Comparative analysis of improved soy-mozzarella cheeses made of ultrafiltrated and partly skimmed soy blends with other mozzarella types

Renda Kankanamge Chaturika Jeewanthi ·
Na-Kyoung Lee · Kyung Ah Lee · Yoh Chang Yoon ·
Hyun-Dong Paik

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Abstract The objective of this study was to improve the physicochemical properties and functional qualities of soy based mozzarella cheeses by ultrafiltration (UF) of soy milk blends, adding skim milk instead of cow's milk or increasing the soy milk proportions in cheese milk. Eight types of mozzarella cheeses made using soy milk and analyzed for nutritional, structural, and functional characteristics for 4 weeks at 4 °C. Cheeses made with cow milk, 10, 20, and 30 % soy milk in cow milk, skim milk, 10 % soy milk in skim milk, and ultrafiltrated 10 % soy milk in cow milk for first and second volume concentrations. Refrigerated storage of the soy-mozzarella led to a decrease in total solid, mineral, protein, fat, and lactose contents and rheological characteristics after 2 weeks. The nutritive quality of the mozzarella tended to increase proportionally to soy milk content, but the physical and functional qualities decreased. The UF-fortified soy-mozzarella showed more improved qualities among the other soy cheeses like long shelf life, improved nutritional, structural and functional qualities. Blends of 10–20 % soy milk and UF soy milk blends can be used to achieve good quality, nutritive mozzarella cheese, even with skim milk instead of cow milk in a milk shortage.

Keywords Soy milk · Mozzarella cheese · Low-fat cheese · Soy-mozzarella · Ultrafiltration-fortified cheese · Mozzarella analysis

Introduction

Several legume-based milks and milk products have been developed in an attempt to extend the supply of milk-like products, especially in areas where milk is in short supply. Soy milk has become more popular due to its resemblance to dairy milk in appearance and composition. The soybean (*Glycine max*) is a plant belonging to the family leguminosae and sub family papilionaceae. Soybean was named as the 'magic crop' by IITA because of its unique position among leguminous crops; mature seeds contain 40 % protein and 20 % oil, which means soybeans occupy an intermediate position between legumes and oilseeds having more protein (Iyagba 2010). Soy milk contains high amounts of protein, iron, unsaturated fatty acids, and niacin, but low amounts of fat, carbohydrates, and calcium as compared with cow's milk and human milk. When considering the cheese production, soy milk can provide the vegetable origin of nutritional cheese, the cheese-like product as cow milk (Rinaldoni et al. 2014). It also produces high quality milk at a comparatively cheaper cost. Soy milk can therefore be used to solve the protein gap among the low-income earners in a country. Cheese-making has historically been a way to preserve the most desirable components of milk. Existing cheese has advantages of fewer digestive problems and a high content of saturated fats (Karaman and Akalin 2013; Rinaldoni et al. 2014). Nowadays, producing high-quality cheeses that meet consumers' expectations is crucial in order for cheese makers to remain competitive. Mozzarella is a cheese variety of the

R. K. C. Jeewanthi · N.-K. Lee · K. A. Lee · Y. C. Yoon ·
H.-D. Paik (✉)
Department of Food Science and Biotechnology of Animal
Resources, Konkuk University, 120-Neungdong-ro, Gwanjin-gu,
Seoul 143-701, Republic of Korea
e-mail: hdpaik@konkuk.ac.kr

H.-D. Paik
Bio/Molecular Informatics Center, Konkuk University,
120-Neungdong-ro, Gwanjin-gu, Seoul 143-701, Republic of Korea

pasta filata family which is soft, white, unripened, lightly salted and consumed shortly without a long aging period. The melting and stretching characteristics make mozzarella a key ingredient in the manufacture of pizza (Banville et al. 2013; Lucey 2008). There is an immense interest in developing low-fat mozzarella cheese and new trends are focused on the use of natural and low-cost raw materials. The low moisture, part skimmed (PS) mozzarella is popular due to its preferable functional characteristics. Also, low-fat mozzarella is preferable for health reasons. UF of milk can be used to produce popular new dairy products and dairy-based foods that are higher in protein, and lower in carbohydrates and moisture. Non-thermal UF of milk is a better option for reducing moisture in cheese milk by concentrating without changing the healthy nutritional qualities to make low moisture and PS mozzarella. In the present market, there are commercial soy-mozzarella cheese products called as 'imitation mozzarella soy products'. However, they are poor in meltability and lack of hardness (Shurtleff and Aoyagi 2013). Nowadays food researches develop or produce soft cheeses using soy milk, considering the fact of high water retention capacity of soy proteins (Li et al. 2013; Liong et al. 2009; Rinaldoni et al. 2014). However, seems no much awareness to use soy milk in mozzarella cheese production. The objective of this study was to determine the possibility of improving the physicochemical properties and functional qualities of soy-mozzarella cheeses by UF of soy milk blends, adding skim milk instead of cow's milk or increasing the soy milk proportions in cheese milk.

