indicated that estimating the yield of cheese depends on the fat and casein of milk as well as the moisture content of the cheese. The higher the moisture in the cheese the more the yield and vice versa. The water content of cheese is independent of water content of the milk. Cheese making operations can determine the amount of water required in cheese to meet the standards of identity.

**Predicting Cheese Yields**

Many formulas have been derived by many workers to predict cheese yield as listed by Davis (12):

A. Formulas based on fat and casein:

1. Babcock, et al. (1910):
   
   Cheese yield = 1.1 fat + 2.5 casein

2. Van Slyke and Price (1932):
   
   Cheese yield = 1.63 (casein + fat)

   
   Cheese yield = 1.4 (casein + fat) + 1.04
4. McDowall formula (1936) (using his data):
   a. Cheese yield = 1.22 (casein + fat) + 2.32
   b. Cheese yield = 1.07 fat + 2.35 casein

5. Shelton and Meaney (1937, 1938):
   
   Yield = \( F - \frac{4F}{100} + C - \frac{4C}{100} + \frac{22C}{100} \times 2.26 \)

   This formula makes the following assumptions:
   a. Four percent of the milk fat lost in the whey.
   b. Four percent of the milk casein lost in the whey.
   c. A retention in the cheese of non-casein solids-not-fat equivalent to 22% of the casein.
   d. A cheese moisture content equivalent to 126% of the solids-not-fat retained.

6. The above formula was simplified by McDowall in 1939 to:
   
   \( \text{Yield} = 0.96 \text{ fat} + 2.67 \text{ casein.} \)

B. Formula based on total solids or fat plus solids-not-fat:

   \( \text{Yield} = \text{fat} + \frac{1}{3} \text{ solids-not-fat}. \)

   The above formula was derived by VanDam and Janes in 1931.

C. Formula based on milk fat and protein in milk and on water and salt in the cheese:

   Bergman and Joost in 1953 suggested the following formulas:
   a. \( \text{Yield} = 0.91 F + 0.77P + 0.48 + \frac{W(0.77P + 0.48)}{(100 - W)} \)
   b. \( \text{Yield} = \frac{91F + 77P + 40}{100 - S + W} \)

   where:
   
   \( F = \) Represents the percentage of fat in milk.
   \( P = \) Percentage of protein in milk.
$W$ = Percentage of water in cheese.

$S$ = Percentage of salt in water.

**D. Formula based on fat and total nitrogen (or total protein):**

Schulz and Kay in 1957 proposed the following formula:

$$\text{Yield} = \text{net fat} + 0.75 + \frac{0.825 \ W_{ff}}{100 - 1.1 \ W_{ff}} \ P$$

where:

- net fat = milk fat - whey fat.
- $W_{ff} =$ moisture content of the fat-free cheese.
- $P =$ protein content of the milk, assuming 75% of this goes into the cheese.

This formula was simplified to:

$$\text{Yield} = \text{net fat} + F(P)$$

where:

- $F =$ a factor which varies with the moisture content of the fat-free cheese.

Schultz and Kay gave values of $F$ for different varieties of cheese according to change in the moisture percent in fat-free cheese.

**E. Formula based on fat and casein in milk and moisture content of cheese:**

Formula derived by Van Slyke and Price (45) to predict the yield of Cheddar cheese:

$$Y = \frac{[0.93F + (C - 0.1)] \ 1.09}{1 - W}$$

where:

- $Y =$ Kg Cheddar cheese per 100 Kg milk.
- $F =$ Percent fat in the milk.
\[ C = \text{Percent casein in the milk.} \]
\[ W = \text{Kg water per Kg cheese.} \]

The Van Slyke formula assumes that 93\% of milk fat is recovered in the cheese, 0.1 Kg of milk casein per 100 Kg of milk is lost in the whey, other milk solids (not fat and casein) plus salt added represent nine percent of cheese fat and casein.

None of the above formulas have received wide acceptance except the Van Slyke and Price formula (45). Ernstrom (14) suggested the possibility of using the cheese yielding capacity of milk as a means of paying for milk in the cheese industry and used the Van Slyke and Price (45) yield formula for Cheddar cheese as a basis of this program (14). Many suggestions have been made for component pricing of milk based on fat, protein, solids-not-fat (19). The difficulty of establishing values for each component or group of components in milk has limited their success (9). Ernstrom's program (14) is being used successfully (9).
METHODS AND PROCEDURES

Milk and Cheese Source

Cheese was made at Olympia Cheese Company in Olympia, Washington during the period from June 28, 1981 to July 30, 1981. Analysis of milk fat and protein were done in the Olympia Cheese Company Laboratory. The analysis of cheese fat and protein were done in the Department of Nutrition and Food Sciences at Utah State University, Logan, Utah.

