MILK COMPOSITION AND CHEESE YIELD

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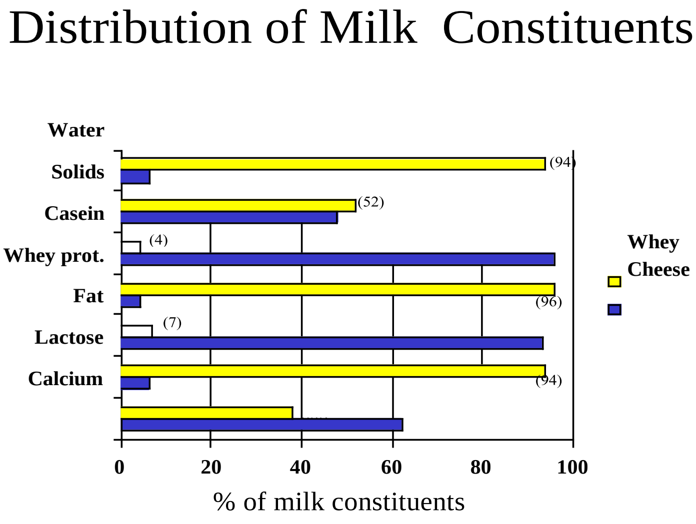
Introduction

Since milk costs represent approximately 85% of the cost of producing cheese, it is only fitting that we take a close look at milk composition and how much cheese we get from a specific source of milk. Cheese is a product in which the protein and fat of the milk are concentrated, so it is clear that cheese yield is related to casein and fat content of the milk (1).

When the Wisconsin dairy sheep industry got started in the mid 1990s, cheesemakers had to get accustomed to a whole new source of milk. All were familiar with cow milk and some were familiar with goat milk. However, sheep milk was much more concentrated with about twice as much fat and 40% more protein that cow or goat milk. They also found that sheep milk responded differently in the cheese make procedure. It was more sensitive to rennet, coagulated faster, produced a firmer curd and yielded more cheese per unit of milk than cow milk. Our objective of this report is to review factors impacting sheep milk composition and the resulting impact on cheese yields obtained from sheep milk.

Figure 1 shows what the distribution of milk constituents are in the cheesemaking process. About 96% of the casein, 93% of the milkfat, and 60% of the calcium will be retained in the curd of Cheddar cheese. The majority of the whey proteins, lactose and water are separated out in the form of whey. Since the moisture portion of cheese is actually whey, we do retain small amounts of whey proteins and lactose in the final cheese, proportionate to the moisture content. However, it is obvious that the fat and casein content of the milk will be the key constituents of milk that will contribute the most towards the yield of cheese. With that in mind, let's look at some of the factors that impact sheep milk composition and how those may impact cheese yield:

Figure 1. Distribution of milk components in Cheddar cheese.



Breed of sheep

Alichanidis and Polychroniadou (2) have reported milk composition for a number of European and Asian breeds (Table 1). Milkfat ranges from 5.33% for Nadjii to 9.05% for Vlahico ewes. Milk protein ranges from 4.75% to 6.52%. Jordan and Boylan (3) reported milk composition for some of the domestic sheep breeds in the U.S. that were bred more for market lambs (Table 2). Some of the earlier producers in Wisconsin started milking operations with Dorset ewes that produced high solids milk. At the present, most producers are including some dairy genetics in their flock in the form of East Fresian or Lacaune sheep. These breeds tend to produce more milk per lactation but with lower solids.

Table 1. Milk composition of various European and Asian breeds of dairy sheep.

Breed	*Fat, %*	*Protein, %*	*Lactose, %*	*Total solids, %*
Lacaune	7.40	5.63	4.66	----
Boutsico	7.68	6.04	4.80	19.30
Vlahico	9.05	6.52	----	20.61
Karagouniko	6.43	5.97	4.95	18.15
Nadjii	5.33	4.75	4.48	15.42
Friesland	7.30	5.82	4.37	18.46
Merino-Balbass	5.84	5.29	4.69	16.89

Ref.: Alichanidis & Polychroniadou, 1999.

Table 2. Milk composition of various domestic breeds of sheep.

