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Process Development of Mozzarella Farm Cheese from Buffalo Milk

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Abstract

The objective of this research was to improve and develop the process of mozzarella cheese manufacturing from buffalo whole milk. Qualities of buffalo raw milk and manufacturing conditions were studied and included curd cutting time (0-75 min), cooking temperature (43, 45 or 47°C) and pre-stretched curd pH (5.1 and 4.9). The qualities of buffalo farm milk met the buffalo milk standards (TAS 6007-2021). A 10 kg pasteurized milk was inoculated with lactic acid bacteria at 40ºC and 0.1 g rennet was added after achieving 0.1 pH decrease in milk. Inoculation starter culture and rennet enzyme caused the pH to drop and milk coagulum to occur. The pH of cultured milk decreased with increasing hardness of milk curd after renneting. At 60 min after renneting the milk curd was suitable for cutting. Low cooking temperature (43°C) prevented cheese curds to coalesce. On the other hand, cooking the cheese curds at a higher temperature (47°C) promoted hardening of the cheese curds. While cooking temperature at 45°C the cheese curds were soft, agglomerated with good stretchability. Chemical compositions of cheese from pre-stretched curd pH 5.1 or 4.9 was similar. Textural quality in terms of hardness and chewiness of pre-stretched curd pH 5.1 were better than that of pH 4.9. The pre-stretched curd pH 5.1 had a better stretchability quality compared to pH 4.9. Recommended manufacturing conditions for mozzarella farm cheese were 60-min curd cutting time, 45°C cooking temperature and pre-stretched curd pH 5.1, respectively.

Introduction

Milk production and the processing industry play important roles in driving Thailand's economy. Thailand's dairy industry is growing along with advance in science and technology in terms of varieties, quality and safety of dairy products. Cow milk is the major raw material for the products, however insufficient raw milk production is a limitation for the development of Thailand's dairy industry. Dairy industry operators seek new sources of raw milk such as goat, sheep and buffalo milk, along with the development of processing to add value to new lactations, as a method to reduce importing dairy products. Especially cheese, which is in

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high demand in the food service industry. At present, local consumption of dairy products which includes foreigners residing in Thailand is increasing. Domestic cheese products are produced by large and small entrepreneurs. Mozzarella is the most popular cheese for the food service industry and related food processors such as pizza and bakery industry. Appropriate technology for producing mozzarella cheese helps small and medium enterprise (SME) to develop their cheese derived from the local milk supply.

Imported mozzarella cheese is sold in most markets in Thailand and is packed in brine as a soft fresh type of mozzarella cheese. Stretchability of heated mozzarella cheese is the most desired and accepted as a good cheese produced from buffalo milk. The texture of mozzarella cheese is influenced by manufacturing steps such as milk standardization, homogenization, cooking time and temperature, as well as pH of curds and stretching temperature. (Jana & Mandal, 2011; Paz et al., 2017). Cheese milk with high fat-to-protein ratio yields a softer cheese than that of higher protein milk. Low fat-to-protein ratio milk released some oil during the baking of the cheese (Guinee et al., 2000). Low-fat mozzarella cheese was harder in texture or springier than the full-fat cheese and showed poor melting characteristics (Tunick, 1991; Lefevere et al., 2000; Zisu & Shah, 2007).

Yazici et al. (2010) reported that curd pH at whey drainage was important to curd's ability to be laminated and stretched in hot water. While Paz et al. (2017) noted whey drainage at a low pH (around pH 5.0 - 5.3) which offered low hardness cheese with long and thin threads microstructure creating a distinctive texture of mozzarella cheese. In addition, structural and rheological properties as a result of interactions between structural components (calcium and soluble N/total N ratio) were pH dependent (Yazici et al., 2010). Stretching mozzarella cheese curd under high temperature encouraged protein matrix interactions and changes occur in the calcium balance which had an effect on cheese texture (Choi et al., 2008; Gonçalves & Cardarelli, 2021).

Murrah Dairy, a family-run small and medium enterprise (SME), is the pioneer of buffalo dairy production in Thailand. Murrah's dairy farm started in 2003 with 60 heads of Murrah buffaloes with 120 kg/day of raw milk and has since increased to 400 heads in 2022 with 1,600-2,000 kg/day of raw milk. Fresh mozzarella cheese are manufactured at the farm and sold in Bangkok supermarkets and the farm shops. Fresh mozzarella cheese in brine is made daily from whole pasteurized milk. Defects have been observed such as the outer surface of cheese is not smooth during storage in brine and the texture is hard. Therefore, the main objective of this study was to find optimum conditions of milk curd cutting time, cooking temperature of cheese curd and pH of pre-stretched cheese curd to produce a good textural quality mozzarella cheese.