Materials and methods

Materials The starter culture used for mozzarella was Thermophilic Y 082 D (Clerici Sacco International Srl, Cadorago Como, Italy), a mixed culture with *Lactobacillus bulgaricus* and *Streptococcus thermophilus*. Double strength (IMUC 290) calf rennet was obtained as the product named NATUREN from Australian CHR. HANSENS laboratory Inc., Melbourne.

Preparation of soy milk Mature soy beans (Baektae, white soybean) were obtained from a Korean supermarket. Raw soybeans 10 kg were washed, added to 10× of tap water and kept for 12 h at 14–20 °C, drained and blended with 2× weighted distilled water at 85,000 rpm for 5 min. Then, the milk was first filtered using a muslin cloth. Remained milk extracted using a dehydrator (W-60 T, Hanil Electric Co., Seoul, Korea) from the puree and again filtered in the same way and combined before pasteurization.

Ultrafiltration treatment Milk UF was carried out at 25 °C and at a pressure of 10.3 and 6.3 bar for the inlet and outlet,

respectively (Imtiaz et al. 2013). This was equipped with flat sheet UF membranes of GR-60-PP which were made of polysulphone. The molecular weight cut-off range was 5 kDa. The experiment was carried out in a spiral wound type module (DSS LabUnit M20, Alfa Laval Nakskov, Denmark). The total effective surface area of the membranes was 0.036 m². After the first filtration, the retentate was subjected to a second filtration and concentrated to 2:1 and 3:1 volumetric concentration ratios, respectively.

Milk concentrations and analysis Cow's milk was obtained from a Korean dairy farm. The skim milk was obtained from a local market in Korea. Raw fresh milk obtained and then pasteurized in 73 °C for 15 s using the cheese vat. To assess the potential of using soy milk to make different types of cheese, we used different milk combinations. Three different types of mozzarella were made by selective combinations of 10 %, 20 %, and 30 % soy milk with fresh cow's milk (A, B, and C, respectively). Then, to decrease the fat content in milk, we used skim milk instead of cow's milk with 10 % soy milk (AS). For comparison, S type cheese was made by only skim milk. To make low-moisture cheese types, 10 % soy milk was blended with cow milk and then ultrafiltered for first and second volume concentration factors (AUF1 and AUF 2). After the additions or preparations, 80 mL was analyzed by using Milk analyzer (Milko scan minor, Foss, Hillerød, Denmark).

Cheese manufacturing Cheeses were manufactured according to standard procedures. The milk was tempered to 30 °C before inoculation with cheese starter culture. After adding rennet (3 %) and starter culture (2 %), the milk was left to ripen for 45 min. The resulting curd was cut into 1 cm cubes. The curds were cooked at 38 °C by heating slowly at a rate of 1 °C rise per 5 min with agitation until the pH dropped to 6.1–6.2. The whey was drained and the curds were cheddared at 38 °C and turned every 15 min until the pH dropped to 5.4–5.5. The curds were milled, made into a ball and put it in to a 85 °C hot water and stretched. Then, the stretched cheese ball was put into (2 % w/w) salted solution for 2 h. Finally, portions were wrapped in foil and vacuum packaged separately for 4 weeks analysis. The cheese samples were stored at 4 °C.

Compositional analysis Total solid (TS) and ash contents were measured according to the AOAC method (2000). Grated cheese was analyzed for protein, fat, and lactose levels. Water-soluble extracts of the cheese were prepared by the method of Kuchroo and Fox (1982). Kjeldahl was used to measure protein content and fat was measured by the modified Mojonnier method (AOAC 2000). All the chemical measurements were done in triplicate after 0, 1, 2, 3, and 4 weeks of ripening.

Analysis of physical and structural characteristics The mozzarella cheese was analyzed for its color using a Hunter Tristimulus Colorimeter (model D25-9; Reston, VA). Hunter L, a, b, and the CIE L*, a*, b* color scales were considered. Using a No.10 cork borer, 3 replicates of cylindrical cheese samples were measured. Textural and rheological analyses were performed to assess springiness, brittleness, gumminess and cohesiveness at 25 °C using a Fudoh Rheometer (Model NRM-2001, Fudoh Kogyo Co., Tokyo, Japan). Cheese specimens were taken approximately 25 mm in length and width with a 20 mm height. Specimens were removed at different angles relative to the axis of the cheese cubes to avoid effects due to orientation of the curd. To obtain the values by giving the same force of compressing the cheese samples. Table speed of 60 mm/min, adaptor No.5, and intrusion distance of 10 mm were used.

Analysis of functional characteristics Meltability was counted by the Schreiber test (Kosikowski and Mistry 1997) and the stretchability was determined by the fork test (USDA 1980). The browning test was performed using the colorimeter-based procedure (Mukherjee and Hutkins 1994).

