Influence of Presalting and Brine Concentration on Salt Uptake by Ragusano Cheese¹

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ABSTRACT

The impact of presalting and nonsaturated brine on salt uptake by Ragusano cheese was determined. The study included four treatments: 1) the traditional method using no presalting and saturated brine, 2) presalting and saturated brine, 3) no presalting and 18% brine for 8 d followed by 16 d in saturated brine, and 4) presalting and 18% brine for 8 d followed by 16 d in saturated brine. Cheese blocks were weighed and sampled before brine salting (time 0) and after 1, 4, 8, 16, and 24 d of brining for each treatment. Presalting delivered 60% of the normal level of salt in the center of the block prior to brine salting without decreasing the rate of uptake of salt from either saturated or 18% brine. Use of 18% salt brine for the first 8 d of 24 d of brine salting increased the rate of salt uptake, compared with 24 d in saturated brine. The increased rate of salt uptake with 18% brine compared with saturated brine was related to the impact of salt brine on the moisture content and porosity of the cheese near the surface of the block. Brine with higher salt content causes a rapid loss of moisture from cheese near the surface of the block. Moisture loss causes shrinkage of the cheese structure and decreases porosity, which impedes moisture movement out and salt movement into the block. The use of 18% salt brine for the first 8 d delayed the moisture loss and cheese shrinkage at the exterior of the block and allowed more salt penetration. (**Key words:** brine, presalting, Ragusano cheese)

Abbreviation key: NP18%B = no presalting and 18% brine, NPSB = no presalting and saturated brine, P18%B = presalting and 18% brine, PSB = presalting and saturated brine.

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INTRODUCTION

Ragusano cheese is a brine-salted, pasta-filata cheese that is made primarily on farms in the eastern region of Sicily. The first 3 to 8 d of brine salting of the blocks of Ragusano cheese is done on the farms and followed by continued brine salting at an aging center. Typically, saturated brines are used at both locations. If the penetration of salt into the 15- to 16-kg blocks of cheese is too slow, then the incidence of gas due to growth of undesirable bacteria and other quality defects in the cheese after brining increases. To avoid gas defects and reduce risk of loss of cheese during aging, the managers of cheese aging centers have brine salted the blocks of Ragusano cheese for longer periods of time (40 to 60 d) and dry salted the cheese surfaces for 1 to 2 wk, followed by additional brine salting, which achieves a much higher salt content. This may reduce gas defects, but excessively high salt reduces consumer acceptability of the cheese. It is typical to age the cheese for as long as 12 mo, but most of the cheese is sold at 4 to 6 mo of age.

The process of salt uptake during brine salting of cheese has been studied for other cheese varieties. Geurts et al. (1974b, 1980) characterized moisture loss and salt uptake in brine salted Gouda cheese. Geurts et al. (1974b) found that salt penetrates into cheese, inducing a weight gain, and moisture exits the cheese causing a weight loss during brining. Resmini et al. (1974) found that use of brine that was not fully saturated produced a faster rate of salt uptake in Parmigiano Reggiano cheese than saturated brine. In all of these studies the cheeses contained no directly added salt to the cheese curd prior to brining. The impact of presalting on salt uptake from brine has not been reported. The objective of the study was to determine if presalting the curd before stretching and use of brine that was not fully saturated (i.e., 18% salt) would influence the amount and rate of salt uptake from brine.

MATERIALS AND METHODS

Cheese Making

Milk produced by Brown Swiss, Holstein and mixed breed cows from three farms, from the two milkings

(morning and evening) was collected and transported to the Consorzio's pilot plant. The raw whole milk (864 L) was heated in a stainless steel vat to 35°C and filtered mechanically from the vat into five wooden cheese vats (the tina), which contain typical natural microflora that serve, along with bacteria in the milk, as starter culture. Natural rennet from the stomach of lambs (Riga Bianco, Caglifacio Clerici s.p.a., Cadorago, Co, Italy) was added to the milk in the amount of 23 g/100 L of milk. The coagulation temperature was 34.5°C. The complete cheese-making process with pictures of each step in the process has been reported previously (Licitra, 1995).

After 78 min, the milk coagulum was at the right consistency and it was broken (i.e., cut), in traditional way (Licitra et al., 1998), with a wooden staff with a disc at the end of it (the rotula), using a circular stirring motion for 4 to 5 min. When the curds were of corn grain size, 79°C water was added until the curd reached a temperature of 39°C (first cooking). The curd plus whey was stirred continuously during the first cook (5 min), and then the curd was allowed to settle to the bottom of the vat. At this point the curd size was about 4 × 4 mm. The whey was removed from the vat and used to make the ricotta cheese. The curd was also removed from the vat and left to drain on a wooden table (the mastredda), for about half an hour.

After draining in the mastredda, the curd was cut into slices about 3 cm thick, placed back into the vat, and cooked a second time by adding hot (84°C) ricotta whey. The temperature of the curd before the second cooking was 35.3°C. The vat was covered to avoid a rapid decrease in temperature. The amount of liquid added was 1.2 L/kg of curd. During the second cooking step, the slices of curd remained immersed in the hot ricotta whey for about 80 min. Once the second cooking was completed, the curd slices reached a final temperature of 43°C, and they were put into the mastredda and left there to ripen for 18 h at 16 to 22°C.

After ripening, the curd reached a pH of 5.23 and a temperature of 16°C. The curd was cut with a knife into long, uniform, 1-cm thick slices. Normally, for Ragusano cheese production the amount of the batch is 15 to 16 kg/block, however, for the purpose of this experiment the slices were weighed and divided into 22 batches of 3.8 kg each. Next, a random choice was made to either stretch the 11 presalted or the 11 nonpresalted portions first. The order of the 3.8-kg batches selected within either presalted group or the nonpresalted group was randomized. Two cheese-makers stretched 11 batches each.

Stretching of Cheese

The 11 nonpresalted cheeses were made by placing the slices of curd into a small wooden container (the

staccio) where they were soaked in 10 L of 73°C water for 5 min. The stretching process was done by hand using a special tool (50 × 10 × 2 cm) made of wood (the manuvèdda), which helps the cheese-maker increase his leverage during the stretching of the curd. The stretching process expels whey from the 3.8-kg mass of cheese, develops the typical fibrous structure of the pasta filata cheese, and, at the same time, minimizes the air remaining inside. In this way, the 3.8-kg formable curd mass forms a smooth spherical shape.

The 11 presalted cheeses were made by mixing salt directly into the curd in three increments, 5 min apart. The salt was added at 2% of the weight of the curd to reach 2.5 to 3% of salt in moisture after stretching. To minimize the loss of salt into the stretching water, 4.5% by weight of salt was added to 10 L of stretching water at 76°C. The stretching water temperature was higher for the presalted cheeses because the salt made the curd firmer during stretching and a slightly higher temperature was required for the cheese to soften and form easily. The stretching process was done as explained above.

