

Effect of Sodium Caseinate and Whey Protein Isolate Fortification on the Physical Properties and Microstructure of Corn Milk Yogurt

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ABSTRACT

*The aim of this research was to investigate the impact of sodium caseinate and whey protein isolate (WPI) fortification on the physical properties and microstructure of corn milk yogurt. The addition of sodium caseinate and/or WPI enhanced lactic acid production and counts of *Streptococcus thermophilus* and *Lactobacillus bulgaricus*. The hardness, adhesiveness, gumminess, lightness, water holding capacity, consistency and whey drainage increased whereas syneresis and yellow color decreased at higher concentrations of milk proteins. The optimal milk protein addition for improving the physical properties and texture of corn milk yogurt was 4% (w/v) of sodium caseinate.*

Key words: Corn milk yogurt, Sodium caseinate, Whey protein isolate, Milk protein

INTRODUCTION

Yogurt is the most-studied cultured dairy product. It is typically made from cow milk by the proto-cooperative action of two homofermentative bacterial cultures, *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* (De Brabandere and De Baerdemaeker, 1999; Tamime and Robinson, 1999; Lourens-Hattingh and Viljoen, 2001). However, efforts to produce a diversity of cultured products have been made by researchers in recent years to formulate yogurt from a variety of food sources, including soymilk (Granata and Morr, 1996), coconut milk (Siripanporn et al., 2000), grape juice (Öztürk and Öner, 1999), a combination of mango pulp-soymilk and buffalo milk (Kumar and Mishra, 2004), also a combination of skim milk and soymilk containing saccharified-rice solution (Park et al., 2005).

Corn milk is extracted from sweet corn (*Zea mays saccharata*) and pasteurized or heat-treated in the range of UHT. Due to its pleasant taste and nutritive

value and that it overcomes the problems of lactose intolerance and saturated fat of cow milk (USDA, 2004), corn milk has become popular in Thailand since 2004.

In this research, corn milk was used as the principal ingredient for yogurt making. Making yogurt from corn milk not only increases the diversity of fermented products, but also produces a new product that combines the good sensory characteristics and nutritional value of corn milk with the desirable yogurt flavor. However, to maintain other physical characteristics of yogurt, for example, body and texture, consumer acceptance, appearance and mouthfeel, the milk base may need to be fortified. Addition of dried dairy ingredients is a common practice in yogurt manufacture. In general, dried dairy ingredients can be divided into two groups. The first group consists of casein-based products such as skim milk powder (SMP), sodium caseinate and calcium caseinate, while the second group is whey-protein-based and includes whey protein isolate (WPI) and whey protein concentrate (WPC) (Amatayakul et al., 2006). The addition of dried dairy ingredients causes an increase in density of the protein matrix in the gel microstructure, and reduction of syneresis in yogurt (Remeuf et al., 2003; Everett and McLeod, 2005; Amatayakul et al., 2006; Saint-Eve et al., 2006). For soymilk yogurt, sodium caseinate stimulates acid development and coagulates the soy protein (Karleskind et al., 1991; Granata and Morr, 1996). For a novel corn milk yogurt, it is important to investigate the properties of the yogurt as affected by the added milk proteins.

Since the dried dairy ingredients exhibit diverse functional and structural characteristics, it is appropriate to consider their application in the form of blends. However, the blends to be used should be carefully studied prior to recommending their application. This study aimed to examine the effect of sodium caseinate and WPI, incorporated individually or blended in different proportions, on the pH value, lactic acid content, count of yogurt starter cultures, physical properties, texture and microstructure of the corn milk yogurt. Sodium caseinate at 0-4% and WPI at 0-1% were employed in this study because cow milk generally contains about 3-4% protein which consists of 80% casein and 20% whey protein (Fox and McSweeney, 1998; Walstra et al., 1999).

MATERIALS AND METHODS

Preparation of sweet corn milk

The sweet corn variety used in this study was an ATS-5 that was harvested on the 23rd day after silking of the corn plant. The sweet corn was purchased from Thaweesak Sweet Corn Group, Chiang Mai province, Thailand in September-November 2003. To prepare the corn milk, the sweet corn cobs were firstly husked, the silks removed and washed with water. The seeds were then separated from the cleaned cobs using knives. The corn seeds were extracted using a fruit extractor (Moulinex, Spain) to produce a milk solution. The corn milk solution was then filtered through a clean cloth and stored at -18°C until use.