Statistical analysis Mean values and SD were measured using SAS (2004). One-way analysis of variance (ANOVA) and Duncan's multiple range test ($P \leq 0.05$) were used to establish the significance of differences.

Results and discussion

Composition of cheese milk The cheese milk used for making cheese has a profound influence on cheese composition, the casein (CN) to fat ratio, TS, lactose, ash, moisture levels, and extent of acid development in the finished cheese (Traordinary Dairy 2001). The chemical composition of cheese milk is shown in Table 1. An increase in soy milk concentration leads to a decrease in fat and lactose content of the milk, while shows an increase in protein. In comparison, UF (AUF1 and AUF2) and PS cheeses (S and AS) had a low fat content. The protein-to-fat ratio of milk in the production of mozzarella varied with the addition of different protein levels of soy milk or skim milk.

Composition of cheese The general compositions of the cheese are presented in Table 2. The soy cheeses made from UF soy milk blends exhibited maximum TS contents of 47–49 %, before ripening. New York State has specified TS contents of 42–48 % for low-moisture mozzarella and 40–48 % for PS mozzarella (Kosikowski 1960). TS of every sample decreased slightly as storage period increased. TS decreased to 37–41 %, which is below the range for PS soy

Table 1 Nutrition composition as milk composition

Sample ^a	Fat (%)	Protein (%)	Protein : fat	Lactose (%)	Total solid (%)
Control	3.76	3.21	0.85	5.30	12.80
A	3.46	3.27	0.94	4.48	12.78
B	3.03	3.39	1.12	4.11	13.02
C	2.49	3.46	1.39	3.83	14.56
AS	1.63	2.86	1.75	4.22	8.25
S	2.00	2.72	1.36	4.02	8.20
AUF1	2.86	3.38	1.18	4.06	9.98
AUF2	2.23	4.89	2.19	4.56	10.95

^a A~AUF2 represents the different milk mixtures that were used to make mozzarella cheeses (Control 100 % cow milk; A 10 % soy milk in cow milk; B 20 % soy milk in cow milk; C 30 % soy milk in cow milk; S skim milk; AS 10 % soy milk in skim milk, AUF1 UF for first volume concentration of 10 % soy milk in cow milk; AUF2 UF for second volume concentration of 10 % soy milk in cow milk)

cheese, after 2 weeks. The cheeses with soy blends of 20 and 30 % also significantly ($P \leq 0.05$) reduced TS after 2 weeks and seemed softer, little moist and more pliable. Structural damage of these cheeses was observed after 2 weeks as a result of destruction of CN components. The addition of soy milk and the UF concentration factor significantly increased the protein and ash retention in the cheeses. Protein is the major and dominant component of cheese that gives the desired firmness, stretch and meltability, all essential characteristics of mozzarella. The protein content in soy and cow's milk blended cheese ranged from 22.06 to 28.76 % for 4 weeks, while UF-fortified soy cheese had protein content in the range of 19.76–29.85 %. The protein retention in the PS cheese was higher with aging due to the strong structure of increased CN that resulted from the addition of powder skim milk in the cheese milk. However, the results suggest that the use of skim milk instead of cow's milk with 10 % soy milk, has no significant effect on the protein content of the mozzarella. There was an obvious decrease in ash content of every sample after 2 or 3 weeks of storage. The decrease of ash originated from a vital role in the making of the para-casein matrix, the function of mozzarella. Fat plays a dramatic role in the rheological factors of mozzarella. It has been reported that when the fat content of the mozzarella decreases, the moisture retention also decreases, giving the cheese a poor meltability and stretch characteristics (Rudan et al. 1999). Every sample showed reduced fat content with aging and with increment of soy milk. The fat content of soy-blended cheese ranged from 8.35 to 15.38 %, just before storage. Comparatively, UF samples had a slight reduction in fat content with its concentration. Lactose content of the control cheese was 1.53 ± 0.32 % (Data not shown). During storage, the lactose content decreased significantly ($P \leq 0.05$) for all cheese types and with

Table 2 Compositional changes of mozzarella cheeses made from different blends during 4 weeks refrigerated storage at 4 °C