Materials and methods

1. Raw milk collection

Raw milk from Murrah buffalo (*Bubalus bubalis*) was collected and cool-transported from the farm at Plaeng Yao District, Chachoengsao Province, to the dairy processing laboratory at the School of Food Industry, King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok. The received milk was sampled for quality analyses. The raw milk was pasteurized at 65ºC for 30 min, cooled and kept in the refrigerator (5 ± 1ºC) until used within 24 - 48 hr.

2. Quality of raw milk

Physical, chemical and microbial properties of raw milk samples were analyzed (American Public Health Association [APHA], 2012). Temperature (°C), clot on boiling test (COB) and specific gravity were determined. The analysis of the fat was conducted by Gerber method (%), protein (%), total solids (TS, %), solids non-fat (SNF), pH and titratable acidity (%TA as lactic acid). Methylene blue reduction test (MBRT), coliform (CFU/mL), standard plate count (CFU/mL), and lactic acid bacteria (LAB) (CFU/mL) were determined.

3. Manufacturing of Mozzarella farm cheese

Commercial condition of Murrah mozzarella farm cheese and literature review was applied. Three batches (replicates) of pasteurized milk of 10 kg each were heated to 40°C. Milk pH was determined before inoculated with lyophilized lactic acid bacteria (*Lactobacillus helveticus* plus *Strepto-coccus thermophiles*) (FD-DVS, Chr. Hansan, Denmark). Milk was thoroughly stirred after inoculation, ripened to a 0.1 pH decrease before rennet enzyme at 0.1 g (Chr. Hansan, Denmark) was added. The temperature was controlled at 40°C until milk curd was developed. The milk curd was cut to approximate 1x1x1 cm and allowed to heat at 40°C for 5 min. The temperature of the cheese curds was gradually increased to cooking at 45°C. The curds were stirred during cooking until pH 6.2 was obtained for whey drainage, followed by cheddaring and milling, respectively. The milled curds were kneaded and stretched in hot water (> 95ºC), molded into cheese balls of 150 g. The mozzarella cheese balls were stored in 1% NaCl solution at refrigerator temperature and subjected to quality analysis.

4. Determinations of curd cutting time, cooking temperature and pH of pre-stretch curd in mozzarella cheese process

4.1 Determination of milk curd cutting time

Pasteurized milk was inoculated as described above in section 3 and CHY-MAX rennet was added after ripened milk had a 0.1 pH decrease with the temperature controlled at 40ºC. The pH and hardness of milk curd were determined every 15 min during milk ripening. The hardness of milk curd was analyzed by the TA-XT2i Texture Analyzer (Texture Technologies Corp., Scarsdale, NY, USA) with a cylinder probe (diameter 50 mm). A compression probe attached to a 5 kg compression load cell was used to compress the sample at 1.0 mm/s to a depth of 10 mm from the surface. An optimal curd cutting time was determined by the time of a strong milk curd developed and this cutting time was used in the cheese process for this study.

4.2 Determination of cooking temperature

The cooking temperature was determined by inoculating and renneting pasteurized milk as in Section 4.1, followed by curd cutting, cheese curds and whey were heated and stirred at 3 different cooking temperatures (43, 45, or 47°C) until the pH of whey was about 6.2 (Zisu & Shan, 2005; Gulzar et al., 2019). The optimal cooking temperature was determined by visual assessment of the curds which included adhesion, hardness and stretch ability.

4.3 Determination of pH of pre-stretched curds

After the completion of the cooking step (section 4.2), whey was drained and the cheese curds followed cheddaring. Cheddaring is a process of rebuilding of the cheese mass structure, which is a critical developmental stage of the final taste and texture. The cheddaring steps involved the cutting, stacking and turning of blocks of curd. Cheese curds were agglomerated to curd mass. The curd mass was cut to slabs and stacked on top of each other at 45°C. The stack was turned every 15 min to allow the curd to heat evenly. Whey pH was measured every 10 min until the pH was 5.1 or 4.9 (Gulzar et al., 2019) before milling the cheese mass. The milled curds were kneaded and stretched in hot water (> 95ºC), molded into cheese balls of 150 g. The mozzarella cheese balls were stored in 1% NaCl solution at refrigerator temperature and subjected to quality analysis. Qualities of mozzarella cheese were analyzed, including microbial, chemical and physical quality.