Breed	*Fat, %*	*Protein, %*	*Lactose, %*	*Total solids, %*
Suffolk	6.8	6.2	4.8	18.5
Targhee	6.5	6.1	4.8	18.1
Finn	5.7	5.7	4.8	16.8
Dorset	6.7	6.5	4.8	18.3
Lincoln	6.5	6.1	4.8	17.3
Rambouillet	7.0	6.2	4.9	18.7

Ref.: Jordan & Boylan, 1995.

Season or lactation

Several researchers (4,5) have reported on seasonal changes in milk composition of dairy sheep. Both fat and protein tend to increase throughout the lactation (Table 3). This would typically result in higher cheese yields in late lactation milk. However, as shown in Table 4, fat increases at a disproportionate level to casein in late lactation so that the C/F ratio decreases throughout the lactation (6). This will impact the type of cheeses that might be produced throughout the season unless milk is standardized by removing some of the excess milkfat from late lactation milk. If milk is not standardized, fat losses in the whey will increase toward the latter part of the lactation and cheese yields will decrease.

Table 3. Effect of season on composition of sheep milk.

Component	*Early*	*Midseason*	*Late*
Fat, %[a]	6.26	6.50	7.82
Protein, %[a]	4.98	5.36	5.61
Fat, %[b]	3.6	7.3	8.8
Protein, %[b]	5.1	5.4	6.3

Ref.: [a] Barron, et al., 2001.
[b] Requena, et al., 1999.

Table 4. Effect of season on composition of Lacaune sheep milk.

Component	*48-55 days*	*132-139 days*	*174-192 days*
Fat, %	6.05	7.89	8.33
Protein, %	4.91	6.20	6.21
Casein, %	3.70	4.78	4.74
C/TP, %	80.1	80.4	80.1
C/F ratio	.611	.606	.569

Ref.: Pellegrini, et al., 1997.

Management systems

In 1999, UW researchers (7) reported on the effects of three different weaning and rearing systems on milk production and lamb growth. The three systems consisted of weaning at day 1 (DY 1), separating lambs for 15 hr from late afternoon till morning and machine milking once daily in the morning (MIX), and weaning at 30 days (DY30). After 30 days all three groups were milked twice per day. Table 5 shows the fat and protein content of milk for each of these systems throughout the lactation. As usual, fat levels increased throughout the lactation. However, protein levels decreased through the lactation for the DY1 and MIX ewes. During the first 30 days, the MIX ewes produced milk with abnormally low levels of milkfat. We are currently evaluating the cheese yielding potential of milk from DY1 and MIX ewes to determine the quality of the milkfat in the reduced-fat MIX milk (8). Milk compositions of these two milk supplies are shown in Table 6. MIX milk was extremely depressed in milkfat to the point that the milk had a C/F ratio of 1.59 while the DY1 milk was more typical at a C/F ratio of .70. McKusik et al. (7) report that milkfat was depressed in the MIX milk due to impairment of the milk-ejection reflex and retention of larger fat globules in the udder. Our study is designed to determine if the milkfat composition of the MIX milk is uniquely different from DY1 and more traditional sheep milk supplies.

Table 5. Effect of management systems on composition of sheep milk.

		DY1	*MIX*	*DY30*
Fat, %	Pre-wean	4.88	3.24	
	Peri-wean	4.90	4.78	4.21
	Post-wean	5.14	5.25	5.30
Protein, %	Pre-wean	5.52	5.36	
	Peri-wean	5.12	5.04	5.07
	Post-wean	5.07	5.11	5.30

Ref.: McKusick, et al., 1999.

Table 6. Milk composition of different management system ewes in cheesemaking trials.

Component	*DY1*	*MIX*	*DY30*
Fat, %	6.78	2.72	4.68
Protein, %	6.13	5.51	5.75
Casein, %	4.75	4.32	4.50
C/TP, %	77.0	78.0	78.0
C/F ratio	.70	1.59	.96

Ref.: Jaeggi, et al., 2002.

Milk quality

The somatic cell count (SCC) of milk is representative of the health of the udder and can be an indicator of the potential presence of mastitis. As the SCC increases in the milk supply, the composition of milk also changes. Table 7 shows the results of a study that was reported at the 6th Great Lakes Dairy Sheep Symposium in Canada (9). As SCC increased, milkfat and the C/TP ratio decreased. Protein recovery rate was lower in the high SCC milk while cheese yield was not significantly different. In a study that we reported on last year (10), The C/TP ratio decreased with increasing SCC but fat and protein were somewhat variable (Table 8). The cheese yield dropped from 16.03% down to 15.09% with an increase in SCC. Lower cheese yields were attributed to lower casein and fat contents of the higher SCC milk. Cheese graders also noted increased levels of rancidity in the higher SCC cheese. No major differences were noted in cheese texture between the different levels of SCC.