The temperature of the curd mass at the end of stretching for both the nonpresalted and presalted cheeses was about 44 to 46°C. At the end of the stretching, each spherical mass of cheese, still warm, was placed into the mastredda with wooden shaping blocks to form a cube of 15.2 × 15.2 × 15.2 cm. The weight of each block of cheese decreased during stretching from about 3.8 to 3.5 kg. Each cheese was promptly marked with a letter (treatment) and a number (sampling day) so that the cheese could be correctly identified in the brine tank. The cheeses remained in the mastredda for 22 h at about 18°C. After the 22-h period, one of the 11 presalted and one of the 11 nonpresalted cheeses were analyzed before brining. Five of the 10 presalted blocks and five of the 10 nonpresalted blocks were submerged in a saturated brine for 24 d. The five remaining blocks of presalted and the five of the nonpresalted cheeses were submerged in a brine containing 18% salt for 8 d, and then they were moved to the saturated brine until 24 d. The blocks were kept submerged by placing a heavy gauge stainless steel mesh screen with a weight on top of the floating blocks. The size of the weight was selected so the blocks would not be pushed against the bottom of the tank. Several times each day the weight and the stainless steel screen were removed from the blocks, the brine was stirred, and the orientation of the blocks was rotated.

Preparation of Brine

Two brine solutions were prepared at 18°C for use in the study: one saturated and one at 18% salt. The

initial saturated brine (about 30%) used in this experiment was one that had been used for approximately 2 yr in the pilot plant for production of Ragusano cheese. Old saturated brine was used because it would contain a normal calcium content and pH, to avoid the effects of the softening of the cheese rind during the brining, the loss of the deep yellow color, and stickiness (Geurts et al., 1972) that occurs with a new brine that contains no calcium and high pH.

The 18% brine solution was prepared by removing some volume of the saturated brine and diluting with water to reach a concentration in salt of 18%. The pH of the 18% brine was adjusted by directly adding lactic acid to achieve the same pH as the saturated brine (about pH = 5.00). The new 18% brine was used for 2 wk to brine other blocks of Ragusano cheese before starting the experiment, in order to equilibrate the calcium content.

The final volumes of brine in the two tanks were the same (about 150 L). The saturated brine was kept saturated by leaving immersed a container full of salt. The nonsaturated was maintained at 18% NaCl by measuring salt concentration using a Baumé hydrometer (1 to 30° Bé) (Sacco s.r.l., Mi, Italy) and adding an appropriate amount of salt once each day. The temperature for both brines was kept constant at $18^{\circ}\text{C} \pm 2$, using a circulating refrigerated water bath (Neslab Instruments Inc., New Inghton, NH).

Milk for Cheese-making

Milk samples were collected from the stainless steel vat at 35°C , and they were tested for fat, crude protein, and lactose content using an infrared milk analyzer (AOAC, 2000; method number 33.2.31; 972.16), for SCC (AOAC, 2000; method number 17.13.01; 978.26), for the titratable acidity, and pH. The average raw whole milk used in three cheese-making sessions had an acidity of 0.153 g of lactic acid/100 ml and a pH of 6.69 at 35°C . The fat, crude protein, and lactose content were 3.35, 3.29, and 4.59%, respectively, with a content of somatic cells of 543,000/ml.

Sampling and Analysis of Cheese

Cheeses were sampled at 0 time (before brining), 1, 4, 8, 16, and 24 d. Each experimental block ($15.2 \times 15.2 \times 15.2$ cm) of Ragusano cheese, at the sampling day, was weighed and divided in four portions P1, P2, P3, and P4 (Figure 1). The exterior portion (P1) represented all six faces of the block (approximately 0.6 cm thick) and was 21.6% of the total block weight. The P2 portion was removed (approximately 1 cm thick), after removal of the P1 portion, from all the six faces of the block and

Figure 1. Division of a block ($15.2 \times 15.2 \times 15.2$ cm) of Ragusano cheese into four portions (P1, P2, P3, and P4) with P1 representing the exterior portion and P4 representing the portion in the center of a block.

Table 1. ANOVA model.

Independent variables	df	Analyzed as	Error term
Whole plot			
S ¹	1	Category	S × B × R
B ²	1	Category	S × B × R
R ³	2	Block	Model error
S × B	1	Interaction	Model error
S × B × R	6	Interaction	Model error
Subplot			
T ⁴	1	Continuous	Model error
T × S	1	Interaction	Model error
T × B	1	Interaction	Model error
T × T	1	Continuous	Model error
T × T × S	1	Interaction	Model error
T × T × B	1	Interaction	Model error
Error	54		

¹S = Impact of presalting.²B = Brine concentration.³R = Replicate.⁴T = Time.

was 29.5% of the total block weight. The P3 portion (approximately 1 cm thick) was removed next and represented about 21.1% of the total weight. The cube remaining of about 10 × 10 × 10 cm was the central portion (P4), representing about 27.8% of the total weight of the cheese block.

Each portion (P1, P2, P3, and P4) was weighed, cut into cubes, and grated. Expressible serum (represents the moisture in the cheese that is not bound to protein or tightly held by the protein matrix) was determined by centrifugation at 12,500 × *g* for 75 min (25°C) (Guo and Kindstedt, 1995). Moisture content was determined by drying a 3-g sample in a forced air oven at 100°C for 24 h (AOAC, 2000, method number 33.2.44; 990.20), the salt content by the Volhard method (AOAC, 2000, method number 33.7.10; 935.43), and the pH with a gel filled electrode (model: HA405—DXK—S8/120, Mettler Toledo Process Analytical Inc., Wilmington, MA).

Experimental Design and Statistical Analysis

Four treatments were included: 1) the traditional method using no presalting and saturated brine (**NPSB**), 2) presalting and saturated brine (**PSB**), 3) no presalting and 18% brine (**NP18%B**) for 8 d followed by 16 d in saturated brine, and 4) presalting and 18% brine (**P18%B**) for 8 d followed by 16 d in saturated brine. Cheese manufacture was replicated three times during 3 wk in March. The four treatments were made from the same milk on each day of cheese manufacture. Cheese blocks were sampled immediately before the brine salting and after 1, 4, 8, 16, and 24 d of brine salting for each of the four treatments.

Data were analyzed using the GLM procedure of SAS (version 8, 1999, SAS Institute, Cary, NC) using the split plot model shown in Table 1. The time was transformed as follows: time = d of brining – [(last testing day – first testing day)/2]. This transformation made the data set orthogonal with respect to time. This transformation directs the ANOVA model to consider the effect of presalting (S) and brine concentration (B) in the whole plot at the midpoint of time of brining (i.e., d 12).