5. Determinations of mozzarella cheese quality

5.1 Microbial quality

Lactic acid bacteria (CFU/mL or g) of the mozzarella cheese were determined (APHA, 2012).

5.2 Chemical quality

Fat content by Gerber (%), protein content (%w/w), solids non-fat (%SNF) and moisture content (%) of mozzarella cheese were determined (APHA, 2012).

5.3 Physical quality

Weight loss (%) of mozzarella cheese was calculated. Textural quality of cheese included hardness, cohesiveness, springiness and chewiness was performed using a TA-XT2i Texture Analyzer. The mozzarella cheese was cut into pieces of 2x2x2 cm. The cheese sample was analyzed by a compression TPA mode, optimized test conditions were 50 mm diameter cylinder; test speed, 1 mm/s; pre-test speed, 1 mm/s; post-test speed, 1 mm/s and distance, 10 mm. Stretch distance (mm) and tension force (N) of the cheese were performed with tension mode by TA-XT2i Texture Analyze with cheese extensibility rig probe.To prepare cheese samples, 5 g of cheese was placed on top of sandwich bread and then baked in an oven at a temperature range of 130-140ºC for a duration of 1.30 min. The melted cheese was measured at 10 mm/s to a height of 120 mm from the surface (modified from Zisu & Shah, 2007).

6. Statistical analysis

Experimental design used in manufacturing of cheese was a completely randomized design (CRD). Results were presented as means ± standard deviation (S.D.) of 3 replications. The data were statistically analyzed using one-way analysis of variance (ANOVA) to determine the curd cutting time, cooking temperature and pre-stretched pH of mozzarella cheese. Means difference was analyzed using Duncan's multiple range tests (DMRT) with a confidence level at 95%. The analysis of the data was performed using SPSS for Windows®, version 16.

Results and discussion

1. Quality of raw milk

Raw buffalo milk was white in color compared to cow milk which was slightly yellow in color. Buffalo milk had a sweet taste and fresh sensation. Physical, chemical and microbiological qualities of buffalo milk are shown in Table 1. Specific gravity (at 20ºC) of Murrah buffalo milk ranged from 1.031 to 1.033 g/cm^3. Qualities of buffalo milk and cow milk in this study were different. Specific gravity of buffalo milk was higher than cow milk (Table 1), this was due to higher fat (6.24%) and SNF (9.51%) contents. The COB test and alcohol test showed negative (-) results indicating the buffalo farm milk was fresh, normal, and stable to heat coagulation. Alcohol test was more sensitive than the COB test. In addition, the alcohol test could be detecting the medium-acidity milk (pH <6.4). Milk which passes the COB test, but it may fail the alcohol test. Colostrum and mastitis milk may also fail the alcohol test (Nurliyania et al., 2015).

The pH (6.68) and titratable acidity (0.15% as lactic acid) of buffalo farm milk was normal. Both pH and titratable acidity of milk depended on feeding, lactation number, stage of lactation, health of an animal and handling of milk at the farm (Şahin et al., 2014; Suranindyah et al., 2015). Buffalo milk had a comparatively higher SNF (9.51%), TS (15.92%), fat content (6.24%) and protein content (3.62%) compared to cow's milk. Milk from Murrah's buffalo had average values of 9.48-10.10%SNF and 15.61-16.53%TS (Meena et al., 2007; Ren et al., 2015; Kapadiya et al., 2016; Sales et al., 2017). Milk fat played an important role in quality of cheese as a plasticizer; a low-fat cheese had a coarse and hard texture compared to a full fat cheese. In addition, milk fat is a good flavor carrier and flavor enhancer. Milk protein was the most important component in buffalo milk manufacturing. Casein, the major milk protein had the lowest solubility at an isoelectric point pH 4.6 (20°C), casein was coagulated while serum protein (whey protein) was soluble. About 80% of the total nitrogen of cow milk and buffalo milk was casein protein. Buffalo milk had a higher casein/protein ratio (80.44%) and high calcium content of casein, this enhanced efficiency of cheese manufacturing (Food and Agriculture Organization of the United Nations [FAO], 2022). Fat and protein contents of raw buffalo milk from Murrah Farm were 6.24% and 3.62% respectively, which compiled to the standard of raw buffalo milk (Thai Agricultural Standard [TAS] 6007-2021). Variations in chemical composition of milk could be due to the species, condition of the animal and the environment (Walstra et al., 2006).