Cheese Making Procedure

Three vats of Mozzarella cheese were made daily, four days a week for five weeks. The cheese making procedure was as follows:

1. Fat in the milk was standardized as follows:
   (protein %) x (0.63) = % fat of milk used to make skim Mozzarella cheese.
   (protein %) x (0.85) = % fat of milk used to make whole milk Mozzarella cheese.

2. Setting the milk and cutting the curd:
   Lactic starter was added to the vat as milk was being pumped into it. The vat eventually contained about 9091 Kg of milk and about 38.6 Kg of lactic starter. One hour after filling began the vat weight was taken and then 0.71-0.85 Kg rennet was added. The vat was set at 34°C (93°F). Decolorizer (0.1% sodium benzoate and 1% sodium propionate) was added just before the rennet. After 30 minutes the curd was cut.
3. Cooking the curd:
   Cooking began five minutes after cutting the curd. The temperature was raised to 41.5°C (107°F) over a 30-40 minute period.

4. Draining:
   Curd was drawn at one h 40 min after setting. The curd was separated from the whey by a screen and dropped into 49°C (120°F) water.

5. Agitation:
   Curd was agitated for two to three hours until pH was near 5.4 and the proper texture was achieved.

6. Forming curd blocks:
   Curd was then dropped into a molder and extruded into 2.3 Kg (5 lb) blocks.

7. Cooling:
   Cheese blocks were placed in fresh water at 4.4°C (40°F) for 15-20 min.

8. Brining:
   Cheese blocks were then transferred to brine (95-97% NaCl) solution at 3.5-4.4°C (38-40°F) and left for ten h (skim Mozzarella cheese) or 12 h (whole milk Mozzarella).

9. Package:
   Cheese blocks were pulled from the brine, drained for a short time and packaged in 18.2 Kg (40 lb) packages.

Milk Analysis

The percentages of fat and protein in milk samples were determined
using a Multispec M infrared milk tester at 40°C. The weight of the milk in every vat was taken by a dip stick. The dip stick reading was converted to the weight of milk by using suitable table prepared for each vat. Vats were recalibrated just prior to the beginning of this study.

Cheese Analysis

Cheese fat was determined by the Babcock method (18). Moisture in the cheese was determined by the oven method (45) with slight modifications in which beakers (50 ml) were used instead of dishes. The oven was set at 110°C. Samples of cheese were left in the oven for 16 h.

Protein in the cheese was measured by a Kjeldhal procedure (3) with some modifications. Methyl red-methylene blue indicator was used instead of methyl red indicator. Seventy milliliters of 50% NaOH was added carefully to the digestion flasks. HCl (0.1N) was used to titrate the ammonia held by the Boric acid. Total protein in the samples was obtained by multiplying percent total nitrogen by a factor of 6.38. Total protein obtained was multiplied by 0.78 (10) to estimate percent casein in the samples.

Weight of the cheese was taken separately for each vat during the packaging of the cheese.

Statistical Analysis

The data collected was used to evaluate each of three models. The models are:

Model 1  (same form as Van Slyke formula)

\[ Y_1 = \frac{(aF + (0.78P - b))c}{1 - W} \]
where:

\[ a = \text{Percent milk fat retained in the cheese.} \]

\[ b = \text{Kg milk casein lost in the whey per 100 Kg milk.} \]

\[ c = \text{Amount of other milk solids (not fat and casein) plus salt added as a percent of cheese fat and casein.} \]

**Model 2** (casein lost as a percent of total casein rather than as a constant amount) and based directly on protein rather than 0.78P.

\[ Y_2 = \frac{(aF + bP)}{1 - W} \]

where:

\[ a = \text{Percent milk fat retained in the cheese times percentages of milk solids (not fat and casein) and added salt.} \]

\[ b = \text{Percent milk protein retained in the cheese times percentages of other milk solids (not fat and casein) and added salt.} \]