Starter culture preparation

Stock culture

The freeze-dried starters of *S. thermophilus* No. 894 (ATCC 19258) and *L. delbrueckii* subsp. *bulgaricus* No. 892 (ATCC 11842) (Thailand Institute of Scientific and Technological Research, Thailand) were grown for 18 h at 37°C in M17 broth (Merck, Germany) and MRS medium (Merck, Germany), respectively. One loop of each culture was transferred into 10 ml of litmus milk prepared by mixing 16% (w/v) skim milk powder (SMP) (Mission, Thailand), 2% (w/v) of 1% (w/v) litmus concentration (BDH, England) and 0.3% (w/v) yeast extract (Difco, USA). The inoculated culture was incubated for 18 h at 37°C and stored at 5°C until use.

Mother culture

An individual mother culture was freshly prepared before conducting the experiment by inoculating one loop of stock culture into 100 ml of sterilized milk medium containing 16% (w/v) SMP and 0.1% (w/v) yeast extract. The inoculated culture was incubated at 37°C for 18 h and kept at 5°C until use.

Corn milk yogurt preparation

Distilled water was added to the corn milk in a ratio of 1:2, corn milk to water. The diluted corn milk was then preheated to 90°C prior to adding 2% (w/v) lactose, 4% (w/v) sodium caseinate and 0.4% (w/v) gelatin. The mixture was stirred for 5 min, followed by heating at 95°C for 5 min (Raphaelides and Gioldasi, 2005), and then cooled to 40°C. It was then inoculated with 2% (v/v) of yogurt starter culture which was composed of *S. thermophilus* and *L. delbrueckii* subsp. *bulgaricus* in a ratio of 1:1. The inoculum was poured into sterilized plastic cups and incubated at 40°C for 4 h until a pH 4.4-4.6 was reached. The set corn milk yogurts were prepared in triplicate.

Chemical analysis

Samples of corn milk yogurt were analyzed for total solid, protein contents, total acidity and pH value. The total solid, protein and total acidity were measured using the methods of AOAC 990.20, 991.20 and 947.05, respectively (AOAC, 2000). The total acidity was expressed as % lactic acid. The pH values were measured by a pH-meter Consort C830 (CE, Belgium).

Microbiological analysis

The yogurt samples were subjected to microbiological analysis for the viable numbers of yogurt starter cultures. *S. thermophilus* was enumerated using M17 agar (Merck, Germany) that was acidified to pH 6.8 by 1 M HCl (Merck, Germany) as described by International Dairy Federation (1997). The samples were incubated at 37±1°C under aerobic condition for 48 h. *L. delbrueckii* subsp. *bulgaricus* was enumerated by MRS agar (Merck, Germany) that was acidified to pH 5.4 using 100% glacial acetic acid (Merck, Germany). The samples were incubated at 37±1°C under anaerobic condition for 72 h (International Dairy

Federation, 1997).

Color

Color of corn milk yogurt was measured by a colormeter (Minolta Data Processor DP-301, Chroma Meter CR-300 Series, Japan), using the CIE L*C*h scale values.

Physical properties

Whey drainage

Whey drainage was removed from the corn milk yogurt, using a syringe within 24 h after the yogurt fermentation was completed. The relative amount of whey drained off (in ml per 100 ml of initial sample) was calculated as the whey drainage. This method was modified from the method of Fiszman et al., (1999).

Syneresis

A method of Wu et al., (2001) was used to measure the syneresis of corn milk yogurt. The analysis was carried out within 24 h after the yogurt fermentation was completed. The analysis was done using a Whatman filter paper number 1 to cover a Buchner funnel. After that, 20 g of the yogurt was spread in a thin layer to cover the surface of the filter paper. The funnel was then arranged on the top of an Erlenmeyer flask and the flask was connected to a vacuum pump. When all the system was set up, the yogurt was filtered under vacuum for 10 min. The liquid that passed through the filter paper was collected and recorded. The percentage syneresis was calculated as the weight of the liquid divided by the weight of the initial sample, multiplied by 100.