Table 7. Effect of SCC on milk composition in Italy.

Component	*SCC<500,000*	*500T – 1 M*	*1 M – 2 M*
Fat, %	6.61	6.34	6.36
Tr. Protein, %	5.25	5.45	5.51
Casein, %	4.18	4.26	4.20
C/TP, %	79.7	78.2	76.3
C/F ratio	.632	.672	.660

Ref.: Pirisi, et al., 2000.

Table 8. Effect of SCC on milk composition in Wisconsin.

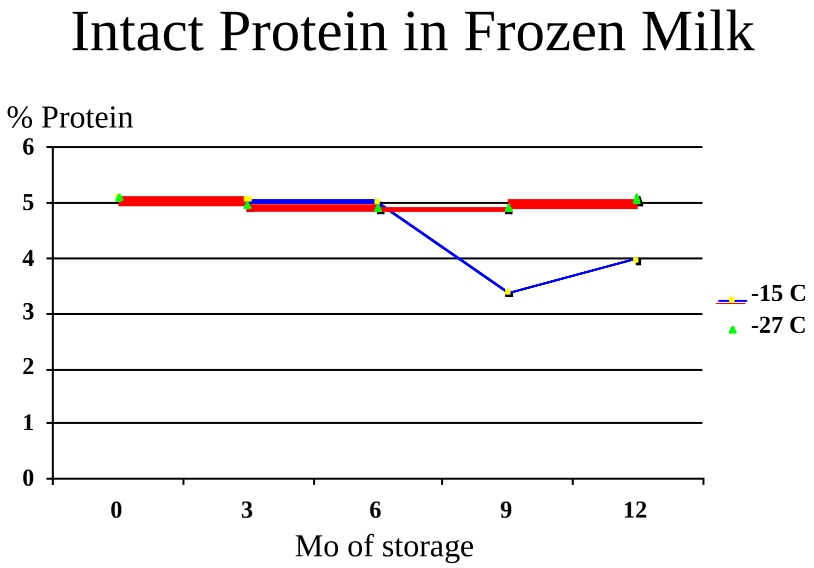
Component	*<100T*	*100T – 1 Mil.*	*> 1 Million*
Fat, %	5.49	5.67	4.86
Protein, %	5.23	5.31	5.02
Casein, %	3.99	3.97	3.72
C/TP, %	76.3	74.8	74.0
C/F ratio	.73	.70	.77

Ref.: Jaeggi, et.al., 2001.

Milk storage

Last year we reported on the studies we conducted on the stability of frozen sheep milk (11,12). In 1997, several of our cheesemakers experienced problems with destabilized casein in sheep milk that had been frozen and stored in home freezers. The destabilized casein would not react in the coagulation process and there was significant loss in cheese yield from that frozen milk. Cheesemakers also experienced a significant increase in occurrence of rancid flavors in the home-freezer frozen milk. When we compared milk that was frozen and stored in home freezers versus commercial freezers, we found that after 6 months of storage at -15°C (5°F), casein destabilization was experienced (Fig. 2). At 9 months of storage, we experienced over 40% destabilization of the casein. The primary cause for destabilization of the casein was the high concentration of calcium in sheep milk. Based on our study, we recommend fast freezing of the sheep milk and storage at -27°C or lower for up to 12 months. If freezing in a home freezer (-12°C), limit storage of the frozen milk to 3 months maximum.

Figure 2. Effect of protein stability in frozen sheep milk.



Nutrition of the ewe

At the 5th Great Lakes Dairy Sheep Symposium, Spanish researchers reported on the effect on nutrition on ewe's milk quality (13). They reported that a high level of nutrition will reduce the level of milkfat but increase milk protein and casein. Conversely, a negative energy balance will decrease milk protein and increase milkfat. Milk protein will increase with an increased level of dietary protein. When feeding higher levels of concentrate in the diet, milkfat will be decreased and milk protein will be increased. The degree of impact from nutrition of the ewe will obviously be limited by the potential milk production capacity of the animal dictated by genetics.