RESULTS

Total Salt Content and Moisture Loss During Brining

During brine salting of cheese it is typical for blocks of cheese to lose weight (Geurts et al., 1974b, 1980). This behavior was observed in the present study. In 24 d of brine salting, all 3.5-kg blocks lost between 300 to 360 g of weight (Table 2). There was no impact of presalting on weight loss during brining, but there was an effect of brine concentration. The cheeses that were kept in saturated brine for 24 d lost ($P < 0.01$) more weight during brining than cheeses that were in 18% brine for the first 8 d (Table 3, Figure 2). There was a significant linear and quadratic effect of time on weight loss (Table 3, Figure 2) and there was a significant interaction of the quadratic effect of time and concentration of brine. After 24 d of brine salting the average weight loss, as a percentage of the initial block weight for all presalting and brining treatments, was 11.3% of the original weight. This would imply that the blocks shrunk to about 89.6% of their original size. This

Table 2. Weight in grams, from 0 to 24 d of brining, for portions P1, P2, P3, and P4 of each treatment: PSB, P18%B, NPSB, and NP18%B.¹

Days	P1	P2	P3	P4	Total weight	Original weight
PSB						
0	694	1095	807	982	3578	3584
1	910	888	691	999	3487	3551
4	934	928	658	891	3411	3582
8	975	932	636	768	3311	3542
16	916	856	616	796	3184	3559
24	845	919	601	786	3150	3522
P18%B						
0	694	1095	807	982	3578	3584
1	894	899	661	981	3435	3488
4	865	1021	628	878	3392	3507
8	901	972	757	759	3389	3540
16	832	887	668	904	3292	3601
24	785	801	713	900	3199	3675
NPSB						
0	847	1006	697	1002	3552	3559
1	1018	821	651	971	3461	3537
4	1090	765	666	864	3384	3550
8	945	846	652	834	3278	3557
16	947	871	613	749	3180	3519
24	985	792	543	815	3135	3530
NP18%B						
0	847	1006	697	1002	3552	3559
1	1008	888	626	941	3463	3522
4	911	953	624	879	3367	3498
8	761	1028	692	824	3305	3468
16	800	992	662	760	3214	3515
24	813	791	655	865	3124	3485

¹PSB = Presalting and saturated brine; P18%B = presalting and 18% brine; NPSB = no presalting and saturated brine; NP18%B = no presalting and 18% brine.

shrinkage is similar to that reported (86%) by Payne and Morison (1999) for Gouda cheese. The shrinkage does not occur uniformly within the block. Geurts et al. (1980) reported that at the exterior portion of the cheese decreased by 30% in volume. It is likely that a similar

Figure 2. Mean total weight loss (g) per 3.5-kg block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

shrinkage occurred at the surface of the blocks of cheese in our study.

The salt content in each portion of each block, by treatment, is shown in Table 4. The total salt content of the blocks of cheese was influenced ($P < 0.01$) by both presalting and the concentration of salt in brine (Table 3). Total salt content was higher (i.e., least square mean) for NP18%B and P18%B cheeses than NPSB and PSB cheeses (Table 5). The salt content increased with time of brining (Figure 3), and there was an interaction of brine concentration with both the linear and quadratic terms for days of brining (Table 3). It is interesting to note that if the background level of salt added (i.e., amount present at d 0 of brining) to the cheese for the two presalted treatments is subtracted, then the uptake of salt from brine is almost identical for the presalted and nonpresalted cheeses (Figure 3). It is also important to note that the cheese in the 18% brine for first 8 d took up more salt after both 8 and 24 d than cheeses held in the saturated brine for the full 24 d. The use of presalting combined with the 18% brine achieved a total salt content of 125 g in 8 d, while the traditional method of no presalting and saturated brine only achieved a salt content of 69 g in 8 d (Figure 3).

Table 3. Sums of the squares and probability values (in parentheses) for the ANOVA analysis of the impact of presalting (S) and brine concentration (B) on the total weight loss, total salt content, total moisture loss, and salt and moisture content (%) of a 15.2 × 15.2 × 15.2-cm block of Ragusano cheese.

Factors	df	Total weight loss (g)	Total salt content (g)	Total moisture loss (g)	Salt content (%)	Moisture content (%)
Whole plot						
S	1	7.026 (0.87)	4,577.991* (<0.01)	4,226.323* (0.03)	3.814* (<0.01)	0.143 (0.73)
B	1	23,995.928* (<0.01)	7,929.710* (<0.01)	4,337.180* (0.03)	6.696* (<0.01)	3.614 (0.11)
R ¹	2	14,386.750* (<0.01)	6,732.877* (<0.01)	35,018.550* (<0.01)	4.088* (<0.01)	7.564* (<0.01)
S × B	1	52.816 (0.75)	112.118 (0.28)	318.839 (0.56)	0.206 (0.10)	0.171 (0.64)
S × B × R	6	1,557.250 (0.82)	717.171 (0.28)	3,209.881 (0.75)	0.742 (0.15)	6.394 (0.25)
Subplot						
T ²	1	1,058,007.299* (<0.01)	141,491.602* (<0.01)	1,973,318.385* (<0.01)	150.246* (<0.01)	926.402* (<0.01)
T × S	1	425.153 (0.38)	363.795 (0.05)	1,575.506 (0.20)	0.324* (0.04)	0.113 (0.71)
T × B	1	499.243 (0.34)	4,967.466* (<0.01)	2,317.124 (0.12)	4.743* (<0.01)	2.568 (0.08)
T × T	1	69,211.996* (<0.01)	12,322.788* (<0.01)	139,943.165* (<0.01)	10.102* (<0.01)	46.902* (<0.01)
T × T × S	1	63.305 (0.73)	0.142 (0.97)	57.454 (0.80)	0.0001 (0.99)	0.221 (0.60)
T × T × B	1	6,000.488* (<0.01)	560.572* (0.02)	2,892.979 (0.08)	0.381* (0.03)	1.901 (0.13)
Total SS	71	1,259,526.764	208,763.101	2,333,337.579	206.583	1,081.704
Error	54	28,853.032	5,014.415	50,564.086	4.052	42.686
R ²		0.977	0.976	0.978	0.980	0.960

*Statistically significant ($P < 0.05$).

¹R = Replicate.

²T = Time.

Approximately 50% of the salt had been taken up by the cheese during the first 8 d.

The moisture content in each portion of each block, by treatment, is shown in Table 6. During brine salting of cheese it is typical for blocks of cheese to lose moisture (Geurts et al., 1974b, 1980). Both presalting and concentration of brine had an effect ($P < 0.05$) on total moisture loss (Table 3), but the absolute impact was small (Table 5). Total moisture loss for all of the 3.5-kg blocks was approximately 500 g in 24 d of brining (Figure 4). Nearly half of the moisture loss occurred during the first 8 d of brining.