Constituents ^b	Storage period (wk)	Cheese types ^a		A	B	C	S	AS	AUF1	AUF2
		Control								
Total solid	0	46.97 (0.91) ^a	48.33 (0.47) ^a	50.34 (1) ^a	53.38 (1.02) ^a	42.51 (2.55) ^a	40.46 (1.13) ^a	46.67 (1.06) ^a	48.87 (1.05) ^a	
	1	46.82 (0.98) ^a	47.37 (0.37) ^{ab}	50.20 (1.61) ^a	49.54 (0.86) ^{ab}	41.67 (0.47) ^{ab}	40.43 (1.46) ^a	43.99 (0.48) ^b	47.69 (0.74) ^a	
	2	45.91 (0.66) ^a	47.2 (0.51) ^{ab}	48.32 (1.5) ^{ab}	42.84 (7.45) ^b	40.66 (1.2) ^{ab}	39.6 (0.55) ^a	43.83 (0.35) ^b	47.52 (1.65) ^a	
	3	45.37 (0.81) ^a	45.51 (1.56) ^{ab}	45.21 (2.02) ^b	46.34 (2.86) ^{ab}	40.47 (0.87) ^{ab}	39.3 (0.55) ^a	42.35 (0.85) ^{bc}	47.10 (1.37) ^a	
	4	44.95 (0.35) ^a	45.42 (1.64) ^b	45.36 (1.74) ^b	46.33 (2.83) ^{ab}	37.65 (2.56) ^b	39.15 (0.58) ^a	41.85 (0.68) ^c	46.92 (0.97) ^a	
Protein	0	19.24 (2.84) ^a	24.68 (1.1) ^a	26.9 (0.92) ^a	28.76 (1.56) ^a	19.22 (2.6) ^a	24.21 (1.09) ^a	27.24 (1.3) ^a	29.85 (1.46) ^a	
	1	19.13 (2.81) ^a	24.63 (0.48) ^a	26.55 (0.45) ^a	28.32 (1.29) ^a	19.22 (2.58) ^a	23.56 (0.21) ^a	26.13 (1.53) ^a	29.55 (1.04) ^a	
	2	18.75 (1.99) ^a	23.59 (0.7) ^a	24.42 (1.6) ^a	26.77 (0.27) ^{ab}	19.2 (1.17) ^a	23.51 (0.63) ^a	25.75 (1.26) ^a	27.66 (0.54) ^a	
	3	18.61 (1.48) ^a	23.42 (0.63) ^a	24.17 (1.88) ^a	26.04 (1.92) ^{ab}	19.18 (1.16) ^a	23.42 (0.76) ^a	24.61 (1.02) ^a	25.36 (0.35) ^{ab}	
	4	18.05 (2.22) ^a	22.06 (1.85) ^a	23.63 (1.64) ^a	23.47 (0.62) ^b	19.18 (1.08) ^a	23.33 (0.68) ^a	24.05 (1.48) ^a	19.76 (4.03) ^b	
Fat	0	18.25 (1.69) ^a	15.38 (0.91) ^a	10.83 (0.31) ^a	8.35 (0.06) ^a	7.36 (0.28) ^a	7.25 (0.03) ^a	9.45 (0.1) ^a	9.31 (0.14) ^a	
	1	16.23 (0.99) ^{ab}	14.63 (1.7) ^a	9.58 (1.74) ^a	8.24 (0.03) ^a	7.32 (0.13) ^a	7.04 (0.04) ^a	9.35 (0.21) ^a	9.22 (0.24) ^a	
	2	15.86 (0.51) ^{ab}	12.63 (2.67) ^a	9.25 (2.11) ^a	7.47 (0.76) ^{ab}	7.27 (0.04) ^a	7.01 (0.30) ^a	9.38 (0.06) ^a	9.17 (0.24) ^a	
	3	15.08 (0.51) ^b	11.74 (3.12) ^a	8.74 (1.54) ^a	7.21 (0.45) ^{ab}	7.25 (0.01) ^a	7.00 (0.27) ^a	9.3 (0.14) ^a	8.98 (0.59) ^a	
	4	14.61 (0.04) ^b	11.54 (2.92) ^a	8.35 (1.97) ^a	6.08 (1.37) ^b	6.96 (0.49) ^a	6.75 (0.02) ^a	9.24 (0.16) ^a	8.83 (0.27) ^a	
Ash	0	1.35 (0.07) ^a	1.42 (0.03) ^a	1.47 (0.06) ^a	1.67 (0.08) ^a	1.78 (0.1) ^a	1.85 (0.14) ^a	1.71 (0.11) ^a	2.21 (0.27) ^a	
	1	1.27 (0.03) ^a	1.41 (0.01) ^a	1.43 (0.06) ^a	1.58 (0.01) ^a	1.53 (0.18) ^{ab}	1.75 (0.08) ^{ab}	1.71 (0.2) ^a	2.17 (0.27) ^a	
	2	1.17 (0.04) ^a	1.31 (0.08) ^a	1.30 (0.13) ^a	1.07 (0.12) ^b	1.47 (0.16) ^{ab}	1.65 (0.03) ^{ab}	1.58 (0.2) ^a	2.16 (0.26) ^a	
	3	0.92 (0.14) ^b	0.94 (0.08) ^b	0.92 (0.08) ^b	1.01 (0.06) ^b	1.37 (0.07) ^b	1.34 (0.17) ^{ab}	1.45 (0.04) ^a	1.64 (0.21) ^a	
	4	0.90 (0.08) ^b	0.75 (0.18) ^b	0.82 (0.13) ^b	1.00 (0.08) ^b	1.36 (0.04) ^b	1.11 (0.49) ^b	1.36 (0.03) ^a	1.62 (0.37) ^a	