Water holding capacity

The water holding capacity was measured by a centrifuge method according to a modified method of Parnell-Clunies et al., (1986). Within 12 h of the production of corn milk yogurt, a 10 g sample was centrifuged at 2,000 g for 60 min at 10°C. The supernatant was then removed within 10 min and the wet weight of the pellet was recorded. The water holding capacity was expressed as the percentage of pellet weight relative to the original weight of corn milk yogurt.

Consistency

Yogurt samples were stirred within 24 h after the yogurt fermentation had completed. Yogurts were stirred for 1 min at 1,500 rpm at a temperature of 10°C. Samples were then poured into the slotted compartment of a Bostwick consistometer box until it was full. Consistency was determined by measuring the distance, expressed in cm, over which the samples flowed at 10°C in 30 s after the door of the equipment was removed. The measurement followed the method of González-Martínez et al., (2002).

Texture Profile Analysis (TPA)

TPA was carried out within 24 h after the yogurt fermentation had completed by a modified method of Kumar and Mishra (2004). It was performed using a TA-XT Plus (Stable Micro Systems, UK) with a 5 kg-load cell. Experiments were evaluated by compression tests which generated plot of force (g) vs. time (s). A 35 mm diameter cylindrical aluminum probe was used to measure the textural profile of a set yogurt sample prepared in a 100 ml cup at a temperature of $10\pm 0.5^{\circ}\text{C}$. In the first stage, the corn milk yogurts were compressed by 30% of their original depth. The speed of the probe was fixed at 0.5 mm/s during the pre-test, compression and the relaxation of the samples. The data presented were averages of three replications.

Microstructure

Within 24 h after the yogurt fermentation had completed, 0.3g samples were taken at about 1 cm below the surface and mixed with 0.3 g of 3% aqueous agar solution (Oxoid code L13, England) at 45°C , and the mixtures solidified by cooling at 20°C . The gelled samples were cut into approximately 1 mm cubes and fixed for 20 min at room temperature in a 2.5% glutaraldehyde solution in phosphate buffer (0.1 M, pH 7.3). The primary fixation was conducted twice to cross-link proteins. The fixed samples were then washed with phosphate buffer, and post-fixed in 1% osmium tetroxide solution in phosphate buffer for 1 h to stabilize unsaturated lipids. The post-fixed samples were washed with 0.1M phosphate buffer and dehydrated in a graded ethanol series (15, 30, 50, 70, 80, 95 and 100%, 30 min in each). Dehydrated samples were then dried with a Pelco CPD-2-critical point drier (Ted Pella Co., Redding, CA, USA). Dried sections were fractured with a blade and fragments were mounted on aluminum SEM stubs, and vacuum gold coated with a Fine Coat Jeol-JFC-1100 (Jeol Ltd., Akishima, Japan). Microstructure of the corn milk yogurts was examined with a scanning electron microscope Jeol model JSM-5910LV; (Jeol Ltd., Tokyo, Japan), using a magnification of 5,500X. The preparation of yogurt samples for microstructure examination followed the method of Sandoval-Castilla et al., (2004).

Statistical analysis

The collected data from chemical and microbiological analysis, color and TPA were analyzed statistically by an Analysis of Variance, using a Factorial Experiment in Complete Randomized Design (CRD) with 2 factors. The first factor was concentrations of sodium caseinate, which were 0, 2 and 4% (w/v). The second factor was concentrations of WPI, which were 0, 0.5 and 1% (w/v). A CRD was used to evaluate the data of the physical properties. If the F value from the Analysis of Variance was significant, a Duncan's New Multiple Range test was utilized to determine the significance of differences between treatment means (Montgomery, 2001). The statistical calculation was performed using SPSS statistical software version 10.0.1.

