Pricing of Cow's Milk in Relation to Bulk Milk Somatic Cell Count in the Threshold Range of 400×10^3 cells per Milliliter

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ABSTRACT

The study evaluated the influence of existing bulk milk tank somatic cell count (BMTSCC) thresholds in Israeli dairy herds on 24 hour cheese yield and milk coagulation properties that should be considered in a payment scheme. In experiment 1, 36 bulk tank milk samples were used to evaluate soft cheese yield and the level of correlation with coagulation properties. No correlation was found with BMTSCC and cheese yield. However, a significant correlation was found between curd firmness and cheese yield. In experiment 2, 320 bulk tank milk samples were used to test the level of coagulation properties vs. BMTSCC, which ranged from 64×10^3 to 597×10^3 cells/mL. No correlation was found with curd firmness and rennet clotting time. The results suggest that up to BMTSCC thresholds of 400×10^3 cells/mL the quality of milk does not correlate with the somatic cell count since the milk in the tank represents many individual cows.

Keywords: Bulk Milk Tank Somatic Cell Count; Coagulation Properties; Milk Pricing; Cheese Yield.

INTRODUCTION

Milk is one of the major ingredients for a variety of food products and serves as a protein source in addition to being a nutritious supply of various vitamins, minerals etc., required for child development (1). Food safety refers to ways of preventing the transfer of food borne diseases to consumers by food products. Food quality is usually related to economics through the composition of the product, its production yield and suitability for a variety of products. However, especially in the dairy industry, these terms are often used in an ambiguous way by not separating safety from quality (2). Along the years, dairy farms developed into two forms, i.e., dairy farms that produce products for direct marketing to consumers and dairy farms that produce milk which is sold to large dairies. In the light of these two operations the dairy industry together with law makers established testing procedures to ensure the safety of the milk thus produced, as well as establishing pricing criteria according to its quality.

It is well documented that the somatic cell count (SCC) and its distribution in milk of individual uninfected mammary cow glands is low, ~10-100×10^3 cells/mL depending on cow breed and increases under infection to ~10^5-10^7 cells/mL, including changes occurring in the cell distribution (3, 4). Thus, under clinical infection, which results in high levels of SCC the milk is not suitable for human consumption and is regulatory prohibited from entering the bulk milk tank, regardless of the number of cells but owing to the potential presence of zoonotic bacteria and toxins in the mammary gland and changes thus inflicted on milk composition (5, 6, 7). Intramammary infection (IMI) is the single major cause of udder inflammation causes increased SCC, which negatively affects the quality and quantity of milk produced from

a lactating animal (8, 9). However, cows with subclinical IMI are permitted to be milked for human consumption. In most instances 15-50% of the animals in a herd are infected with subclinical mastitis which cannot be noted by the producer unless somatic cells are measured either by California mastitis test (CMT) or by any other mean. From the viewpoint of safety, most of the bacteria involved in subclinical mastitis are not hazardous to human consumption and therefore are part of the microflora in the bulk milk and over 95% of these bacteria are killed during pasteurization. From the viewpoint of quality, it is acceptable that IMI by *Streptococci* (10, 11), *Staphylococci* including *S. aureus* (12) and coagulase negative staphylococci (CNS) (11,13) have negative effects on the milk, its cheese yield and quality. In most of the cows subclinical mastitis infects only one gland while the other glands produce normal milk with low SCC ($<50\times10^3$ cells/mL). Therefore, the SCC of the whole udder is lower than that of the infected gland. It is usually considered that SCC threshold of $>300\times10^3$ cells/mL per cow indicates infection (14). The difficulty of isolating an infected gland with no visual symptoms and ignoring its influence on the milk quality results in standard milk quality with $200\text{-}400\times10^3$ cells/mL depending on local regulations (EEC Council Directive, 1992; National Milk Producers Federation, 2015; USDA, 2013) (15, 16, 17).