Salt and Moisture Content of the Cheese During Brining

The percent salt in the cheese was influenced ($P < 0.01$) by both presalting and brine concentration (Table 3). Presalting and using less concentrated brine for the first 8 d of brining resulted in a higher least square mean percent salt in the block (Table 5). Presalting

produced a higher salt content in the cheese, particularly during the first 4 d of brining (Figure 5). The use of presalting combined with the 18% brine achieved a salt content of 3.69% in 8 d, while the traditional method of no presalting and saturated brine only achieved a salt content of 2.09% in 8 d (Figure 5). The 18% brine produced a higher salt content of cheese at 24 d, regardless of presalting or not presalting.

The percent moisture in the cheese was not influenced by either presalting or brine concentration (Table 3). Average moisture content of the blocks of cheese for all treatments decreased greatly (about 10 to 11%) during 24 d of brining (Figure 6). Moisture decreased from about 45 to 34%, with about 6% of the 10 to 11% decrease in moisture occurring during the first 8 d.

Moisture, Salt, pH, and Expressible Serum Within Blocks During Brining

The salt content of brine salted cheeses varies systematically from the surface to the center of each block.

Table 4. Percent salt content, from 0 to 24 d of brining, for portions P1, P2, P3, and P4 of each treatment: PSB, P18%B, NPSB, and NP18%B.¹

Days	P1	P2	P3	P4
PSB				
0	1.207	1.207	1.147	1.183
1	3.257	1.513	1.100	1.060
4	4.680	3.047	1.623	1.153
8	5.027	3.760	2.293	1.353
16	5.560	4.530	3.590	2.173
24	5.750	5.273	4.300	2.880
P18%B				
0	1.207	1.207	1.147	1.183
1	3.680	1.657	1.017	0.983
4	5.333	3.437	1.900	1.230
8	5.733	4.400	2.580	1.350
16	7.453	6.370	4.837	3.017
24	7.867	7.033	5.780	3.687
NPSB				
0	0.187	0.167	0.170	0.177
1	1.930	0.367	0.087	0.047
4	3.077	1.580	0.393	0.190
8	3.897	2.477	1.203	0.370
16	4.917	3.800	2.537	1.083
24	5.300	4.470	3.567	1.967
NP18%B				
0	0.187	0.167	0.170	0.177
1	2.783	0.530	0.127	0.070
4	4.587	2.413	0.843	0.193
8	5.637	4.207	2.027	0.517
16	7.163	5.830	3.707	1.270
24	7.420	6.553	5.070	2.663

¹PBS = Presalting and saturated brine; P18%B = presalting and 18% brine; NPSB = no presalting and saturated brine; NP18%B = no presalting and 18% brine.

Guinee and Fox (1986) demonstrated that salt content varies from the center to the outside surface (high at the surface and low in the center) of cheese at the end of brining and that the gradient of salt content is different depending on the geometry of the block of cheese. Licitra et al. (2000) also found very large gradients in moisture and salt content in Ragusano cheese after 180 d of aging, but it was not clear if the moisture gradient developed mostly during aging after brining, or during the brining step.

Moisture. Presalting had no detectable impact on moisture content of cheese in any location within the

Figure 3. Mean total salt content (g) per block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

block (Table 7). In position P1, the 18% brine caused a higher ($P < 0.01$) moisture (least square mean = 34.27%) than the saturated brine (least square mean = 32.34%) (Figure 7), regardless of presalting or not presalting. The moisture content of the exterior portion of the block (P1), for all treatments, decreased from about 42% to about 26% during 24 d of brining. Most of the decrease (from 42 to 32%) in moisture in blocks in saturated brine occurs during the first 4 d of brining. This may have important impacts on the structure and permeability of the cheese block to salt. The cheese held for 8 d in 18% brine did not reach 32% moisture in portion P1 until approximately 12 d of brining. At 8 d, the cheese in 18% salt brine contained about 34.5% moisture in portion P1, while the cheese in saturated brine contained 30.5%. Loss of moisture from the structure of cheese generally causes the cheese to shrink (Geurts et al., 1974b). Therefore, the portion P1 of the blocks of cheese in saturated brine at d 8 would be more compact than the portion P1 of the blocks of cheese in 18% brine. This more compact layer at the surface of the block develops very early for the cheese in saturated brine and then may act as a barrier to moisture and

Table 5. ANOVA least square means for the impact of presalting and brine concentration on total weight loss (g), salt content (g), moisture loss (g), and salt content (%).

	Presalting		Brine	
	Yes	No	Saturated	18%
Total weight loss (g)	179.76	181.99	199.52 ^a	162.23 ^b
Total salt content (g)	107.24 ^a	76.08 ^b	79.68 ^b	103.64 ^a
Total moisture loss (g)	287.00 ^a	258.07 ^b	279.20 ¹	265.87 ¹
Total salt content (%)	3.24 ^a	2.35 ^b	2.44 ^b	3.15 ^a

^{a,b}Least square means different at $P < 0.01$ level.

¹Least square means different at $P = 0.07$ level.

Figure 4. Mean total moisture loss (g) per 3.5-kg block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

Figure 5. Mean salt concentration (%) per block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

salt movement throughout the remaining time of brine salting. The cheese in the 18% brine maintains a higher moisture in portion P1 during the first 8 d, so there is less barrier to moisture and salt movement. This al-

Table 6. Percent moisture content, from 0 to 24 d of brining, for portions P1, P2, P3, and P4 for each treatment: PSB, P18%B, NPSB, and NP18%B.¹

Days	P1	P2	P3	P4
PSB				
0	42.433	44.933	45.067	45.133
1	36.333	43.333	44.400	44.567
4	31.600	39.567	43.500	44.533
8	30.600	37.500	42.233	44.333
16	26.800	34.367	38.667	42.200
24	25.767	32.400	36.533	40.233
P18%B				
0	42.433	44.933	45.067	45.133
1	37.533	43.100	44.567	45.000
4	35.233	40.300	43.367	44.833
8	34.733	38.167	41.667	43.300
16	28.800	33.400	37.267	41.700
24	27.533	31.533	34.733	39.467
NPSB				
0	41.933	44.500	44.500	44.600
1	37.300	43.667	44.433	44.567
4	32.133	40.100	42.900	44.000
8	30.233	38.833	42.000	44.200
16	27.100	34.933	39.867	42.833
24	25.867	33.800	37.533	41.200
NP18%B				
0	41.933	44.500	44.500	44.600
1	38.800	44.200	45.300	45.433
4	34.467	39.867	43.133	44.500
8	34.367	38.100	41.767	45.000
16	28.467	32.867	37.167	41.967
24	26.933	31.300	34.800	39.367

¹PSB = Presalting and saturated brine; P18%B = presalting and 18% brine; NPSB = no presalting and saturated brine; NP18%B = no presalting and 18% brine.

lowed more salt uptake in the first 8 d by the cheese in 18% brine than those in saturated brine (Figure 3). However, at d 8 when the cheeses were switched from 18% brine to saturated brine, the moisture content of those cheeses decreased more rapidly from d 8 to 16 than the cheeses that were in saturated brine from d 0 (Figure 6). It is likely that for the cheeses in 18% brine, portion P1 became more compact between d 8 and 16 due to the more rapid loss of moisture caused by the saturated brine (Figure 7). At this point (i.e., between d 8 and d 16), the barrier properties of position P1 of the cheeses became more similar.