Genetics

In dairy animals, researchers have found that many of the milk proteins can exist in more than one genetic form. These genetic variants of milk proteins have also been reported in dairy sheep (14,15,16). Table 9 lists several genetic variants that have been reported and the corresponding milk composition with each. Sheep with the genetic capacity to produce the CC form of α_{s1} casein will generally have higher fat and casein concentrations in their milk than those animals producing the DD form. The same genetic capabilities also exist for β-lactoglobulin. With ewes producing CC form of α_{s1} casein or AA form of β-lactoglobulin, the higher fat and protein in milk will represent potential increased cheese yield from that milk. In dairy cattle, certain breeds will produce a predominance of certain genetic phenotypes of milk proteins. With further research, this also could be completed for the dairy breeds of sheep.

Table 9. Effect of genetic phenotype on composition of sheep milk.

Protein	*Phenotype*	*Fat, %*	*Protein, %*	*Casein, %*
α_{s1}-Casein	CC	7.08	5.44	4.41
"	CD	7.00	5.30	4.26
"	DD	7.07	5.02	4.06
β-Lactoglobulin	AA	7.13	(5.17)	4.17
"	AB	6.30	(4.98)	4.09
"	BB	6.66	(5.01)	4.05

Ref.: Pirisi, et al., 1999.

Trends in Wisconsin Sheep Milk

When we first started processing sheep milk in 1996, most of the milk was coming from domestic breeds, e.g., Dorsets, that were typically bred for the market lamb market. Fat and milk protein levels were fairly high and cheese yields were in the 18-20% range. As the dairy genetics were introduced into the flocks in the late 1990s, milk production increased but fat and protein levels in the milk were decreasing (Table 10). This obviously impacted cheese yields and cheesemakers were becoming concerned about the milk costs for making specialty sheep cheeses. It was difficult to compete against subsidized imported sheep cheeses, e.g., Pecorino Romano, that was coming into the U.S. at prices lower than the U.S. milk costs for sheep cheeses. This promoted some research into the possible use of blends of sheep and cow milk in some specialty cheeses. The cheesemakers were able to develop some of the typical sheep cheese flavors in these blends. In some cases, we tried to use the unique flavor of sheep milk to produce reduced fat cheeses with improved flavors (17). Table 11 shows one of these blends used for a specialty reduced fat cheese.

Table 10. Trend in sheep milk composition in Wisconsin, 1996-2000.

Year	*Sheep*	*Fat, %*	*Protein, %*
1996	Dorset	5.9-8.7	---
1996	EF-cross	5.4-6.5	---
1997	Dorset-cross	5.54	5.42
1997	EF-cross	5.04	4.96
2000	1/2 EF-cross	5.49	4.65
2000	1/2 Lacaune-cross	5.89	4.91

Table 11. Composition of mixed milk for reduced-fat Muenster cheese production.

Component	*Cow only*	*80:20 Cow/Sheep*
Solids, %	9.78	11.48
Fat, %	1.39	1.73
Protein, %	3.08	3.92
Casein, %	2.38	3.02
C/F ratio	1.71	1.74

Ref.: Ponce de Leon-Gonzalez, et al., 2002.

Milk Composition and the Relationship to Cheese Yield

As we showed in Figure 1, fat and casein are the two primary milk components that are recovered in the cheesemaking process and are directly related to cheese yield. Since casein is the key component in making up the curd matrix that entraps the fat globules, we look at casein relationships with other milk constituents to forecast the potential cheese quality and cheese yield. The C/F ratio is critical in controlling the final fat in the dry matter (FDM) of the finished cheese. Minimum FDM specifications are established for many of the cheeses with standards of identity. The C/TP ratio will give us some potential information on the amount of intact casein that is present in the milk to give us a good gel structure during curd formation. Some of the reported C/F and C/TP ratios for various breeds of dairy sheep are shown in Table 12. Typical C/F ratios needed to produce high quality commodity cheeses are shown in Table 13. In most cases, sheep milk would need to be standardized by removing some cream in order to increase the C/F ratio to produce most of these varieties of cheese. For reduced fat cheeses, significant amounts of fat would need to be removed or additional amounts of solids not fat (SNF), e.g., nonfat dry milk would need to be added to match the targeted C/F ratio needed to produce a quality cheese in an efficient manner. If C/F ratios are significantly lower than the target level, high losses of fat in the whey will be experienced and the cheese yields will be decreased.