RESULTS AND DISCUSSION

Total solid and protein contents

The total solid content was significantly increased with higher level of sodium caseinate and/or WPI concentration ($P<0.05$) (Fig 1). Without supplementation of milk protein, gel structure in the yogurt was not observed. Similar results were reported by others. Remeuf et al., (2003) noted that yogurt making required fortification of 4-5% protein to obtain enough solid content. Lee et al., (1990) reported that soy milk formed a good gel at 8.12% protein contents, while Yazici et al., (1997) found that soymilk supplemented with calcium required only 5.4% protein to form a gel.

The corn milk yogurts with added WPI alone did not form a good gel at any of the tested concentrations. Sodium caseinate was a better fortifying protein, enabling a good gel to form at the concentration of 4% (w/v). Tamime and Robinson (1999) noted that the minimum solid concentration of cow milk yogurt was 8.2-8.65%, but the consistency of yogurt was greatly improved when the solids increased from 12 to 20%. The optimal total solids to produce yogurt from soy milk (Lee et al., 1990) and a mixture of mango pulp, soymilk and buffalo milk (Kumar and Mishra, 2004) were 11.49 and 12.26%, respectively.

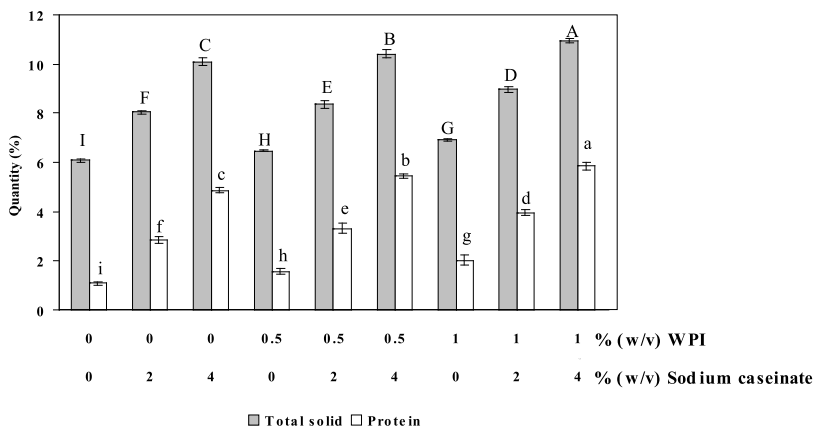


Figure 1. Total solid and protein contents of corn milk yogurts supplemented with different concentrations of sodium caseinate and WPI. Bars with different superscripts were significantly different ($P<0.05$).

pH value and total acidity of corn milk yogurt

The acidity of yogurt increased with increased added sodium caseinate when added either alone or with WPI while the pH decreased in yogurts with increased added caseinate only and increased in yogurts fortified with increasing proportions of sodium caseinate and WPI (Fig 2). This result suggested that sodium caseinate influenced the growth of cultures and production of acid, while the effect of WPI was much smaller than that of sodium caseinate.

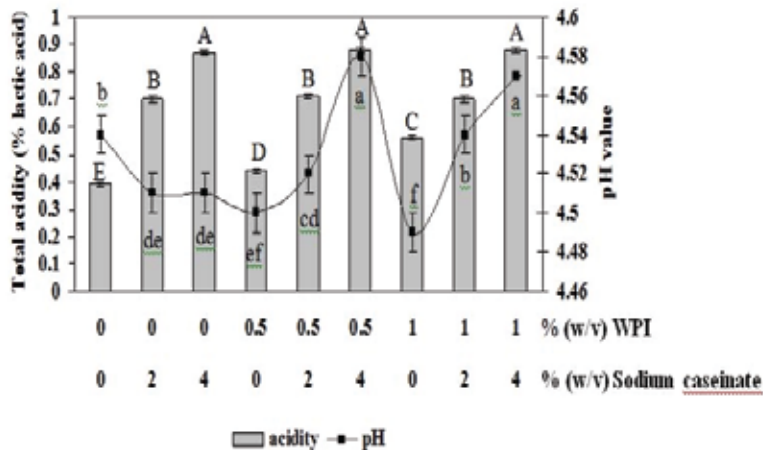


Figure 2. Total acidity and pH value of corn milk yogurts supplemented with different concentrations of sodium caseinate and WPI. Means with different letters were significantly different ($P < 0.05$).