^a Control–AUF2 represents the different cheese types (Control 100 % cow milk; A 10 % soy milk in cow milk; B 20 % soy milk in cow milk; C 30 % soy milk in cow milk; S skim milk; AS 10 % soy milk in skim milk, AUF1 UF for first volume concentration of 10 % soy milk in cow milk; AUF2 UF for second volume concentration of 10 % soy milk in cow milk)

^b Average Mean Values (SD) and ^{a–c} Means within a column with different superscripts are significantly different by Duncan's multiple range test ($P \leq 0.05$)

the soy milk proportions. PS cheeses showed comparatively higher lactose compositions compared to cow milk cheese. The highest lactose content of 1.77 ± 0.12 %, was observed with AUF1 cheese, and more concentrated samples had higher compositions.

Color The color of cheese is an important factor in mozzarella, because it directly affects consumer preference. In general, mozzarella cheese should be white in color and not acceptable when fluctuate highly in temperature differences. According to Metzger et al. (2000), the whiteness is effecting with the state and the fat content of the mozzarella cheese. The experimented mozzarella had higher values for whiteness, less yellowness and slight greenness (Table 3). For every sample, the whiteness and greenness decreased, but yellowness increased with storage time. UF-fortified cheese and cheese C were more susceptible to color change during storage. PS cheese had the least amount of color change with the storage. Adding skim milk instead of cow's milk, in to the 10 % soy milk (Cheese AS) resulted in decreased yellowness and increased whiteness compared to other cheeses, which is desirable for mozzarella due to the lower carotene content.

Rheological characteristics Rheological characteristics reveal the relationships among stress, strain and time scale of foods to understand the effects of processing on products, the

system structure, and the texture. Generally moderate toughness and an adequate stringiness are acceptable characteristics of mozzarella. With aging of cheese there is a decrease in the measured rheological characteristics (Table 4). The CN matrix in cheese becomes softer and less elastic during storage period due to the breakdown of α s1-CN and it loses the cohesiveness, causing the protein matrix to lose strength and elasticity (Tunick et al. 1997). The cohesiveness and springiness of the cheese were not influenced in 10 and 20 % soy milk-blended cheeses on the first day. However, with aging, the springiness, cohesiveness, and brittleness of cheese increased, while gumminess decreased with increasing soy milk proportions. UF cheese showed higher springiness, cohesiveness and brittleness in more concentrated milk. In addition, UF cheeses showed less reduction in gumminess during the time of storage.

Functional properties The functionality of heated mozzarella depends on several factors such as meltability, stretchability, free oil formation, and browning. These properties play heavily on consumer perceptions of cheese quality (Rowney et al. 1999). Meltability is the ability of cheese particles to flow together and form a continuous melted mass (Kindstedt 1993). Due to proteolysis of the structure, the meltability of all cheeses increased (Fig. 1). The highest meltability was displayed by the control cheese. Only cheese A showed a

Table 3 Changes in color values of mozzarella cheeses made from different blends during 4 weeks refrigerated storage at 4 °C