**Model 3** (same as model 2 plus casein:fat ratio controls amount of fat recovered in cheese)

\[ Y_3 = \frac{(0.78P)ab}{F + (0.78P)cF} \]

\[ Y_3 = \frac{(0.78P)ab}{1 - W} \]

where:

\[ \frac{(0.78P)}{F} = \text{percent milk fat retained in the cheese times percentages of other milk solids (not fat and casein) and added salt.} \]

\[ \frac{(0.78P)}{F} = \text{Casein to fat ratio of milk.} \]

\[ c = \text{Percent milk protein retained in the cheese times percentages of other milk solids (not fat and casein) and added salt.} \]
In all three models:

\[ Y = \text{Kg cheese per 100 Kg milk.} \]
\[ F = \text{Percent fat in milk.} \]
\[ P = \text{Percent protein in milk.} \]
\[ W = \text{Kg moisture per Kg cheese.} \]

Gauss-Newton ncn-linear least squares was used to fit each model to the data. The Gauss-Newton method performs a least squares fit of data to a function. The function can depend upon any reasonable number of parameters and can be non-linear. Data can have an arbitrary number of independent variables. Optimal function parameter values are found by the Gauss-Newton iteration method, starting from a set of initial guesses, to minimize the residual sum of squares (34).

Average percent fat recovery, casein lost factor and factor of other milk solids (not fat and casein) and salt added (as a percent of cheese fat and casein) retained in cheese based on the Van Slyke formula (45) were determined with a computer program (APPENDIX). These values were used as the starting point for iteration of the first model. Starting points for the other iterations were based on these values and the average composition of all milk samples.
RESULTS

The following results were obtained by applying Gauss-Newton iteration to the data:

Model 1

\[
Y_1 = \frac{[aF + (0.78P-b)]c}{1 - W}
\]

\[
Y_1 = \frac{[0.88F + (0.78P - 0.02)]}{1 - W}
\]

This suggests that 88% of milk fat was retained in the cheese and that 0.02 Kg of milk casein was lost per 100 Kg of milk. Added salt and other milk solids (not fat and casein) account for yield equal to 12% of cheese fat and casein.

Model 2

\[
Y_2 = \frac{(aF + bP)}{1 - W}
\]

\[
Y_2 = \frac{(0.86F + 0.97P)}{1 - W}
\]

In this model 0.86 represents percent milk fat retained in the cheese times added salt and other milk solids (not fat and casein). The parameter b = 0.97 represents percent milk protein plus accompanying salt and other milk solids (not fat and casein) retained in the cheese.

Model 3

\[
Y_3 = \frac{(0.78P)}{ab \frac{F}{F + cP}}
\]

\[
Y_3 = \frac{1 - W}{F + cP}
\]
In this model \( (0.89)(1.24) F \) represents percent milk fat and other milk solids (not fat and casein) and salt added as a function of cheese fat and casein. Also, 0.78 represents milk protein retained in the cheese times salt added and other milk solids (not fat and casein) as a percent of cheese fat and casein.

For all three models:

\[
Y = \text{Kg cheese per 100 Kg milk.}
\]

\[
F = \text{Percent fat in milk.}
\]

\[
C = \text{Percent casein in milk.}
\]

\[
P = \text{Percent protein in milk.}
\]

\[
W = \text{Kg water per Kg cheese.}
\]

The correlation coefficients \((r)\) between the actual yields and the predicted yields for the three models were found by linear regression.

Table 5 and Figures 5, 6 and 7 show the correlation coefficients \((r)\) between the actual yields and the predicted yields, and the residual sums of squares \((\text{RSS})\) for the three models.

**Table 5. Correlation coefficients \((r)\) between actual and predicted yields and residual sums of squares \((\text{RSS})\) of the three models.**

<table>
<thead>
<tr>
<th>Model</th>
<th>(r)</th>
<th>RSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. (Y_1 = [0.88F + (0.78P - 0.02)]1.12/1-W)</td>
<td>0.7535</td>
<td>40.50</td>
</tr>
<tr>
<td>2. (Y_2 = (0.86F + 0.97P)/1-W)</td>
<td>0.7534</td>
<td>39.49</td>
</tr>
<tr>
<td>3. (Y_3 = (0.89)(1.24) \frac{F}{F + 0.78P/1-W})</td>
<td>0.7533</td>
<td>39.50</td>
</tr>
</tbody>
</table>
Figure 5. Regression of yield predicted by the equation

\[ Y_1 = \frac{[0.88F + (0.78P-0.02)]1.12}{1 - W} \]

versus measured yield.
Figure 6. Regression of yield predicted by the equation

\[ Y_2 = \frac{(0.86F + 0.97P)}{1 - W} \]

versus measured yield.
$\text{ACTUAL YIELD (Y)}$

$\text{PREDICTED YIELD (Y)}$

$Y = 0.96602 + 0.9034x$
Figure 7. Regression of yield predicted by the equation

\[ Y_3 = \frac{(0.89)(1.24) F}{1 - W} \quad F + 0.78P \]  

versus measured yield.
PREDICTED YIELD ($Y_3$)