Milk casein was a source of amino acids and nitrogen for growth of LAB (Shihata and Shah, 2000; Oliveira et al., 2001). Previous work discovered that both sodium caseinate and whey protein hydrolysate could enhance lactic acid production in soymilk yogurt (Granata et al., 1996). In case of cow milk yogurt, however, whey protein stimulated the growth of yogurt starter bacteria that produce lactic acid (Karleskind et al., 1991; Granata and Morr, 1996; Dave and Shah, 1998).

Viable cell counts of starter cultures

Sodium caseinate was found to be more effective than WPI in stimulating the growth of the starter bacteria (Fig 3). The result suggested that addition of 2% (w/v) sodium caseinate with or without addition of WPI provided nutrients that were sufficient for the counts to reach >9.26 log CFU/ml of *S. thermophilus* and >8.27 log CFU/ml of *L. delbrueckii* subsp. *bulgaricus*. The lesser growth of *L. delbrueckii* subsp. *bulgaricus* would be mainly because this culture cannot utilize sucrose in corn milk while sucrose was a nutrient for *S. thermophilus* (Thomas and Crow, 1983; Amoroso and Manca de Nadra, 1992; Wang et al., 2002).

Color

Sodium caseinate and/or WPI significantly affected the color of corn milk yogurt ($P < 0.05$). An increase in the lightness and a decrease in yellow color of corn milk yogurts were observed at higher concentrations of sodium caseinate and/or WPI (Figs 4 and 5). The results were in agreement with the observation of González-Martínez et al., (2002) who studied the change in color as affected by addition of casein. The higher milk protein content increased the total acid content

in corn milk yogurt and yielded better coagulation of protein. The coagulation of protein then affected the structure and surface properties of yogurt. Mor-Mur and Yuste (2003) reported that the increased protein coagulation enhanced the light absorption that resulted in the lighter tones.

According to the obtained h values, the colors of all yogurt samples were yellow (Minolta, 1994). The h value of corn milk yogurt decreased as the proportion of sodium caseinate and WPI in the yogurt increased (Figs 4 and 5).

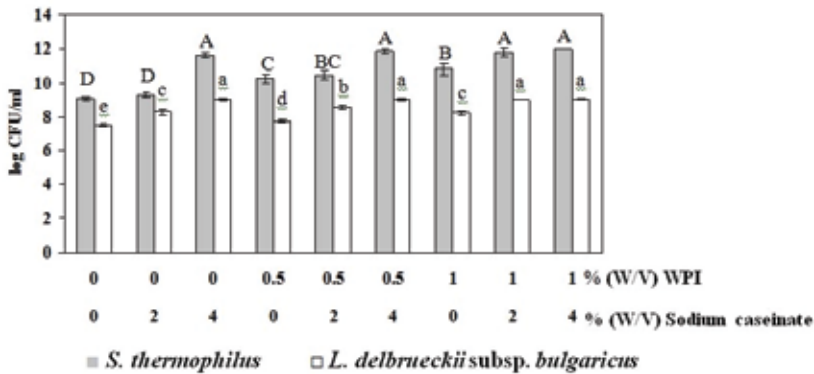


Figure 3. The viable numbers of *S. thermophilus* and *L. delbrueckii* subsp. *bulgaricus* in corn milk yogurts supplemented with different concentrations of sodium caseinate and WPI. Bars with different superscripts were significantly different ($P < 0.05$).