On the farm, the milk is a mixture of all the animals that are milked into the bulk milk tank and the milk composition depends on breed, nutrition and time in lactation as well as on udder infection, while on the industrial level, time and storage conditions are adding to the influence on the milk quality (7, 18, 19). Thus, milk as a row material should be evaluated and priced according to the intended end product. In most countries, bulk milk tank somatic cell count (BMTSCC) of 400×10^3 cells/mL is the threshold for accepting milk for further processing although this level can be higher, for instance, in the USA (17). Currently, BMTSCC thresholds of 400×10^3 cells/mL in many countries is under discussion with the question of how much further should the decrease of BMTSCC be pressed being left open, because there are no clear cut research results that show what the influence of the further reduction in SCC are. On the farm, every cow or gland that is not milked into the bulk milk tank means economical loss. At the same time, the dairy industry should price raw milk according to its value for the end product, i.e., as long as the quantity and quality of the end product is not influenced, the price of the milk should remain the same.

In Israel, ~31% of the milk is used for drinking milk and the remaining 68% is divided between soft cheese (31%), fermented milk (13%) and hard cheese (24%) (Israel Dairy Board, 2014) (20). Similarly, in most large milk producing countries about 30-50% of the milk is used for making marketable products such as cheese, milk and whey powder, butter etc. (21, 22).

The objective of this study was to evaluate the influence of existing BMTSCC thresholds in Israel on the milk's quantity parameters as represented by 24 h cheese yield and milk coagulation properties that should be considered in a payment scheme. Two experiments were conducted. The first experiment evaluated 24 h cheese yield using a small number of samples to confirm a correlation in the study conditions, while the second focused on coagulation properties of bulk tank milk alone on a large scale.

MATERIALS AND METHODS

Milk sampling and testing

Experiment 1

Three litre milk samples with a variety of SCC levels were collected from 36 bulk milk tanks. Milk for cheese making was transferred to the laboratory in cooled containers. Milk gross composition: fat, protein, lactose and urea content were analyzed at the Israel Cattle Breeders Association central laboratory (Caesarea, Israel) using the Milkoscan FT+ and SCC by the Fossomatic FC (Foss Electric, Hilleröd, Denmark). Milk clotting parameters (RCT, min) and curd firmness (CF, V) after 60 min were tested using the Optigraph© (Ysebaert, Frepillon, France).

Cheese manufacturing was performed as previously described (2). Briefly, six one liter stainless steel containers were placed in a thermostatically controlled water bath. Maxiren 600 (DSM Food Specialties B.V., Delft, The Netherlands) at 0.09 g/L was added to each container and was held for 60 min until cutting into 0.8 cm cubes by stainless steel knives. The cut curd was left to stabilize for 10 min and then temperature was raised to 40° C and cooked for additional 25 min with gentle stirring. The curd was poured into perforated molds and turned over after 10 min. The cheese stored pressed at ~45 g/cm^2 for 24 h at 4° C and whey was collected and weighted for yield calculation. Cheese yield was calculated as the weight at 1 or 24 h per 1 L milk.

Dry matter (DM) in cheese was determined according to Standard Methods (23).

Experiment 2

During 7 month including summer - hot season and winter - rainy season, 320 bulk tank milk samples were collected from Israeli dairy herds all over the country (several herds were sampled 1-3 times). The samples were collected during loading of the delivering tank from the farm to the dairy (1-5 milking). Weekly, 20-30 samples of milk according to SCC levels were transferred in an ice box to the Dairy Science Laboratory at the A.R.O., The Volcani center for clotting parameters analyses. All tests were performed in duplicates.

Mathematical exercise with somatic cell count

Monthly individual milk testing of a dairy herd of 170 milking cows was used to exercise theoretical BMTSCC and milk quantity. The distribution of lactation number, time in the lactation, milk yield, and clinical and subclinical udder infection was typical in the Israeli dairy. The contribution of each cow's SCC to the bulk was calculated be using the SCC × milk yield/total milk in the bulk tank.

Statistical analyses

Correlation models of several parameters were performed using SAS Proc Corr (24). Data are presented as means and SEM. No significant differences were found between times of sampling in each season and therefore analyses was done over sampling time.

Table 1: Milk composition, somatic cell count (SCC), milk clotting parameters (rennet clotting time - RCT, curd firmness - CF) and cheese yield values of 36 milk bulk tank milk samples from different dairy farms (Mean, SEM, minimum and maximum levels).