MBRT was performed to indirectly determine the microbial quality of raw milk. The period of the blue color change estimated the number of bacteria in milk. The MBRT of raw buffalo milk took more than 4 hrs and blue color faded in 6 hrs. Results of standard plate count of buffalo milk were 3.4×10^4 CFU/mL which followed the standard (Thai Agricultural Standard [TAS] 6007-2021). Coliform counts of buffalo raw milk were 2.4×10^3 CFU/mL (3.38 log CFU/mL). Microbial qualities of the buffalo farm milk (Table 1) compiled to the standard of raw buffalo milk (Thai Agricultural Standard [TAS] 6007-2021). In some countries in Europe, particularly France, Italy and Switzerland, cheese is manufactured from raw or unpasteurized milk. In Europe the total microbial count in raw milk is required to be less than 5×10^4 CFU/mL (Fox et al., 2017) and the proper management of raw buffalo milk production and handling resulted in good quality of cheese products.

Table 1 Qualities of raw Murrah Farm buffalo milk, standards of raw buffalo milk and cow milk

	Buffalo milk Murrah Farm	Buffalo milk Standard[1]	Cow milk Standard[2]
Physical quality			
Specific gravity (at 20°C) (g/cm^3)	1.032 ± 0.01	≥1.030	≥1.028
Clot on boiling test (COB)	negative	negative	negative
Alcohol test	negative	negative	negative
Chemical quality			
pH	6.68 ± 0.30	6.6-6.9	6.6-6.8
Titratable acidity (%TA)	0.15 ± 0.01	-	≤ 0.16%
solids non-fat (%SNF)	9.51 ± 1.27	≥ 9.0%	≥ 8.25%
Total Solids (%TS)	15.92 ± 2.60	≥ 14%	-
Fat content (%)	6.24 ± 1.08	≥ 5.0%	≥ 3.35%
Protein content (%)	3.62 ± 0.42	≥ 3.5%	≥ 3.0%
Microbiological properties			
Methylene Blue reduction test (MBRT)	> 4 hrs.	> 4 hrs.	> 4 hrs.
Standard Plate Count (CFU/mL)	3.4 × 10^4	≤ 4×10^5	≤ 5×10^5
Coliform (CFU/mL)	2.4 × 10^3	≤ 10^4	≤ 10^4
Thermoduric bacteria (CFU/mL)	< 10^3	≤ 10^3	≤ 10^3

Remark: [1] Thai Agricultural Standard: Raw buffalo milk (TAS 6007-2021)
[2] Thai Agricultural Standard: Raw cow milk (TAS 6003-2010)

2. Effect of cutting time on hardness of milk curd

The relationship of pH and hardness of milk curd based on the time after renneting at 40°C for 75 min is shown in Fig 1. The hardness of the milk curd increased with time, while the pH of the curd decreased with time which resulted in a stronger milk curd. Efficiency of rennet coagulation and curd formation of cheese milk could be determined by various parameters such as curd tension, curd strength, curd firmness and deformation stress. Several factors influenced milk coagulation by rennet enzymes, such as casein content, fat content, enzyme concentration, pH, calcium ions, size of casein micelles and temperature (Glantz et al., 2010; Fox et al., 2017; Troch et al., 2017).

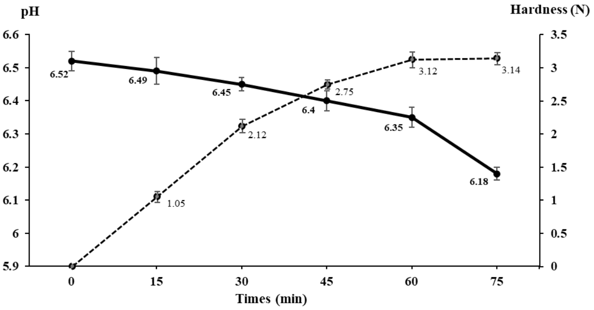

Fig. 1 Relationship of curd hardness (---) and pH (—) of milk after addition of rennet enzyme at 40°C.