The cheese in portion P2 (Figure 8) also decreased in moisture with time of brining, but the change with time was more linear than in portion P1 (Figure 7).

Figure 6. Mean moisture concentration (%) per block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

Table 7. Sums of the squares and probability values (in parentheses) for the ANOVA analysis of the impact of presalting (S) and brine concentration (B) on moisture content of the portions P1, P2, P3, and P4 of a $15.2 \times 15.2 \times 15.2$ -cm block of Ragusano cheese.

Factors	df	P1	P2	P3	P4
Whole plot					
S	1	0.152 (0.74)	0.600 (0.58)	0.213 (0.65)	1.829 (0.19)
B	1	62.109* (<0.01)	2.426 (0.29)	7.168* (0.03)	0.340 (0.55)
R ¹	2	10.361 (0.25)	8.685* (0.05)	11.787* (<0.01)	12.946* (<0.01)
S $\times$ B	1	0.681 (0.66)	2.347 (0.20)	0.087 (0.76)	0.101 (0.67)
S $\times$ B $\times$ R	6	7.680 (0.91)	10.807 (0.28)	5.788 (0.41)	5.099 (0.19)
Subplot					
T ²	1	1,612.978* (<0.01)	1,345.422* (<0.01)	776.222* (<0.01)	223.462* (<0.01)
T $\times$ S	1	0.337 (0.76)	0.268 (0.66)	1.725 (0.18)	1.273 (0.14)
T $\times$ B	1	0.004 (0.97)	10.166* (<0.01)	18.629* (<0.01)	6.623* (<0.01)
T $\times$ T	1	216.940* (<0.01)	90.076* (<0.01)	1.262* (0.25)	6.236* (0.02)
T $\times$ T $\times$ S	1	0.071 (0.88)	0.007 (0.94)	0.002 (0.96)	0.808 (0.24)
T $\times$ T $\times$ B	1	16.922* (0.04)	0.041 (0.86)	0.068 (0.79)	10.139 (0.62)
Total SS	71	2,245.657	1,619.395	885.616	283.553
Error	54	196.967	75.671	49.842	30.566
R ²		0.912	0.953	0.944	0.892

*Statistically significant ($P < 0.05$).

¹R = Replicate.

²T = Time.

There was a significant interaction of time $\times$ brine concentration in portion P2 (Table 7), with the 24-d-old cheeses in saturated salt brine having a higher mois-

ture content (approximately 34%) than cheeses held in 18% brine for the first 8 d (approximately 31.4%) (Figure 8). This relationship between moisture and brine

Figure 7. Mean moisture (%) in the P1 portion of the block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

Figure 8. Mean moisture (%) in the P2 portion of the block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

Figure 9. Mean moisture (%) in the P3 portion of the block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

treatment is the opposite of that observed for portion P1. The more compact layer of cheese at the surface of the block in portion P1 for cheeses placed in saturated brine at d 0, begins to act as a barrier to movement of water out of the block and movement of salt into the block. All three positions (P2, P3, and P4) clearly show the effect of the barrier. The cheeses in saturated brine for 24 d had a higher moisture content in these positions (Figures 8, 9, and 10), with the largest impact in position P3.

Salt. There was a significant impact of presalting on overall salt content of portions P2, P3, and P4 ($P < 0.01$), and there was a less pronounced effect ($P < 0.06$) of presalting for portion P1 (Table 8). In general, the salt content of the presalted blocks was higher than blocks that were not presalted (Table 5). Figures 11 to 14 are

Figure 10. Mean moisture (%) in the P4 portion of the block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

the same data as those in Table 4 for percent salt in the cheese by portion, but the contribution of the salt from the presalting treatment has been subtracted from the data. This allows the effect of brine concentration on salt uptake by the blocks and salt content to be seen more clearly. In portions P1 to P4 (Figures 11 to 14), the percent salt due to uptake from the saturated brine was similar for presalted and nonpresalted cheeses. For 18% brine, the percent salt due to uptake was much higher than from saturated brine, particularly for portions P1, P2, and P3 (Figures 11, 12, and 13). In portion P1 and P2, it appeared that the uptake of salt was higher in the cheese that was not presalted, particularly after 8 d when all the cheeses were in saturated brine. In portion P1, between 8 and 16 d there was a large decrease in moisture (Figure 7), which corresponded to a larger increase in percent salt taken up in the cheeses in 18% brine than those in saturated brine (Figure 11). From d 16 to 24, the increase in percent salt taken up in these cheeses is slower because the cheese in position P1 has contracted due to the moisture loss and then acted as a barrier to more rapid salt uptake. The impact of 18% brine on the percent salt due to uptake can be seen clearly in portion P3 (Figure 13), but it is not as strong in portion P4 by 24 d (Figure 14). It is likely that after the cheese is removed from the brine and continues to age, there will be some further diffusion of salt into the interior of the cheese from portions P1 and P2.

pH and Expressible Serum. The pH of all cheeses for all portions were in the range of 5.0 to 5.3. The ANOVA models for the impact of presalting and brine concentration on cheese pH during 24 d of brining generally explained less than 40% of the variation in the data. Thus, no significant impacts of presalting or brine concentration on cheese pH were detected (data not shown). The ANOVA data for the impact of presalting and brine concentration on expressible serum are shown in Table 9. No impact of presalting and very little impact of brine concentration were detected. The most important observation is the strong impact of both the linear and quadratic terms of time in the ANOVA for the expressible serum data (Table 9). Relative differences in expressible serum among treatments and changes with time are a reflection of the ease with which water and salt can move within the cheese. A decrease in expressible serum indicates moisture and salt will move less easily. The expressible serum content of the cheese in all portions decreases rapidly during the first few days of brining (Figures 15 to 18). The expressible serum at d 0, just before brining, was lower for all treatments in portion P1 (Figure 15) than for the other three portions (Figures 16, 17, 18). This was due to absorption of water from the surface of the blocks by

Table 8. Sums of the square and probability values (in parentheses) for the ANOVA analysis of the impact of presalting (S) and brine concentration (B) on salt content of the portions P1, P2, P3, and P4 of a 15.2 × 15.2 × 15.2-cm block of Ragusano cheese.