Variable	Mean	SEM	Minimum	Maximum
Fat (g/L)	38.0	1.1	28.3	48.2
Protein (g/L)	34.5	0.2	31.9	36.7
Casein (g/L)	25.8	0.2	25.5	27.7
Lactose (g/L)	51.6	0.1	49.6	52.8
SCC ($\times 10^3$)	221.5	8.4	132.0	404.0
log SCC	5.33	0.01	3.40	5.61
RCT (min)	20.67	0.23	18.75	24.03
CF (V)	9.44	0.20	7.23	11.86
Cheese weight at 1 h (g)	173.62	2.33	152.62	196.52
Cheese weight at 24 h (g)	158.46	2.14	139.13	179.70
Dry matter in cheese at 24 h (g)	66.61	1.21	55.17	77.65

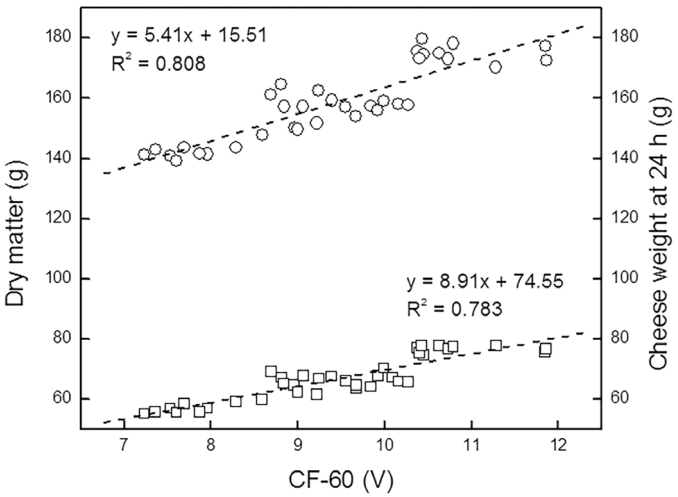

Figure 1: Dry matter in cheese (□) and cheese weight at 24 hours (○) vs. curd firmness at 60 min (CF-60).

RESULTS

Experiment 1

The Mean, SEM, minimum and maximum values of milk and cheese variables of the 36 tanks from of the different farms are summarized in Table 1. The BMTSCC ranged from 132×10^3 to 404×10^3 cells/mL, which is close to the upper level of the Israeli threshold. At that range, no significant differences and no correlation were found between BMTSCC, RCT, CF and Cheese weight at 1 or 24 h (Table 2). Positive significant correlations ($P<0.001$) were found between CF, cheese weight at 1 or 24 h and fat, protein and casein levels. Negative significant correlations were found between RCT and CF (P=0.04) and lactose (P=0.004). Thus, the high correlations between CF and cheese weight and dry matter in cheese (Figure 1) enabled to perform the second experiment with high accuracy.

Experiment 2

The Mean, SEM and minimum and maximum levels of milk variables and the correlations between coagulation properties: RCT or CF, constituents and SCC of milk of the 320 milk tanks from different dairy farms are summarized in Table 3. BMTSCC ranged from 64×10^3 to 597×10^3 cells/mL and no correlations were found with CF and RCT. The individual BMTSCC *vs.* CF are presented in Figure 2, showing a ran-

Table 2: Correlations between coagulation properties: rennet clotting time (RCT) or curd firmness (CF) or cheese weight (g) after 1h or 24h, cow milk constituents, somatic cell count (SCC) and log SCC (LSCC).