ACTUAL YIELD ($Y$)

$Y = 3.65476 + 0.63006X$
DISCUSSION AND CONCLUSIONS

The purpose of this study was to develop an equation to predict the yield of Mozzarella cheese from milk of different compositions. Three model formulas were derived to predict Mozzarella cheese yield.

In the first model, the fat lost accounted for 12% of total milk fat. This means that 12% of milk fat was lost in the whey and 88% retained in the cheese. In Cheddar cheese the fat loss factor is 7-10% (14, 45). Therefore, there is more loss of milk fat in the manufacture of Mozzarella cheese than in the manufacture of Cheddar cheese.

Many factors contribute to the relatively high loss of fat in Mozzarella cheese. These factors are: 1) blending in hot water, then molding hot curd and cooling in salt brine, 2) vigorous agitation of the curd and 3) cutting the curd into small particles. Nilson (26) mentioned that considerable fat and solids-not-fat losses occur during mixing, cooking and molding of Mozzarella curd, with the greater loss occurring during molding. He also stated that the design of mechanical equipment can contribute to this loss as can fat level, curd pH and water temperature.

In the second model, 0.86 represented milk fat that remained in the cheese plus part of the added salt and other milk solids (not fat \(0.78p\)) and casein), while in the third model \((0.89)(1.24)^{F}\) represented the percent milk fat retained in the cheese times added salt and other milk solids (not fat and casein) as a function of cheese fat and casein. Casein to fat ratio \((C/F)\) influences the percentage of fat which goes into whey (30). The more fat there is relative to casein, the more fat will be lost in the whey. One purpose of using
standardization is to minimize the loss of fat into the whey (18). Van Slyke and Price (45) indicated that fat in low test milk was of slightly greater value (as far as yield is concerned) than was fat in rich milk. Since milk used for Mozzarella cheese is standardized (so variations in casein to fat ratios are small) this concept could not be adequately evaluated. There was not enough variation in C/F ratios to see whether the yields were influenced or not. This model may be more useful for other cheese varieties where variations in casein to fat ratios are high.

In model 1, the casein lost factor was 0.02. In other words, 0.02 Kg milk casein per 100 Kg milk was lost in the whey. In Cheddar cheese the casein lost factor is 0.1. Therefore, in Mozzarella cheese less casein is lost in the whey. For model 2, the assumption that casein is equal to 78% of milk protein was not taken into consideration and 97% represented the percent milk protein retained in the cheese plus some of the added salt and other milk solids (not fat and casein). For model 3, 0.78 represented the percent milk protein retained in the cheese plus added salt and other milk solids.

The recovery factor of added salt and other milk solids (not fat and casein) was 1.12 in the first equation. Added salt and other milk solids (not fat and casein) accounted for 12% of the cheese fat and casein. In Cheddar cheese, added salt and other milk solids (not fat and casein) represent 9% of cheese fat and casein. Recovery factor of added salt and other milk solids (not fat and casein) is higher for Mozzarella cheese than for Cheddar cheese.

Table 5 shows the residual sums of squares for the three models. The residual sum of squares of the first equation was 40.50 that for
the second equation was 39.49, and that for the third equation was 39.50. Figures 5, 6 and 7 show the regressions of yield predicted by equations 1, 2 and 3 versus measured yields. The correlation coefficient (r) between actual yields and the predicted yields for the three equations were 0.7535, 0.7534 and 0.7533 respectively as shown in Table 5. The differences among the three correlation coefficients and the residual sums of squares of three equations were insignificant. As a result, Mozzarella cheese yields can be predicted equally well by using any of the three equations. However, the first model is recommended because average percent fat recovery, casein lost factor and the factor for other milk solids and salt added (as a percent of cheese fat and casein) retained in cheese are represented by the constants in the formula. In both of the other models the constants cannot be explained as having a physical meaning.