Factors	df	P1	P2	P3	P4
Whole plot					
S	1	1.903 (0.06)	2.983* (<0.01)	5.432* (<0.01)	7.291* (<0.01)
B	1	17.042* (<0.01)	13.911* (<0.01)	4.423* (<0.01)	0.417* (<0.01)
R ¹	2	5.167* (<0.01)	6.979* (<0.01)	4.558* (<0.01)	2.439* (<0.01)
S × B	1	0.896 (0.22)	0.534 (0.06)	0.076 (0.49)	0.044 (0.55)
S × B × R	6	2.171 (0.71)	1.059 (0.35)	0.228 (0.96)	0.053 (0.99)
Subplot					
T ²	1	22.919* (<0.01)	232.060* (<0.01)	167.372* (<0.01)	47.863* (<0.01)
T × S	1	1.209 (0.15)	0.696* (0.04)	0.095 (0.44)	0.04 (0.55)
T × B	1	8.053* (<0.01)	9.037* (<0.01)	5.601* (<0.01)	1.547* (<0.01)
T × T	1	48.446* (<0.01)	20.509* (<0.01)	0.510 (0.08)	1.479* (<0.01)
T × T × S	1	0.095 (0.69)	0.054 (0.55)	0.058 (0.55)	0.092 (0.38)
T × T × B	1	0.970 (0.20)	1.160* (<0.01)	0.088 (0.46)	0.022 (0.67)
Total SS	71	355.975	326.558	212.975	79.458
Error	54	31.443	8.386	8.649	6.433
R ²		0.912	0.974	0.959	0.919

*Statistically significant ($P < 0.05$).

¹R = Replicate.

²T = Time.

Figure 11. Mean salt (%) in portion P1 of the block with background level of salt from presalting treatment subtracted. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

Figure 12. Mean salt (%) in portion P2 of the block with background level of salt from presalting treatment subtracted. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

Figure 13. Mean salt (%) in portion P3 of the block with background level of salt from presalting treatment subtracted. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

the wooden forms used to shape the cheese for 22 h after stretching. Thus, the moisture content of P1 at d 0 was about 2 to 3% lower than P2, P3, and P4 at d 0 (Table 6). Generally, the decrease in expressible serum occurs faster at the exterior of the cheese (P1, Figure 15) than in the interior (P4, Figure 18). The expressible serum decreased to zero in all positions by about 8 d of brining.

DISCUSSION

Role of Salt in Cheese

The addition of salt to cheese probably evolved, from a historical perspective, because it helped prevent spoilage and made it possible to store the valuable nutrients of milk in a concentrated form. The addition of salt

during the cheese-making process can be either by direct addition of dry salt before blocks or wheels are formed or after block formation by immersion of the blocks in a concentrated salt solution. Dry salting results in a uniform distribution of salt within a block of cheese, while brine salting creates a gradient of salt content from the outside to the center of each block (Guinee and Fox, 1986), which persists even after 180 d of aging (Licitra et al., 2000).

Salt concentration in cheese influences many of the chemical, enzymatic, and microbiological processes that occur during cheese aging that create the typical flavor and texture of each cheese variety. The presence of salt in the aqueous phase of cheese promotes the extraction of intact caseins from the casein matrix into solution in the water phase of the cheese (Guo et al., 1997) and makes these caseins more available for proteolysis. The addition of salt can also affect the distribution of some enzymes within the structure of cheese. In milk, the enzyme plasmin is bound in the casein micelles and therefore remains bound in the casein matrix of the curd at the point of separation of curd from whey (Politis et al., 1992). As the pH of the curd decreases and salt is added, plasmin is transferred from the casein matrix into the aqueous phase of the cheese (Grufferty and Fox, 1988). The rate of casein breakdown during cheese aging decreases as salt concentration in the aqueous phase of the cheese increases (Thomas and Pearce, 1981). Addition of salt to cheese decreases water activity and generally has an inhibitory effect on both desirable and undesirable bacteria present in cheese (Marcos, 1993). Addition of dry salt to Cheddar type cheeses, in combination with a decrease in temperature, stops production of acid by starter culture bacteria (Lawrence and Gilles, 1982). Generally, cheeses with very high salt content remain firmer and develop less flavor during aging.

Factors Influencing Salt Uptake During Brining

Typically, a saturated sodium chloride brine is used for brine salting cheese. The temperature of brine salting varies depending on the type of cheese. Many factors influence the rate at which salt will penetrate a block or wheel of cheese. The size and shape of a block of cheese will influence the rate of salt penetration, with smaller cheeses and cheeses with flat surfaces taking up salt faster than larger cheeses and cheeses with cylindrical shapes (Guinee and Fox, 1986). Geurts et al. (1974b) and Resmini et al. (1974) found that cheese (Gouda and Parmigiano Reggiano, respectively) absorbed salt more rapidly from higher temperature brine (i.e., 18 to 20°C) than lower (i.e., 12.5 to 13°C) temperature brine and that salt diffusion in the water phase of

Figure 14. Mean salt (%) in portion P4 of the block with background level of salt from presalting treatment subtracted. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

Table 9. Sums of the squares and probability values (in parentheses) for the ANOVA analysis of the impact of presalting (S) and brine concentration (B) on expressible serum content of the portions P1, P2, P3, and P4 of a $15.2 \times 15.2 \times 15.2$ -cm block of Ragusano cheese.

Factors	df	P1	P2	P3	P4
Whole plot					
S	1	0.0189 (0.65)	0.434 (0.55)	0.319 (0.60)	0.001 (0.99)
B	1	1.355* (<0.01)	0.005 (0.95)	0.099 (0.77)	0.205 (0.85)
R ¹	2	19.631* (0.02)	48.175* (<0.01)	50.052* (<0.01)	49.304* (<0.01)
S × B	1	0.188 (0.77)	0.106 (0.86)	0.949 (0.61)	0.801 (0.63)
S × B × R	6	0.488 (0.99)	6.638 (0.93)	6.346 (0.94)	32.588 (0.17)
Subplot					
T ²	1	55.091* (<0.01)	268.146* (<0.01)	369.622* (<0.01)	424.725* (<0.01)
T × S	1	0.452 (0.66)	4.133 (0.28)	2.497* (<0.01)	1.023 (0.59)
T × B	1	0.026 (0.92)	0.000 (0.99)	0.425 (0.74)	0.000 (0.99)
T × T	1	36.962* (<0.01)	192.737* (<0.01)	248.588* (<0.01)	238.477* (<0.01)
T × T × S	1	0.301 (0.72)	0.309 (0.77)	0.151 (0.84)	0.378 (0.74)
T × T × B	1	0.904 (0.54)	0.005 (0.97)	0.444 (0.73)	0.184 (0.82)
Total SS	71	250.716	761.184	939.241	995.910
Error	54	126.901	190.136	197.682	185.831
R ²		0.493	0.750	0.789	0.813

*Statistically significant ($P < 0.05$).

¹R = Replicate.