	Fat	Protein	Casein	Lactose	SCC	log SCC	RCT	CF	Cheese weight at 1 h	Cheese weigh at 24 h
Fat	1	0.82	0.71	-0.19	0.10	0.10	-0.14	0.90	0.92	0.97
		<0.001	**<0.001**	0.28	0.57	0.55	0.43	**<0.001**	**<0.001**	**<0.001**
Protein	0.82	1	0.78	-0.07	0.01	0.04	0.05	0.80	0.80	0.85
	<0.001		**<0.001**	0.70	0.97	0.80	0.77	**<0.001**	**<0.001**	**<0.001**
Casein	0.71	0.78	1	-0.307	0.18	0.18	0.30	0.61	0.75	0.78
	<0.001	**<0.001**		0.13	0.38	0.38	0.14	**0.001**	**<0.001**	**<0.001**
Lactose	-0.19	-0.06	-0.31	1	-0.19	-0.17	-0.46	-0.06	0.18	-0.22
	0.28	0.70	0.13		0.28	0.32	**0.004**	0.75	0.29	0.22
SCC	0.10	0.01	0.18	-0.19	1	0.98	0.72	0.01	0.06	0.06
	0.57	0.97	0.38	0.28		**<0.001**	0.676	0.99	0.59	0.74
LSCC	0.10	0.04	0.18	-0.17	0.98	1	0.044	0.02	-0.06	0.06
	0.55	0.80	0.38	0.32	**<0.001**		0.80	0.90	0.71	0.74
RCT	-0.14	0.05	0.30	-0.46	0.07	0.04	1	-0.35	-0.10	-0.06
	0.43	0.77	0.14	**0.004**	0.68	0.80		0.04	0.545	0.76
CF	0.90	0.80	0.62	-0.06	0.01	0.02	-0.34	1	0.87	0.88
	<0.001	**<0.001**	**0.001**	0.75	0.99	0.90	0.04		<0.001	<0.001
Cheese weight at 1 h	0.92	0.80	0.75	-0.14	0.06	-0.14	-0.10	0.86	1	0.98
	<0.001	**<0.001**	**<0.001**	0.41	0.75	0.41	0.55	**<0.001**		**<0.001**
Cheese weight at 24 h	0.97	0.85	0.79	-0.21	0.06	-0.21	-0.06	0.89	0.98	1
	<0.001	**<0.001**	**<0.001**	0.24	0.74	0.74	0.76	**<0.001**	**<0.001**	

dom distribution. Fat and protein levels had no direct effect on RCT or CF. Lactose was the single constituent in the milk that had a negative correlation with RCT, i.e., lower lactose level resulted in longer RCT, and positive correlation with CF, i.e., lower lactose level resulted in weaker CF.

Table 3: Milk composition, somatic cell count (SCC), rennet clotting time (RCT), curd firmness (CF) and its correlations with RCT and CF of 320 bulk tank milk samples from different dairy farms (Mean, SEM, minimum (Min.) and maximum (Max.) levels).

Variable	Mean	SEM	Minimum	Maximum	RCT (sec)		CF (V)	
					R	*P*	*R*	*P*
Fat (g/L)	37.7	0.21	29.3	44.2	0.072	NS	0.055	NS
Protein (g/L)	33.5	0.10	30.4	36.5	0.170	NS	0.091	NS
Lactose (g/L)	49.8	0.10	4.41	51.6	-0.250	**0.001**	0.231	**0.001**
SCC ($\times 10^3$)	235	115	64	597	0.179	NS	-0.015	NS
RCT (min)	21.45	3.48	12.87	38.11	-	-	-0.828	**0.001**
CF (V)	8.69	1.16	4.08	13.18	-0.828	**0.001**	-	-

Mathematical exercise with somatic cell count

All the cows, including the 5 with clinical infection, were not treated with antibiotics. Therefore, if all cows were milked into the bulk tank the total milk volume will be 7094 L

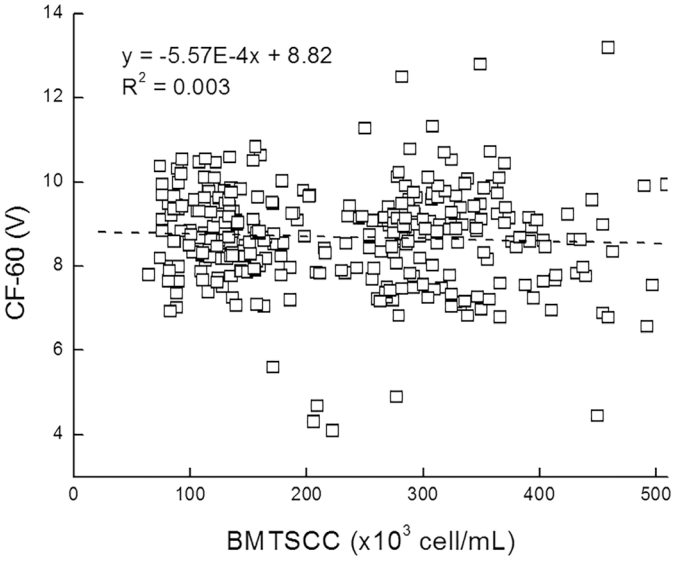

Figure 2: Curd firmness at 60 min (CF-60) vs. bulk milk tank somatic cell count (BMTSCC $\times 10^3$ cells/mL).