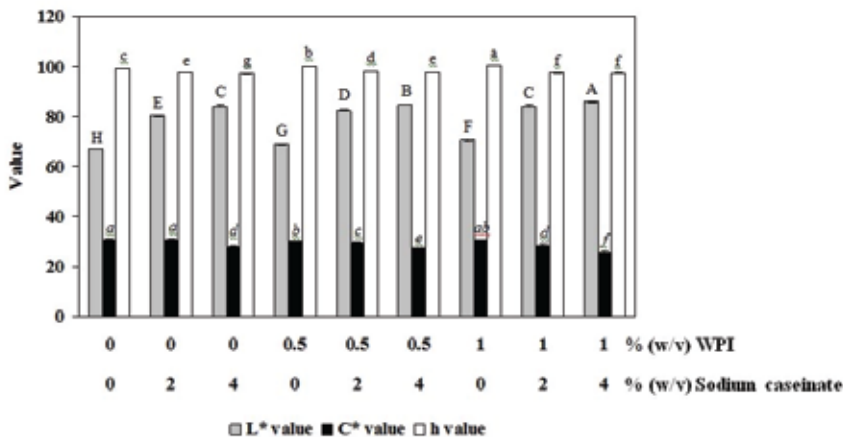


Figure 4. Color of corn milk yogurts fortified with different concentrations of sodium caseinate and WPI. Bars with different superscripts were significantly different ($P < 0.05$).



0 0 0 0.5 0.5 0.5 1 1 1 % (w/v) WPI
 0 2 4 0 2 4 0 2 4 % (w/v) Sodium caseinate

Figure 5. Corn milk yogurts fortified with different concentrations and types of milk protein.

Physical properties

The results (Table 1) revealed that the components in corn milk alone could not produce a product with a curd structure of yogurt. Thus, the physical properties of corn milk yogurt without addition of milk protein are not presented. However, corn milk could support the growth of *S. thermophilus* and *L. delbrueckii* subsp. bulgaricus as indicated by the reduction of pH (Fig 2). The total solid and protein contents in the corn milk yogurt were 6.07±0.08% and 1.09±0.07%, respectively (Fig 1), which were lower than those in cow milk yogurt. The important proteins in corn milk were zein (prolamins) and corn glutelin (Pomeranz, 1987; Lásztity, 1996) that cannot form a gel in the acid conditions of yogurt.

Table 1. Physical properties of corn milk yogurts supplemented with different levels of sodium caseinate and WPI*.

Sodium caseinate (%)	WPI (%)	Whey drainage (%)	Syneresis (%)	Water holding capacity (%)	Bostwick distance (cm)
0	0.0	ND	ND	ND	> 24
2	0.0	13.22±0.20 ^b	77.72±0.71 ^b	32.61±1.06 ^c	> 24
4	0.0	0.58±0.13 ^f	74.93±0.88 ^{cd}	40.63±1.22 ^b	10.03±0.50 ^c
0	0.5	23.82±0.18 ^a	81.76±0.75 ^a	32.80±1.07 ^c	> 24
2	0.5	2.35±0.40 ^d	77.21±1.33 ^{bc}	40.79±1.69 ^b	11.46±0.13 ^b
4	0.5	1.50±0.28 ^c	72.55±2.32 ^{de}	42.34±1.47 ^{ab}	6.15±0.84 ^e
0	1.0	0.62±0.18 ^f	71.43±1.24 ^c	42.17±0.42 ^{ab}	19.54±0.85 ^a
2	1.0	6.43±0.71 ^c	75.52±1.90 ^{bc}	42.43±2.20 ^{ab}	7.54±0.27 ^d
4	1.0	6.27±0.91 ^c	67.84±1.61 ^f	44.52±2.62 ^a	5.72±0.18 ^e

*Values in a column followed by different letters were significantly different ($P<0.05$).
 ND = Not determined

Table 1 shows that the whey drainage of corn milk yogurts decreased with increased proportion of sodium caseinate or WPI. The increase of total solids and protein contents might enhance the interactions between particles and, as a result, the ability of yogurt to hold water increases (Gastaldi et al., 1997; Amatayakul et al., 2006). Fortification with sodium caseinate and WPI gave different levels of whey drainage. For example, at 0.5% (w/v) WPI, the whey drainage decreased with increased concentrations of sodium caseinate. On the other hand, the proportion of sodium caseinate had no effect on whey drainage at 1.0% (w/v) WPI ($P \geq 0.05$). This may be because the high whey protein to casein ratio induced shrinkage of the gel, which led to increased whey drainage or whey separation (Lucey, 2004; Farnsworth et al., 2006). Syneresis was reduced with increased proportions of sodium caseinate and/or WPI. In contrast, water holding capacity of the corn milk yogurt increased with increasing proportions of the fortifying proteins while the ratios of sodium caseinate and WPI did not make a significant difference ($P \geq 0.05$) (Table 1). Generally, higher total solid causes an increase in density, and reduces pore size in the protein matrix of the yogurt gel. This leads to a reduction of syneresis and improvement of the water holding capacity of the gel (Keogh and O'Kennedy, 1998; Lorenzen et al., 2002; Sodini et al., 2004; Amatayakul et al., 2006). Keogh and O'Kennedy (1998) explained that casein and β -lactoglobulin interact chemically on heating. This effectively increases the concentration of gel-forming protein in the yogurt matrix and reduces syneresis through increased entrapment of serum within the interstices of the whey protein molecules attached to the surface of the casein. Augustin et al., (1999) noted that the denatured whey protein content had the major influence on resistance of yogurts to syneresis.