Optimal pH range of cheese milk for rennet activity was about 6.0-6.3 (McSweeney et al., 2017) which the rennet activity increased but pH decreased. The optimal temperature for rennet activity was 40-42°C and the enzymatic activity stopped at 55°C (Vignola, 2002; Croguennec et al., 2008). Determination of optimal cutting time by investigating changes in pH and hardness of the milk curd after renneting at 40°C (Fig. 1) showed that a decrease in pH with coagulation time and rennet activity increased the hardness of the curd. Cutting time was important to quality and yield of the final cheese product. At 60 min after renneting pH of the milk curd was greatly reduced from 6.35 to 6.18, with significant increase of the curd hardness to 3.12 N and slowly continued to 3.14 N with constant hardness at 75 min after renneting. Early cutting time (before 60 min) resulted in weak curds with hardness of 1.05-2.75 N. When weak and soft curd was cut before the skin developed, the curds broke up and shattered leading to more fine curds, greater fat loss and cheese yield loss (El-Gawad & Ahmed, 2011). However, longer rennet coagulation time (after 60 min) resulted in poor syneresis of the curds during the cooking stage and increased in cheese moisture (Johnson et al., 2001). Therefore, monitoring pH of curd in addition to coagulation time were applicable guideline for the farm cheese manufacturing. From the result, it is recommended that the curd cutting time for the mozzarella farm cheese at 60 min after renneting, or at pH 6.35 of the milk curd. This result is consistent with the findings of Gulzar et al. (2019) that curd cutting was pH 6.40

3. Effect of cooking temperatures on cheese curd texture

Three levels of cooking temperatures at 43, 45, or 47°C were studied. After milk curd cutting, curds were held at each cooking temperature, while whey was expelled at the same time the curds slowly shrunk. Cooking was controlled until pH of curds was 6.2 before whey drainage. Cooking or heating cheese curd and whey after cutting promoted syneresis, or an expulsion of whey from curd, firming the curd and increased acidity. Cooking temperatures affected curd adhesion, stretch ability and curd hardness (Aldalur et al., 2019). Cutting the curd, curd acidity, cooking temperature and stirring are all factors that promoted the syneresis of cheese curd (McSweeney, 2007). The syneresis was essential to control moisture, to influence texture and flavor of the cheese. Varying the cooking temperature used for production of mozzarella cheese range from 38-44°C. (Yun et al., 1993; AH & Tagalpallewar, 2017).

In this study, cooking curd at 47°C resulted in the hardest curd (Table 2), while at 43°C a soft and non-agglomerated mass curd was obtained. Cooking temperature at 45°C showed suitable hardness of the curds. At 47°C resulted in longer stretched curd with stiff texture (hardness). Therefore, the cooking temperature at 45°C was the optimal temperature. Temperature and pH were mutual contributing factors of curd syneresis. The cooking temperature and cooking rate influenced characteristics of the cheese, increasing the temperature resulted in a dry and hard surface curd due to the moisture loss, decrease in the meltability (Tunick et al., 1993) and the whey was held in the curd, meanwhile low temperature cooking gave a slow rate of syneresis (McSweeney, 2007). Cooking the curd at 45°C until the curd had a pH 6.2, obtained before whey draining and cheddaring, was suggested by Zisu & Shan (2005) and Gulzar et al. (2019).

Table 2 Observation results of cheese curd at various cooking temperatures

	43°C	45°C	47°C
Adhesion	-	+	+
Stretch ability	+	++	+++
Hardness	-	+	++

Remark: - means non detectable
+ means low /++ medium / +++ high detectable

4. Effect of pre-stretched curd pH on quality of mozzarella cheese

Cheddaring rebuilt the curd mass due to restructure of links between casein micelles and fat globules. Texture and structure of curd was developed along with rapid increase of acidity and the built structure was similarly to chicken breast muscle (Mironenko, 2017). In this this study, during cheddaring at 45°C the pH of the cheese curd slowly decreased due to activity of the starter culture. Fox et al. (2017) reported that cheddaring increased ratio of dissolved calcium to calcium bound casein of curd. Soluble calcium (as percentage of total calcium in the curd) was found to increase from 5% to 40% when the pH was decreased from cooking stage to cheddaring stage. In addition, the pH of the curd at cheddaring was the most influential factor in the ability of the curd to be stretched (Yazici et al., 2010; Paz et al., 2017). The pH of the curd, prior to stretching, influenced both textural and microstructural characteristics of the cheese.