Storage period (wk)		Cheese types ^a								
		Control	A	B	C	S	AS	AUF1	AUF2	
0	L * ^c	87.23 (0.96) ^{a b}	87.38 (0.19) ^a	91.86 (0.08) ^a	90.58 (3.76) ^a	91.51 (0.04) ^a	92.49 (0.21) ^a	88.78 (0.04) ^a	86.6 (0.08) ^a	
	a *	−4.3 (0.03) ^a	−2.04 (0.19) ^a	−1.13 (0.04) ^a	−3.05 (0.06) ^a	−1.64 (0.01) ^a	−1.61 (0.28) ^a	−2.84 (0.03) ^a	−3.18 (0.01) ^a	
	b *	12.76 (0.21) ^d	12.77 (0.11) ^{cb}	14.43 (0.07) ^c	11.02 (0.08) ^c	14.75 (0.04) ^b	11.23 (0.04) ^c	15.33 (0.27) ^c	16.72 (0.03) ^b	
1	L *	86.96 (0.05) ^a	87.26 (0.21) ^{ab}	91.77 (0.03) ^a	93.08 (0.01) ^a	90.05 (0.06) ^b	92.47 (0.01) ^a	88.59 (0.04) ^a	86.08 (0.06) ^a	
	a *	−4.13 (0.03) ^b	−2.02 (0.07) ^{ab}	−1.11 (0.01) ^a	−3.07 (0.01) ^{ab}	−1.6 (0.03) ^a	−1.61 (0.14) ^a	−2.7 (0.07) ^a	−3.15 (0.00) ^a	
	b *	14.04 (0.27) ^c	12.53 (0.11) ^c	14.56 (0.06) ^c	10.89 (0.36) ^c	14.82 (0.28) ^b	11.32 (0.08) ^c	16.34 (2.28) ^c	16.76 (0.03) ^b	
2	L *	84.63 (0.12) ^{ab}	86.25 (0.14) ^a	91.02 (0.03) ^a	87.33 (3.11) ^a	89.56 (0.15) ^{bc}	92.46 (0.00) ^a	86.92 (0.66) ^b	84.64 (0.14) ^a	
	a *	−4.03 (0.08) ^{cb}	−1.96 (0.01) ^{abc}	−1.06 (0.06) ^{abc}	−2.69 (0.1) ^b	−1.59 (0.01) ^b	−1.59 (0.14) ^a	−1.98 (0.05) ^b	−3.12 (0.03) ^a	
	b *	14.88 (0.1) ^b	13.04 (0.14) ^{ab}	14.61 (0.07) ^{cb}	16.52 (1.68) ^b	15.32 (0.42) ^{ba}	11.55 (0.1) ^b	28.99 (0.57) ^b	17.15 (0.57) ^b	
3	L *	82.22 (0.41) ^{bc}	85.56 (0.15) ^a	90.96 (0.72) ^b	78.2 (1.92) ^b	89.1 (0.58) ^{cd}	92.44 (0.06) ^a	75.61 (0.16) ^c	79.25 (1.92) ^b	
	a *	−3.99 (0.04) ^c	−1.94 (0.03) ^{cb}	−1.02 (0.04) ^{cb}	−0.73 (0.08) ^c	−1.56 (0.01) ^{bc}	−1.58 (0.01) ^a	−0.81 (0.07) ^c	−2.68 (0.03) ^b	
	b *	15.67 (0.1) ^a	13.12 (0.15) ^{ab}	14.76 (0.04) ^b	21.13 (1.83) ^a	16.05 (0.07) ^a	11.68 (0.03) ^{ab}	32.48 (0.21) ^a	19.09 (0.6) ^a	
4	L *	80.57 (0.12) ^c	82.07 (1.89) ^b	90.94 (0.16) ^b	76.37 (0.02) ^b	88.52 (0.01) ^d	92.44 (0.01) ^a	74.82 (0.46) ^c	79.21 (1.47) ^b	
	a *	−3.78 (0.04) ^d	−1.91 (0.03) ^c	−0.98 (0.01) ^c	−0.72 (0.05) ^c	−1.52 (0.01) ^c	−1.58 (0.01) ^a	−0.71 (0.06) ^c	−2.48 (0.06) ^c	
	b *	16.28 (0.48) ^a	13.27 (0.25) ^a	14.99 (0.1) ^a	21.48 (2.22) ^a	16.14 (0.07) ^a	11.75 (0.04) ^a	32.88 (0.25) ^a	19.89 (0.76) ^a	

^a Control~AUF2 represents the different cheese types (Control 100 % cow milk; A 10 % soy milk in cow milk; B 20 % soy milk in cow milk; C 30 % soy milk in cow milk; S skim milk; AS 10 % soy milk in skim milk, AUF1 UF for first volume concentration of 10 % soy milk in cow milk; AUF2 UF for second volume concentration of 10 % soy milk in cow milk)

^b Average Mean Values (SD) and ^{a–g} Means within a column with different superscripts are significantly different by Duncan's multiple range test ($P \leq 0.05$)

^c L* value=degree of lightness from black (−) to white (+), a* value=degree of green (−) and red (+), b* value=degree of blue (−) and yellow (+)

Table 4 Changes in rheological properties of mozzarella cheeses during 4 weeks refrigerated storage at 4 °C