Adding sodium caseinate and/or WPI increased the consistency of corn milk yogurt (Table 1). The corn milk yogurts fortified with $<4.0\%$ (w/v) sodium caseinate which had $<10.08\%$ total solid (Fig 1) had a soft gel. This characteristic of soft gel could be due to the low solid content. Therefore, the increase in total solid through additions of sodium caseinate and/or WPI facilitated the gel formation. The less-open gel structure formed with high protein content would produce an aggregate network with high consistency. This was in agreement with Gozález-Martínez et al., (2002) who studied the influence of substituting milk powder for whey powder on yogurt quality. However, in their study, corn milk fortified with a low concentration of milk protein generally produced yogurt with a very weak gel. A hard gel was obtained at 4% sodium caseinate and 1% (w/v) WPI, when the total solid and protein contents were 10.94 and 5.86%, respectively (Fig 1).

Texture profile

Adding milk proteins positively affected the textural properties of corn milk yogurts. Hardness of the corn milk yogurts increased as higher levels of sodium caseinate and/or WPI were added (Fig 6). The similar result was reported by Gastaldi et al., (1997) Oliveira et al., (2001) and Amatayakul et al., (2006). The increase in total solid and casein contents led to an increase in the protein network and the number of linkages between particles in the yogurt matrix (Gastaldi et al.,

1997; Keogh and O’Kennedy, 1998). According to Amatayakul et al., (2006), the denatured whey protein on the surface of casein micelles increased with a reduction in the sodium caseinate to WPI ratio. This would prevent the coalescence of casein micelles and network formation, and result in decreased hardness of the yogurt. The same trend was shown for the adhesiveness study. The springiness was not significantly affected by the additions of sodium caseinate or WPI.