Table 4: Theoretical calculation of milk volume and bulk milk tank somatic cell count according to individual cow milk yield and SCC (in parenthesis - no. of cows).

Group	Number of cows and state of health	Bacteria	Milk (L)	SCC × 10^3 cell/mL	Milk loss (L)
1	Clinical (5)	*E. coli*	230	3,286	
2	Subclinical 1[1] (10)	Streptococci Post *E. coli*	460	1,307	
3	Subclinical 2[2] (65)	CNS	2568	250	
4	Free of infection (90)		3838	51	
1,2,3,4	170		7094	309	
2,3,4	165		6864	209	230
3,4	155		6406	131	690

[1] Subclinical 1 - >1,000×10^3 cells/mL
[2] Subclinical 2 - <1,000×10^3 cells/mL

with 309 × 10^3 SCC/mL (Table 4). By separating the 230 L of the clinically infected cows from the bulk milk tank, the BMTSCC will reduce to 209 ×10^3, while separating all the cows with SCC >1000 ×10^3 (Groups 1 & 2) the BMTSCC will reduce to 131 × 10^3 with additional milk loss of 460 L, resulting in total milk loss of 9.7% (7094-6406 L). Alternatively, if only the infected quarters of each of the cows with the clinical infection and subclinical infection with SCC >1000 × 10^3 cells/mL (Groups 1 & 2) will be separated, then only ~170 L (~25% of the 690 L) will be lost with minor changes in the BMTSCC. Manipulations with this set of cows when BMTSCC is the major critirion for milk quality and with no clear regulation of individual gland/cow, can demonstrate the many combination of the contribution of these cows to the bulk tank milk.

DISCUSSION

Milk safety has to be the major criteria in utilizing milk for human consumption. Somatic cell count, which is an indicator of inflammation, is an optimal tool for obtaining a clue whether an individual gland or a cow is suspected to be infected in one or more of its glands (25, 26). However, this indicator loses its sensitivity when it is implemented on the bulk milk tank due to unlimited combinations of possible milking of glands which have high individual SCC. Bulk milk is a mixture of all the animals milked at a certain point of time; therefore the quantity and quality contribution of each individual animal is minimal and the influence of infected glands on the BMTSCC is out of proportion due to the amount of its milk. Theoretically, only 2.5% of the milk constituents (fat, protein, lactose etc.) in the bulk milk tank will result from infected glands, if all animals in a herd yield daily the same amount of milk and 10% are coming from a single infected gland. At the same time the level of SCC could double or even triple. Implementation of milk payment schemes and thresholds of BMTSCC to the cow dairy industry decades ago reduced the risked of zoonosis and pathogens. Currently, according to country, BMTSCC is <400×10^3 cells/mL above which the milk should not be considered for human consumption, since higher cell counts might point to possible inclusion of milk from clinical infected glands. As demonstrated in the mathematical exercise BTMSCC is not the best parameter for predicting milk quality and are new/more parameters are necessary. With the current threshold and under the responsibility of the farmer, milk payment should focus on milk quality. Mastitis has an important economic impact on the dairy industry, however; the major loss is on the farm due to antibiotic treatments, discarded milk due to treatment, reduction of milk production and animal culling (26, 27). Most of the calculation studies of the economic impact of mastitis relates to the farm and not to the dairy industry although both suffer losses (28).

The dairy industry utilizes milk for a variety of products, thus, milk price should be according to limiting factors that are related the end product, i.e., shelf-life for drinking milk and milk coagulation properties for cheese making. In the current study the quality of bulk milk as indicated by SCC was evaluated by its coagulation properties and cheese yield. Most milk tanks were within the thresholds of <400×10^3 cells/mL while herds, milk composition and storage time were random. Under these conditions, no correlations were found between BMTSCC and CF and cheese weight at 24 h. The dairy looks for the best quality milk in order to achieve both product quality and reproducibility. However, quality has different meanings that influence different dairy products, for example: high fat and casein levels for cheese and low fat for drinking milk.

CONCLUSIONS

The results suggest that up to the thresholds of 400×10^3 cells/mL in the bulk milk tank, quality of milk as expressed by 24 h cheese yield and clotting parameters does not correlate with SCC, since the milk in the bulk tank represents many individual cows. The study also calls for introduction of more

indicators that relate to milk quality such as lactose and other milk constituents, which might serve in predicting the above trends.

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