²T = Time.

cheese was much slower than for salt diffusion in pure water. Resmini et al. (1974) also found that salt uptake was faster when a nonsaturated brine (approximately

16%) was used for the first 5 to 6 d of brining followed by a saturated brine until 24 d. The pH and calcium content of brine can also influence salt uptake and the

Figure 15. Mean expressible serum (g/100 g cheese) in the P1 portion of the block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

Figure 16. Mean expressible serum (g/100 g cheese) in the P2 portion of the block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

Figure 17. Mean expressible serum (g/100 g cheese) in the P3 portion of the block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

surface characteristics of the cheese. Geurts et al. (1972) found that a brine pH (about 5.00) similar to the cheese pH and a calcium concentration in brine of about 0.5 to 0.6% was necessary to avoid soft rind defects and abnormal uptake of salt in Gouda cheese.

When salt penetrates cheese, during brine salting, there is a movement of water out the block of cheese into the brine (Geurts et al., 1974b). Generally, the weight of water expelled from the block is larger than the weight of salt taken up. Predication of the rate of penetration of salt into cheese during brine salting (i.e., diffusion coefficient) has been mathematically modeled by many investigators (Geurts et al., 1974b, 1980; Guinee and Fox, 1983; Luna and Chavez, 1992; Payne and Morison, 1999; Turhan and Gunasekaran, 1999). Factors within a block of cheese that influence the rate

at which salt can move from the exterior surface to the center of the block are: porosity of the cheese, tortuosity of the channels of water within the structure of the cheese, proportion of water that is bound in cheese, viscosity of the free water portion of the cheese, and interaction of sodium with the protein matrix. The porosity of cheese is influenced by its moisture content. In two cheeses of the same type, the cheese with higher moisture content absorbs salt more rapidly (Geurts et al., 1974b), because it has a higher porosity. Salt travels from the exterior surface to the center of a block of cheese within the water phase of the cheese. Salt cannot travel through the protein matrix or the fat phase of cheese. Thus, the higher the moisture content of a cheese, the more porous the structure. The higher the degree of tortuosity of the channels of water within structure of a block of cheese, the more slowly salt will penetrate the block (Geurts et al., 1974b). Some cheese manufacturing factors could influence the tortuosity of the water channels within the microstructure of cheese. Pasta filata cheeses, Mozzarella, for example, have a fibrous structure with a definite orientation of fibers and channels of water (Oberger et al., 1993). This structure could influence the rate of salt penetration in these types of cheeses during brine salting.

Not all the moisture within the microstructure of cheese is available as a medium for movement of salt. Geurts et al. (1974a) estimated that about 0.10 to 0.15 g of water per gram of protein is bound to the protein in cheese. The bound water at the interfaces of the casein matrix and water phase of the cheese effectively reduces porosity and increases tortuosity. The viscosity of the free water phase of cheese is higher than pure water. The water phase of the cheese contains dissolved minerals, lactose, lactic acid, intact proteins, and proteolysis products. Guo et al. (1997) reported that the protein content of the expressible serum from Mozzarella cheese increased with time of storage and salt content from about 3% crude protein to nearly 10% crude protein over a period of 10 d after manufacturing. Increases in protein concentration and concentration of calcium in the water phase of cheese could make large changes in the viscosity of the water phase. The viscosity of the water phase would also be temperature dependent, with lower brining temperatures favoring higher viscosity (Payne and Morison, 1999) and slower salt penetration. The typical brine temperature during the first 3 to 8 d of brining is 18°C, as used in the present study. Changing brine temperature might be another parameter (in future research) that could be used in addition to reducing brine concentration, to reduce the frequency of early gas defects. A lower temperature may reduce growth of gas producing bacteria but it could also reduce the rate of salt penetration into the cheese. While so-

Figure 18. Mean expressible serum (g/100 g cheese) in the P4 portion of the block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

dium chloride has a relatively small molecular size compared with the pore sizes within the matrix of the cheese, the sodium ions can displace calcium ions from the casein matrix and interact with negatively charged side groups of the casein. The exchange of sodium ions for calcium ions on the matrix (Payne and Morison, 1999) may also impede the rate of movement of salt into the cheese.

Impact of Presalting and Brine Concentration on Salt Uptake

Ragusano cheese is still produced today using the traditional manufacturing technology on farms (Licitra et al., 1998). The cheese is brine salted for 3 to 8 d on the farm and then transported to an aging center for further brining. A slow rate of salt uptake during the first 8 d of brining can increase the frequency of quality defects, particularly gas production. Therefore, presalting of the cheese before stretching and use of brine that was not fully saturated were investigated as potential approaches to achieve higher salt content throughout the cheese in a shorter time.

Presalting. Presalting of pasta filata cheese before stretching can be a useful approach to obtain blocks of uniform composition and to quickly establish a normal salt concentration throughout the cheese. This technique has been demonstrated for Mozzarella cheese (Barbano et al., 1994). Presalting of Ragusano cheese before stretching was used to achieve a partial incorporation of salt into the block prior to brine salting. The NPSB treatment represents the current commercial approach used for salting Ragusano cheese and achieves about 1.97% salt in the center (P4) of the block in 24 d (Table 5). Presalting achieved about 1.20% salt content in the PSB cheese in all four positions at d 0, compared with about 0.18% salt in the NPSB treatment. Presalting contributed approximately one third of the final salt at 24 d in the NPSB treatment at d 0 (Figure 5). However, the proportion contribution of the presalt to the final salt content within different portions of the block was different. The salt provided by presalting represented about 23% (at d 0) of the final salt that would normally be present at 24 d in the P1 portion of the NPSB treatment and about 60% of the salt that would normally be present in portion P4 of the NPSB treatment (Table 5). Thus, presalting could be a practical technique that could be used at the farm to achieve about 60% of the final salt content of P4 portion of the cheese on d 0 and have the potential for reducing quality defects associated with slow salt penetration during brining.

Brine salting. Resmini et al. (1974) reported that use of brine at concentrations below saturation in-

creased the rate of salt uptake in cheese. This observation is of practical importance for Ragusano cheese because it would be a relatively simple technological change that could be done at a farm level. The rate of salt penetration (Table 3) was faster ($P < 0.01$) for the cheeses held in 18% brine for the first 8 d, than for cheeses held in saturated brine and the weight of the block was increased by salt uptake (Figures 3 and 5). The final salt content of the cheese after 24 d of brining was higher ($P < 0.01$, Table 3) for treatments (P18%B and NP18%B, Figure 5) using 18% brine for 8 d followed by 16 d in saturated brine than the treatments (PSB and NPSB, Figure 5) using saturated salt brine for all 24 d. At the same time, the blocks of the treatments (PSB and NPSB, Figure 5) using saturated salt brine for all 24 d, lost more moisture (Figures 4 and 6) than they took up in salt, resulting in a net loss of weight (Figure 2). These results are consistent with those of Resmini et al. (1974).