Table 12. Casein relationships for breeds of dairy sheep.

Breed	*C/TP ratio*	*C/F ratio*	*Reference:*
Lacaune	.783	.596	2
Boutsico	.760	.598	2
Karagouniko	.732	.679	2
Friesland	.792	.631	2
E. Fresian cross	.763	.700	10
Italian species	.797	.632	9
Cyprus species	.774	.685	18

Table 13. Ideal casein/fat (C/F) ratios in cow milk for commodity cheeses.

Cheese	*C/F ratio*
Cheddar	0.70
Mozzarella	0.85
Swiss	0.85
Parmesan	0.80
Havarti	0.60
Reduced fat Muenster	1.73

Sheep Cheese Yields

Cheese yields for sheep milk have been reported in literature by various researchers. Cheese yields have been reported in the following manner:

1) Gross cheese yield after 1 day, lb/100 lb. (3,4)
2) Adjusted cheese yield to *x*% moisture. (16)
3) Quantity of milk (Kg) of milk necessary to make 1 Kg of full-fat cheese. (14,18)
4) $Y = a + b_f x_f + b_p x_p$ (18)

$= -0.20 + 0.011$ fat $+ 0.025$ protein

Some typical cheese yields of several varieties of sheep milk cheeses are shown in Table 14. These cheese yields will vary based on the previous factors we discussed affecting milk composition, especially fat and casein concentrations. Cheese yields also may be affected by various processing variables that we will list later.

Table 14. Reports in literature on cheese yields from sheep milk.

Cheese	*Yield, %*	*Reference:*
Manchego	16.7	3
Feta	18.1	3
Romano	20.2	3
Blue	21.9	3
Halloumi	18.4	18
Manchego type	16.1	10

Predicting Cheese Yield

The cheese yields listed in Table 14 were measured after the cheese manufacturing process was completed. There was no opportunity for the cheesemaker to predict the potential cheese yield and make adjustments to possibly improve those yields with milk standardization or changing of the make procedure to improve the recovery of milk solids in the final cheese. When using cow milk, cheesemakers have had cheese yield formulas for over 90 years that are used to predict the potential cheese yield, based on milk composition. In 1910, Van Slyke and Publow (19, 20) proposed the first cheese yield equation to determine potential yield of Cheddar cheese from cow milk. The well established Van Slyke Cheddar Cheese Yield Formula is as follows:

$$\text{Yield} = \frac{(0.93F + C - 0.1)1.09}{100-W}$$

where: F = fat concentration in the milk, %
C = casein concentration in the milk, %
W = moisture, expressed as Kg water per Kg of cheese

Van Slyke and Price (20) also reported another cheese yield formula that was slightly modified:

$$\text{Yield} = (F + C)N$$

With this equation, they provided a table of numbers for N, based on the moisture content of the cheese. This equation did not include a provision to adjust the cheese yield for fat and casein losses in the whey as the previous formula. Hence, the Basic Van Slyke Cheddar Cheese Formula is the one that has been used extensively in the industry and is used as the basis for the multicomponent pricing system used for pricing of raw milk from the producers. This is also the formula used to predict cheese yield potential for sire services and potential production capacity of breeding stock.

The Van Slyke Cheese Yield Formula was developed for Cheddar cheese. It was based on the premise that about 7% of the fat and about 4% of the casein would be lost in the whey. Other cheeses may have different rates of recovery of milk components in the make procedure and the yield formula may need to be adjusted for that make procedure. Such is the case for Mozzarella cheese where Dr. Barbano (21) at Cornell University revised the Van Slyke formula to effectively predict cheese yield for this commodity cheese. His revised formula is as follows:

$$\text{Yield} = \frac{[(.85 \times \%\ \text{fat}) + (\%\ \text{casein} - 0.1)1.13}{1 - (\text{cheese moisture}/100)}$$