Rheological properties	Storage period (wk)	Cheese types ^a							
		Control	A	B	C	S	AS	AUF1	AUF2
Springiness (m)	0	0.96 (0.01) ^{a b}	0.69 (0.05) ^a	0.68 (0.05) ^a	0.85 (0.01) ^a	0.78 (0.01) ^a	1.22 (0.08) ^a	0.85 (0.01) ^a	1.03 (0.04) ^a
	1	0.94 (0.01) ^{ab}	0.66 (0.02) ^a	0.67 (0.01) ^{ab}	0.85 (0.00) ^a	0.76 (0.01) ^a	0.98 (0.10) ^{ab}	0.83 (0.01) ^{ab}	0.98 (0.01) ^{ab}
	2	0.81 (0.11) ^{ab}	0.53 (0.03) ^b	0.65 (0.02) ^{abc}	0.83 (0.02) ^{ab}	0.73 (0.04) ^{ab}	0.95 (0.05) ^{ab}	0.83 (0.00) ^{ab}	0.961 (0.02) ^b
	3	0.78 (0.10) ^{ab}	0.5 (0.02) ^b	0.64 (0.01) ^{bc}	0.81 (0.01) ^{ab}	0.73 (0.02) ^{ab}	0.882 (0.06) ^b	0.78 (0.03) ^{bc}	0.96 (0.02) ^b
	4	0.73 (0.10) ^b	0.47 (0.03) ^b	0.63 (0.01) ^c	0.72 (0.06) ^b	0.71 (0.01) ^b	0.865 (0.01) ^b	0.8 (0.01) ^c	0.94 (0.02) ^b
Brittleness (N)	0	10.13 (0.03) ^a	4.97 (0.09) ^a	6.75 (0.14) ^a	13.94 (0.17) ^a	6.23 (0.02) ^a	7.35 (0.08) ^a	7.1 (0.16) ^a	10.48 (0.15) ^a
	1	9.64 (0.21) ^{ab}	4.87 (0.05) ^a	6.69 (0.10) ^a	12.73 (0.21) ^{ab}	6.06 (0.09) ^a	7.33 (0.03) ^a	7.04 (0.08) ^a	10.38 (0.13) ^a
	2	8.95 (0.41) ^{ab}	3.57 (0.51) ^b	5.38 (0.81) ^b	9.58 (3.4) ^{ab}	5.65 (0.35) ^a	7.24 (0.09) ^a	6.78 (0.12) ^{ab}	9.66 (0.5) ^{ab}
	3	8.77 (0.05) ^{bc}	2.45 (0.61) ^c	4.37 (0.69) ^{bc}	8.64 (2.58) ^b	5.65 (0.1) ^a	6.33 (0.35) ^b	6.52 (0.17) ^b	9.13(0.61) ^b
	4	7.62 (0.90) ^c	1.64 (0.31) ^c	3.77 (0.25) ^c	7.49 (1.02) ^b	4.89 (0.46) ^b	5.82 (0.59) ^b	5.64 (0.33) ^c	7.65 (0.54) ^c
Cohesiveness	0	0.92 (0.02) ^a	0.62 (0.00) ^a	0.69 (0.01) ^a	0.88 (0.03) ^a	0.79 (0.03) ^a	1.05 (0.08) ^a	0.84 (0.07) ^a	0.98 (0.26) ^a
	1	0.91 (0.03) ^a	0.6 (0.01) ^a	0.66 (0.01) ^{ab}	0.87 (0.01) ^a	0.79 (0.03) ^a	1.04 (0.07) ^{ab}	0.84 (0.06) ^a	0.98 (0.27) ^a
	2	0.82 (0.04) ^b	0.59 (0.01) ^a	0.65 (0.02) ^{bc}	0.85 (0.02) ^{ab}	0.76 (0.02) ^a	0.97 (0.01) ^{abc}	0.8 (0.02) ^a	0.95 (0.23) ^a
	3	0.81 (0.02) ^{bc}	0.47 (0.07) ^{ba}	0.63 (0.01) ^{bc}	0.78 (0.06) ^{ab}	0.77 (0.02) ^a	0.88 (0.06) ^{cb}	0.76 (0.05) ^a	0.86 (0.12) ^a
	4	0.74 (0.03) ^c	0.35 (0.14) ^b	0.62 (0.01) ^c	0.74 (0.07) ^b	0.76 (0.02) ^a	0.84 (0.06) ^c	0.76 (0.02) ^a	0.84 (0.15) ^a
Gumminess (N)	0	0.94 (0.02) ^a	0.72 (0.02) ^a	0.71 (0.02) ^a	1.14 (0.03) ^a	0.8 (0.04) ^a	0.85 (0.02) ^a	0.83 (0.01) ^a	1.01(0.1) ^a
	1	0.94 (0.04) ^a	0.69 (0.04) ^a	0.7 (0.01) ^a	1.05 (0.06) ^{ab}	0.8 (0.04) ^a	0.85 (0.00) ^a	0.82 (0.02) ^{ab}	0.99(0.07) ^a
	2	0.9 (0.03) ^a	0.61(0.06) ^a	0.69 (0.02) ^a	0.94 (0.06) ^{bc}	0.8 (0.02) ^a	0.83 (0.01) ^a	0.78 (0.02) ^{bc}	0.98(0.02) ^a
	3	0.87 (0.04) ^a	0.56 (0.04) ^a	0.69 (0.05) ^a	0.89 (0.05) ^c	0.79 (0.01) ^a	0.76 (0.04) ^b	0.77 (0.02) ^c	0.98(0.02) ^a
	4	0.64 (0.15) ^b	0.34 (0.17) ^b	0.64 (0.02) ^a	0.88 (0.03) ^c	0.78 (0.02) ^a	0.72 (0.03) ^b	0.76 (0.01) ^c	0.94(0.05) ^a

^a Control~AUF2 represents the different cheese types (*Control* 100 % cow milk; *A* 10 % soy milk in cow milk; *B* 20 % soy milk in cow milk; *C* 30 % soy milk in cow milk; *S* skim milk; *AS* 10 % soy milk in skim milk, *AUF1* UF for first volume concentration of 10 % soy milk in cow milk; *AUF2* UF for second volume concentration of 10 % soy milk in cow milk)