Why did the cheese in the 18% brine for the first 8 d take up more salt than the cheese that was in the saturated brine for the full 24 d? To understand this, it is necessary to look carefully at the changes in salt and moisture content within individual portions of the blocks in different treatments throughout the 24 d brining period. In nonpresalted cheeses, all of the salt that is in portion P4 to d 24 had to pass through portions P1, P2, and P3. Therefore, changes that occur in the outer portions of the block during the first 8 d of brining may have a profound influence on the rate and total of salt uptake during a fixed period of time. The moisture content of portion P1 of the blocks of cheese at d 8 was influenced greatly ($P < 0.01$) by the concentration of brine (Table 7). Cheeses, regardless of presalting treatment, in 18% brine contained about 4% more moisture in the portion P1 than cheese in saturated brine (Figure 7). This difference is also reflected in the difference in total weight loss (Figure 2) and moisture loss (Figure 4) from the blocks. Cheese with higher moisture would have a more porous structure and allow easier penetration of salt (Geurts et al., 1974b). After 24 d of brining, the salt uptake for the 18% brine treatments (P18%B and NP18%B) in all portions (P1, P2, P3, and P4) was higher than for saturated brine (Figures 11 to 14). At d 8 the cheeses in 18% brine were transferred to the saturated brine and this caused a decrease in moisture content of the P1 portion of the cheeses in the P18%B and NP18%B treatments between 8 and 16 d of brining (Figure 7). This decrease in moisture would have caused shrinkage of the structure of the P1 portion of the cheese and decreased its porosity. After this decrease in porosity, the salt uptake by these cheeses (Figure 11, d 16 to 24) became slower.

Figure 19. Mean salt in moisture (%) in the P1 portion of the block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

Figure 20. Mean salt in moisture (%) in the P2 portion of the block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

The cheeses in saturated brine rapidly decreased in porosity near the surface because of the moisture loss from the P1 portion that occurred during the first 4 d (Figure 7). This change in structure of the cheese in the P1 portion created a barrier to entrance of salt from the brine and exit of moisture from the interior portions of the block of cheese for those cheeses in saturated brine. Portion P1 became a barrier to moisture movement out of the block as can be seen in Figures 8 to 10. In portions P2, P3, and P4, the saturated brine treatments (PSB and NPSB) had higher moisture than the 18% salt brine treatments, which is opposite of the trend in portion P1. This same barrier that did not let moisture move out of the block also became a barrier to salt penetration into the block in portions P2, P3, and P4, as seen in Figures 12 to 14. The use of 18% brine during the first 8 d of brining created less of barrier to salt and moisture movement through portion P1 (i.e., exterior surface) and allowed more rapid penetration of salt into the block and more total salt uptake (Figures 3 and 5). Therefore, the use of 18% brine delayed the shrinkage of the exterior portion of the block and the development of barrier to salt and moisture movement. Shrinkage of the exterior portion of the block would also increase the concentration of solutes in the water phase of the cheese and increase the tortuosity in portion P1. These results are consistent with the idea of formation of a barrier to moisture and salt migration at the surface of the block, as proposed by Resmini et al. (1974).

Presalting by brine concentration interaction. Presalting increases the salt concentration in the aqueous phase of the cheese at time zero, as can be seen for portions P1, P2, P3, and P4 in Figures 19 to 22. The effect is the same for all portions. It might be expected that this increase in osmotic strength of the water phase of the cheese might reduce the rate of salt uptake into

the blocks of the presalted cheeses because of the decreased osmotic gradient from the exterior surface to the center of the block of cheese. No significant decrease in rate of uptake of salt due to presalting was observed for either brine treatment. The salt in moisture content created by presalting is low (approximately 2.5 to 3%) compared with the salt in moisture content of the brine. In addition, even after 24 d of brining the salt in moisture content of the P4 portions is still quite low relative to the brine concentration (Figure 22). The salt concentration in the moisture phase of portion P1 at 24 d for the P18%B and NP18%B treatments (Figure 19) approached the concentration of salt in the saturated brine. Thus, the impact of presalting on the osmotic gradient is fairly small even though the presalting delivers about 60% of normal final salt concentration of portion P4 on d 0.

Figure 21. Mean salt in moisture (%) in the P3 portion of the block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

Figure 22. Mean salt in moisture (%) in the P4 portion of the block. Treatment are PSB (●), P18%B (■), NPSB (▲), and NP18%B (□).

Practical Implications

Even though the results presented in this paper are for 3.5-kg blocks of cheese, based on our previous work (Licitra et al., 2000) we expect that the same trends and relationships for moisture and salt movement will occur in the traditional 15- to 16-kg blocks, which are 15 × 15 × 50 cm. Partial presalting of Ragusano cheese before stretching could be beneficial because it can deliver 60% of the final salt content to the center of the block at d 0 without changing the rate of salt penetration into the block during brining. This is a more important point than it might seem with respect to texture, because a gradient of moisture (and therefore texture) from the outside to the center of the block of cheese would still be developed in cheeses that were presalted. The use of presalting combined with the use of 18% brine could achieve a similar concentration of salt in moisture in 8 to 12 d in all portions of cheese, instead of the 24 d that are required in the NPSB (traditional) treatment (Figures 19 to 22). Looking at Figure 6, this salt concentration would be achieved at a moisture content for the block of about 37.5% at 8 to 12 d at 18°C. Another strategy to control microbial growth in the cheese might be to decrease the temperature (which would reduce the rate of salt penetration, Geurts et al., 1974b) of the 18% brine and keep the total brining time the same as without presalting and 18% brine. The lower temperature of brining might have a further beneficial impact of reducing the growth of undesirable microorganisms in the cheese that produce gas defects.

Presalting of cheese before stretching and use of 18% brine, prior to transporting blocks of cheese to an aging center, are practical changes that could be implemented at a farmhouse cheese-making facility that could have a major impact on reducing the frequency of quality

defects caused by growth of undesirable bacteria. The typical desirable flavors and texture of Ragusano cheese are created by a combination of the characteristics of the milk and the action of microorganisms and enzymes present in the cheese. The impact of presalting and use of 18% brine on the microbiological, chemical, and sensory characteristics of Ragusano cheese during aging needs to be investigated.

CONCLUSIONS

Presalting was able to deliver 60% of the normal level of salt in the center of the block of cheese before the beginning of brine salting without decreasing the rate of uptake of salt from either saturated brine or brine that was not fully saturated. Use of 18% salt brine for the first 8 d of 24 d of brine salting increased the rate of salt uptake, compared with the cheese in saturated brine 24 d. The increased rate of salt uptake with 18% brine compared with saturated brine was related to the impacts of salt brine on the moisture content and porosity of the cheese near the surface of the block. Brine with higher salt content causes a rapid loss of moisture from cheese near the surface of the block. The loss of moisture causes a shrinkage of the structure of the cheese and decrease in porosity, which impedes moisture movement out of the block and salt movement into the block. The use of 18% brine for the first 8 d of brining delayed the moisture loss and shrinkage of the cheese at the exterior of the block and allowed more penetration of salt.

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