This work shows that one can easily and reasonably predict Mozzarella cheese yields and consequently compute the value of milk for the Mozzarella cheese making industry. Further study is recommended to derive more reliable and accurate equations to predict Mozzarella cheese yields by taking into consideration variations in the casein fraction of milk protein. A direct method for casein measurement is recommended. More accurate equations may then be developed for predicting Mozzarella cheese yields by using casein directly rather than a constant percentage of total protein.
REFERENCES


APPENDIX

The following BASIC program was used to find the starting point for iteration of model one based on the Van Slyke and Price formula (45). It was run on an Apple computer.

50: REMINE
60: PRINT: PRINT
100: PRINT "HERE IS THE FOLLOWING WIT A RETURN"
150: PRINT "NAME, ENTRY DATE, YA T, ORDER"
200: PRINT "MILK, MILK, FAT, MILK PROTEIN"
250: PRINT "CHEESE, FAT, CHEESE UP"
300: PRINT "RATING"
350: PRINT "CHEESE SPRING, CHEESE"
400: PRINT "#STATION"
450: PRINT "FRENCH, CHEESE"
500: INPUT A#
550: INPUT B#
600: INPUT C#
650: INPUT D#
700: INPUT E,F,G,H,I,J,K,L
750: M = (P / 100) * D
800: M = 0.79 * M
850: Q = M / 100 * L
900: P = (Q - 0) / N
950: Q = E / 100 * S
1000: R = G / 100 * L
1050: S = R / Q
1100: T = 100 / (G + R + 1)
1150: IF T = POK'S THEN 764, 80
1200: L8 = CHRS (12)
1250: PRINT L8
1300: PRINT "DATE"
1350: "AD"
1400: PRINT "FAT"
1450: "ME"
1500: PRINT "ORDER"
1550: "OB"
1600: PRINT "MILK"
1650: "ID"
1700: PRINT "MILK, FAT"
1750: "ID"
1800: PRINT "MILK, PROTEIN"
1850: "ID"
1900: PRINT "CHEESE, FAT"
1950: "ID"
The following basic program was used to find the starting point for iteration of model one based on the Van Slyke and Price formula (45). It was run on an Apple computer.

```
50 HOME
60 PRINT: PRINT
100 PRINT "ENTER THE FOLLOWING WITH A RETURN AFTER"
110 PRINT "EACH ENTRY - DATE, VAT, ORDER"
120 PRINT "#MILK, MILK, %FAT, MILK %PROTEIN"
125 PRINT "CHEESE %FAT, CHEESE %PROTEIN"
130 PRINT "CHEESE %WATER, CHEESE #STARTER"
135 PRINT "#RENNIN, #CHEESE"
140 INPUT A$
150 INPUT B$
160 INPUT C$
170 INPUT D,E,F,G,H,I,J,K,L
180 M = (F / 100) * D
190 N = 0.78 * M
200 O = H / 100 * L
210 P = (N - O) / N
220 Q = E / 100 * D
230 R = G / 100 * L
240 S = R / Q
250 T = 100 / (G + H + I)
260 PR# 1: POKE 1784, 80
266 L$ = CHR$ (12)
268 PRINT L$
270 PRINT "DATE "; A$
280 PRINT "VAT "; B$
290 PRINT "ORDER "; C$
300 PRINT "#MILK "; D
310 PRINT "MILK FAT "; E
320 PRINT "MILK PROTEIN "; F
330 PRINT "CHEESE FAT "; G
```
340 PRINT "CHEESE PROTEIN
";H
350 PRINT "CHEESE WATER
";I
360 PRINT "#STARTER
";J
370 PRINT "#RENNIN
";K
380 PRINT "#CHEESE
";L
390 PRINT
400 PRINT "#PROTEIN IN MILK
";M
410 PRINT "#CASEIN IN MILK
";N
420 PRINT "#PROTEIN IN CHEESE
";O
430 PRINT "#PROTEIN LOSS
";P
440 PRINT "#FAT IN MILK
";Q
445 PRINT "#FAT IN CHEESE
";R
450 PRINT "FACTOR FOR SALT/ETC
";T
460 PRINT
470 PRINT "THE FORMULA WOULD BE"
480 PRINT " (" INT (S * 1000 + .5) / 1000;" FAT + CA
SEIN - "; INT (P * 1000 + .5 ) / 1000;" ) "; INT (T * 100
0 + .5) / 1000
490 PRINT "YIELD = ------------
---------------------
500 PRINT " ( 1 -
WATER)"
510 PRINT 0
530 HOME : PRINT : PRINT
540 PRINT "TYPE Y TO REPEAT"
550 GET Y$ 560 IF Y$ = "Y" THEN 50
1000 END