These previous formulas were based on cow milk that typically had about 2.5% casein in the milk. As the solids level in milk increases, the estimated loss of 0.1% casein in the whey may not be as accurate as desired. To adjust the Van Slyke formula for higher solids milk, e.g., Jersey milk, and for other potential cheeses, Kerrigan and Norback (22) revised the Van Slyke formula to allow for use of specific fat and casein retention factors for each cheese plant or each variety of cheese produced within a plant. Their formula is as follows:

$$\text{Yield} = \frac{[(RFxF) + (RCxC)]RS}{1.0 - W}$$

where: RF = fat retention factor
F = % fat in the milk
RC = casein retention factor
C = % casein in the milk
RS = solids retention factor
W = moisture in the final cheese, (%/100)

With this formula, a cheesemaker can incorporate retention factors that are typical for that specific plant and the variety of cheese being produced. In the original Van Slyke equation for Cheddar cheese, the assumption was that a cheesemaker would experience 93% recovery of fat and 96% of the casein in the cheese. In the final cheese, there was about 9% additional solids in the form of whey proteins, lactose and ash that was present in the whey that was the moisture portion of the cheese. As moisture in the cheese increases, the RS will also increase and that is the basis of the RS of 1.13 for Mozzarella cheese as reported by Dr. Barbano (21). Retention factors for Cheddar, Mozzarella, and Swiss cheese are shown in Table 15 (23).

Table 15. Fat and casein retention factors for commodity cheeses.

Cheese	*RF factor*	*RC factor*	*RS factor*
Cheddar	.93	.96	1.09
Mozzarella	.85	.96	1.13
Swiss	.77	.94	1.10

Ref.: Kerrigan & Johnson, 1985.

Predicting Sheep Cheese Yield

With the wide variation in sheep milk composition that we have experienced over the past 6 years, our cheesemakers have requested a cheese yield formula to use to predict potential cheese yields from sheep milk. We have not been able to find a widely accepted cheese yield formula covering traditional sheep milk cheeses. Since the cheesemakers are very familiar with the use of the modified Van Slyke formula for their cow milk cheeses, we were hoping that we could determine retention factors that could be used in the Van Slyke formula to allow us to predict potential sheep milk cheese yields. Some fat and protein retention values have been reported for non-traditional sheep cheeses (Table 16). There are wide variations in fat and protein retention in the cheeses reported.

Table 16. Fat and protein recoveries from sheep milk.

Fat recovery, %	*Protein recovery, %*	*Reference:*
78.0-81.4	75.4-79.5	9
65	65	24
86.9	78.6	18

To assist the Dairy Sheep Coop in establishing some type of mechanism for pricing higher solids milk for producers and to provide some mechanism for cheesemakers to determine potential cheese yields from sheep milk, we have set up a study to develop cheese yield equations for some traditional sheep milk cheeses. The objectives of the study are:

1. To determine cheese yield for a hard and a soft sheep milk cheese.
2. Determine the impact of lactation or season on cheese yield.
3. Establish cheese yield formulas for sheep milk.

This first year we are evaluating the production of Manchego-type cheese with early, mid, and late lactation milk. Next year, we will follow up with a traditional soft-type cheese with the same lactation periods. Once we have been able to establish fat and protein recovery values for these varieties of cheese, we will propose cheese yield equations that we will evaluate with our cheesemakers for potential use in the future.

Cheese yield formulas are very useful in pricing milk and providing an estimate of cheese yield under defined conditions. Calculated yields are theoretical cheese yields only. The actual cheese yields obtained may be impacted also by processing conditions in the plant. Some of the factors that the cheesemaker has control over are as follows:

1. Storage of milk
2. Milk standardization
3. Heat treatment of milk
4. Homogenization
5. Type of coagulant
6. Curd firmness at cut
7. Salt addition
8. Moisture loss during ripening.

With good process control, recordkeeping and consistent cheesemaking operations, the cheesemaker should be able to have uniform composition and cheese yields throughout the season. This should then result in an efficient and profitable business for the dairy sheep industry.

In conclusion, with milk costs representing about 85% of the cost of making cheese, it is critical that the cheesemaker is able to recover the maximum amount of fat and casein in the form of cheese to provide for an efficient operation. On the other hand, producers that are providing additional solids in their milk supply should be properly compensated for the added value that represents in the form of potential increased cheese yields. With the development of an acceptable cheese yield formula for sheep milk, we are hoping that we can provide a win-win situation for the whole dairy sheep industry.

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