Stretching, a process to develop a fibrous texture of mozzarella cheese, included heating, kneading, and curdling cheddared curd. The fibrous structure was not produced if the pH of the curd was higher than 5.8. Buffalo mozzarella cheese was not suitable to stretch if the pH of the curd was higher than 5.2, because fat was lost during the stretching (Gulzar et al., 2019). The pH of the curd, prior to stretching, influenced both textural and microstructural characteristics of the mozzarella cheese.

The quality of mozzarella cheese produced from buffalo milk with pre-stretching at pH 5.1 or 4.9 are shown in Table 3. Different pre-stretched pH of curd did not affect yields or chemical compositions of cheeses. Lactic Acid Bacteria (LAB) counts of raw milk was $<10^3$ CFU/g (data not shown) and LAB of inoculated pasteurized milk was 2.00×10^6 CFU/g and increased to 6.73×10^7 CFU/g during milk ripening or before renneting (data not shown). Chemical compositions of mozzarella cheese obtained from both curd pH 5.1 and 4.9 were similar.

In this study, pH 5.1 or 4.9 of curds at the end of cheddaring (pre-milling or pre-stretching) resulted in different stretching characteristics of the curds and significantly different textural quality of mozzarella cheese (Table 3). At pH 4.9 the stretched curd showed better plasticizing mass during stretching in hot water compared to that of pH 5.1. Curds at pH 5.1 showed the cheese mass had low-stretched curd and the mass of mozzarella cheese was dry and had a rough surface (Fig. 2). However, this defect became smaller in cheese curd at pH 4.9. The results of this study were consistent with the results of the sensory tests of Gulzar et al. (2019), with the sensory score of the cheese appearance at pH 5.1 was less than 4.9, while the higher score preference for texture. Decrease in curd pH was conducive to the flow of the curd during stretching in hot water; this was due to solubilization of micellar calcium phosphate, an increase in the ratio of soluble to colloidal particles of calcium and an increase in para-casein hydration (Guinee et al., 2000; Yazici et al., 2010). Moreover, dicalcium para-caseinate was converted to monocalcium para-caseinate, which favored fiber formation. The curd pH affected the amount of insoluble water calcium which related to unmelted cheese hardness and chewiness of post melts cheese (Yazici et al., 2010; Gonçalves & Cardarelli, 2021).

Textural properties included hardness, cohesiveness, springiness, chewiness and extensibility of mozzarella cheese, was more dependent on pH factor than other factors (Lucey et al., 2003). Even though the cheese curd mass at pH 4.9 showed better plasticizing and easily to form into molding during stretching than pH 5.1. In contrast the texture of mozzarella cheese produced from pH 5.1 showed better quality than pH 4.9. Hardness and chewiness values of the cheese from pre-stretched curd pH 5.1 were lower than that of pH 4.9 (Table 3). Cohesiveness was the maximum extent at which the material can deform before breaking. The cohesiveness values of nearly 1 indicates high cohesiveness or highly rubbery, while nearly 0 indicates no cohesiveness or

(A) (B)

Fig. 2 Outer and inner texture appearance of mozzarella cheese from pre-stretched curd pH 5.1 (A) and pH 4.9 (B)