^b Average Mean Values (SD) and ^{a–g} Means within a column with different superscripts are significantly different by Duncan's multiple range test ($P \leq 0.05$)

Fig. 1 The effect of storage on meltability of mozzarella cheeses during a 4 weeks storage period at 4 °C. *white diamond*, Control (100 % cow milk); *white square*, A (10 % soy milk in cow milk); *black up-pointing triangle*, B (20 % soy milk in cow milk); *×*, C (30 % soy milk in cow milk); *white circle*, S (skim milk); *black circle*, AS (10 % soy milk in skim milk); *black square*, AUF1 (UF for first volume concentration of 10 % soy milk in cow milk); *black diamond*, AUF2 (UF for second volume concentration of 10 % soy milk in cow milk)

Fig. 2 The effect of storage on stretching ability of mozzarella cheeses during a 4 weeks storage period at 4 °C. *white diamond*, Control (100 % cow milk); *white square*, A (10 % soy milk in cow milk); *black up-pointing triangle*, B (20 % soy milk in cow milk); *×*, C (30 % soy milk in cow milk); *white circle*, S (skim milk); *black circle*, AS (10 % soy milk in skim milk); *black square*, AUF1 (UF for first volume concentration of 10 % soy milk in cow milk); *black diamond*, AUF2 (UF for second volume concentration of 10 % soy milk in cow milk)

Fig. 3 The effect of storage on browning effect of mozzarella cheeses during a 4 weeks storage period at 4 °C. Difference in **a** lightness and **b** redness between before and after baking at 232 °C/2 min. *white diamond*, Control (100 % cow milk); *white square*, A (10 % soy milk in cow milk); *black up-pointing triangle*, B (20 % soy milk in cow milk); *x*, C (30 %

soy milk in cow milk); *white circle*, S (skim milk); *black circle*, AS (10 % soy milk in skim milk), *black square*, AUF1 (UF for first volume concentration of 10 % soy milk in cow milk); *black diamond*, AUF2 (UF for second volume concentration of 10 % soy milk in cow milk)

higher meltability. The poor meltability of B and C, as well as PS cheeses, may be due to the strong structure and non-uniformity of the cheese matrix. The cheese with lower fat content and thus greater volume fractions of the CN matrix formed thicker para-casein fibers with fewer inclusions of fat serum-channels between them (McMahon et al. 1999), resulting in a firmer slightly melting cheese. It has been shown that decreased fat content in mozzarella does not appear to affect the melt characteristics when the moisture content is increased (Fife et al. 1996). AUF1 cheeses had moderate acceptable meltability while PS and AUF2 cheeses had comparatively less meltability and were stable during the storage time. This is explainable by the fact that the energy required to disrupt the CN matrix in non-fat mozzarella is greater due to highly aggregated proteins, which decrease the meltability (Paulson et al. 1998). Stretch refers to the capacity of melted cheese to form fibrous strands that extend under tension (Kindstedt 1995). In almost all cheeses except PS cheeses, the stretchability increased with successive days of storage (Fig. 2), a finding that is in agreement with results from previous studies on mozzarella (Guinee et al. 2002). Soy-blended cheese with more than 20 % soy milk showed a poor stretching ability. The browning of mozzarella is an important quality due to the widespread use of high temperature to bake pizzas. Personal preferences may exist, but high browning color is not preferred. L^* (dark to light) and a^* (red to green) were the most relevant indicators of browning (Beatriz et al. 1994). Figure 3 shows the difference between the first color value prior to baking and the last color value after baking at 232 °C for 2 min. Soy milk did not show any quality defect in browning of made cheeses. In every cheese other than cheese C, the darkness improved with storage time, while the highest browning occurred in the PS cheeses. The addition of soy blends can reduce the browning effect, but skim milk did not reduce the browning due to increased redness of PS. This

finding is in agreement with the observation that PS cheese causes some browning during cooking (Regi 2002). UF cheeses had a relatively low browning effect.

Conclusions

Making mozzarella cheese with soy milk 10–20 % is an acceptable approach to make soy-mozzarella types to a demanding market. Soy-mozzarella with higher proportions of soy milk in blends resulted in nutritiously rich mozzarella. The addition of soy milk proportions in cheese milk tends to decrease the functional quality of mozzarella cheese. Decrease the volumetric concentration of cheese milk by UF, increases the functionality and the nutritional quality of soy-mozzarella cheeses. However, extensive volumetric concentrations results hard type mozzarella cheeses. One volumetric concentration of soy blends (10 % soy milk) by UF gives good quality soy mozzarella cheeses. Soy milk 10 % can also be blended with skim milk to make good mozzarella cheese during times when there is a fresh milk shortage.

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