Table 3 Quality of mozzarella cheese from pre-stretched curds pH 5.1 and 4.9

	pH 5.1	pH 4.9	Other research
Weight loss (%)	13.19 ± 2.52[a]	7.87 ± 1.86[b]	-
Lactic Acid Bacteria (CFU/g)	<10^4	3.1 x 10^5	-
Chemical quality			
Fat (%) [ns]	30.38 ± 1.05	29.38 ± 1.49	28.93 (Gulzar et al. (2019); Pignata et al. (2015); Seth & Usha (2015); Andreatta et al. (2009); Sameen et al. (2008))
Fat Dry Basis (%) [ns]	59.91 ± 1.66	57.91 ± 0.80	55.28 (Seth & Usha (2015))
Protein (%) [ns]	18.49 ± 0.44	19.91 ± 1.10	20.56 (Gulzar et al. (2019); Pignata et al. (2015); Seth & Usha (2015); Andreatta et al. (2009); Sameen et al. (2008))
Total Solids (%) [ns]	50.71 ± 2.26	50.73 ± 0.10	53.70 (Gulzar et al. (2019); Pignata et al. (2015); Seth & Usha (2015); Andreatta et al. (2009); Sameen et al. (2008))
Moisture (%) [ns]	49.29 ± 2.26	49.27 ± 0.10	49.11 (Gulzar et al. (2019); Pignata et al. (2015); Seth & Usha (2015); Andreatta et al. (2009); Sameen et al. (2008))
Textural quality			
Hardness (N)	18.03 ± 1.54[b]	21.59 ± 0.34[a]	17.99 (Paz et al. (2017); Pignata et al. (2015); Salama (2015))
Cohesiveness [ns]	0.66 ± 0.05	0.70 ± 0.01	0.50 (Paz et al. (2017); Salama (2015))
Springiness (mm) [ns]	0.75 ± 0.03	0.89 ± 0.15	0.82 (Paz et al. (2017); Pignata et al. (2015); Salama (2015))
Chewiness (N x mm)	9.08 ± 0.46[b]	13.33 ± 2.09[a]	6.10 (Paz et al. (2017); Salama (2015))
Extensibility			
Tension force (N)	0.20 ± 0.01[b]	0.26 ± 0.02[a]	-
Stretch distance (mm)	57.65 ± 4.35[a]	29.45 ± 2.15[b]	46-109 (Hicsasmaz et al. (2004))

Remark: Mean ± SD. with different superscript letters along a row are significantly different ($p<0.05$)
[ns] means not significantly different ($p \geq 0.05$)

highly brittle (Maldonado et al., 2013). In this study, both cheeses showed intermediate cohesiveness. The cheese from pre-stretched curd pH 5.1 showed better extensibility quality of a longer stretchable distance of 57.65 mm, when melted (Table 3), compared to 29.45 mm of pH 4.9 curd. When considering the stretchability of mozzarella cheese after heat baking, it was found that pH influenced the tension force and the stretchable distance. Elongation of mozzarella cheese from pH 4.9 curd requires a higher force than pH 5.1 curd. The stretchable distance of mozzarella cheese mass from pH 5.1 curd was approximately 2 times of the pH 4.9 curd. This corresponded to lower hardness and chewiness quality of cheese from curd pH 5.1 than pH 4.9. The solubility of calcium phosphate in curd had an effect on increasing the hydration of para-casein whose matrix exhibited good fluidity in pH range 6.0-5.2 (Fox et al., 2017). When the pH was closer to the isoelectric point of casein (pH 4.6), para-casein was contracted and decreased hydration that affected the reducing of para-casein matrix flow. Lower casein hydration led the cheese to become hard, rubbery and dry body. (Arora & Khetra, 2017). The ideal pH to plasticize the cheddared curd was 5.15 (Fox et al., 2017). Normally, optimum pH of curd for stretching of pasta filata cheeses type ranged in 5.5 to 5.1 (Rowney et al., 1999; Maldonado et al., 2013; AH & Tagalpallewar, 2017). In addition, the curd pH affected the amount of insoluble water calcium which related to unmelted cheese hardness and chewiness of post melt cheese (Yazici et al., 2010; Gonçalves & Cardarelli, 2021). The stretching step of mozzarella cheese manufacturing gave a unique fibrous texture of pasta filata type cheese. In this study the curd was stretched in the hot water (> 95°C), kneaded until a soft and smooth mass of stretched curd was obtained before molding to 150 g mozzarella cheese balls. Quality comparisons among mozzarella cheese from this study (pre-stretched curds pH 5.1 and 4.9) and those from prior research are shown in Table 3. Chemical compositions of most cheeses were similar. Textural quality of mozzarella cheese from pre-stretched curds pH 5.1 was close to findings of prior research. This supported the study that the optimal pH of the pre-stretched curds was pH 5.1.

Conclusion

Buffalo farm milk had good potential in terms of physicochemical and microbiological characteristics to be used for mozzarella cheese production. Technically, milk curd cutting time, cooking temperature and pre-stretched curd pH were important to qualities of mozzarella cheese. The role of these factors in cheese production cannot be understated, as they are equally important as the knowledge of cheese culture selection. From this study, a 60-min curd cutting time after renneting, 45°C cooking temperature, and pre-stretched curd pH 5.1. were optimal in manufacturing of mozzarella farm cheese from buffalo milk. The success of this research was applied to quality improvement of mozzarella cheese from Murrah Farm. Finally, this research finding is applicable to SME and industrial cheese production.

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