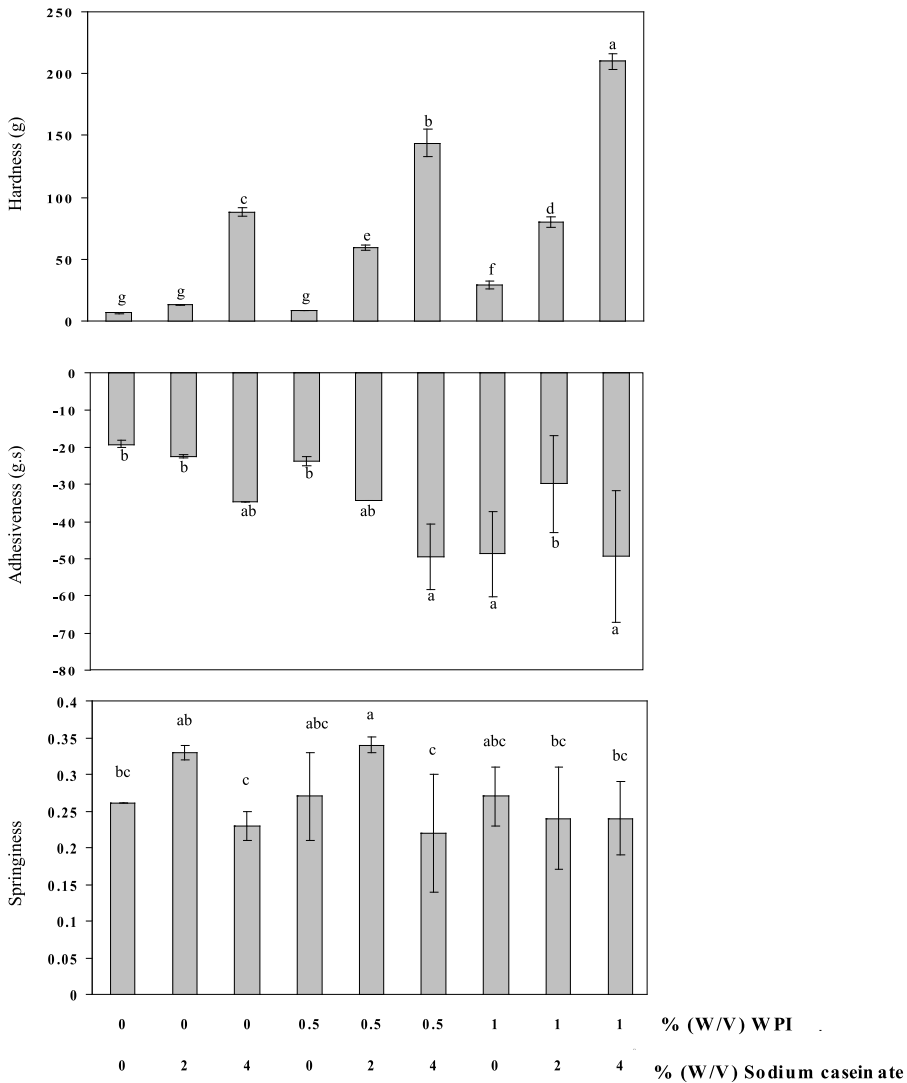


Figure 6. Texture profiles of corn milk yogurts supplemented with different concentrations of sodium caseinate and WPI. Bars with different superscripts were significantly different ($P<0.05$).

Microstructure

Scanning electron micrographs in Fig 7 revealed that the microstructure of the gel of corn milk yogurt was influenced by both types and concentrations of milk proteins, i.e., casein and whey protein. The control corn milk yogurt did not exhibit a gel structure. A thick compact structure and large holes were observed in the control corn milk yogurt. As mentioned previously, zein in corn milk cannot form a gel at pH 4.6. Adding enough milk protein, for example, 4.0% (w/v) sodium caseinate, 1.0% (w/v) WPI and a combination of 4.0% sodium caseinate and 1.0% (w/v) WPI, could enhance the interactions between particles and increase the density of the matrix. This phenomenon induced the formation of a gel structure.

The corn milk yogurt with 4.0% (w/v) added sodium caseinate had a spongy structure with regular pore sizes. Its pore size was smaller than that of the control corn milk yogurt (Figs 7 (b) and (a), respectively). The corn milk yogurt with added 1.0% (w/v) WPI exhibited a non-spongy network with irregular pore size. Thus, the corn milk yogurt with 1.0% (w/v) added WPI had less consistency and hardness (Fig 6).

The gel structure of corn milk yogurt with 4.0% (w/v) added sodium caseinate and 1.0% (w/v) WPI exhibited irregular pore size and a finer network than that of the corn milk yogurt with only sodium caseinate added. Moreover, the micrograph of the fortified corn milk yogurt displayed a shrinkage structure (Fig 7). This shrinkage structure might be responsible for low syneresis, and high values of whey drainage, water holding capacity, consistency, hardness, adhesiveness and gumminess of the yogurt.

Saint-Eve et al., (2006) observed that milk proteins including sodium caseinate, SMP and whey protein concentrate, caused differences in the structure of the gel network. Sodium caseinate provided a gel with a heterogeneous structure with large pores. When yogurts were enriched with whey protein, the protein network was more uniform and the pores of the gel were smaller as compared to those of yogurts to which sodium caseinate was added. Remeuf et al., (2003) stated that the gels of whey protein concentrate-enriched yogurts exhibited a very fine network with small pores. Puventhiran et al., (2002) reported that adding whey protein led to a structure where casein micelles appeared in the form of individual entities surrounded by finely-flocculated protein and linked to very small whey protein aggregates. This structure might increase the number of bonds between particles and explain the dense and finely-branched network in yogurt from whey protein-enriched milk.

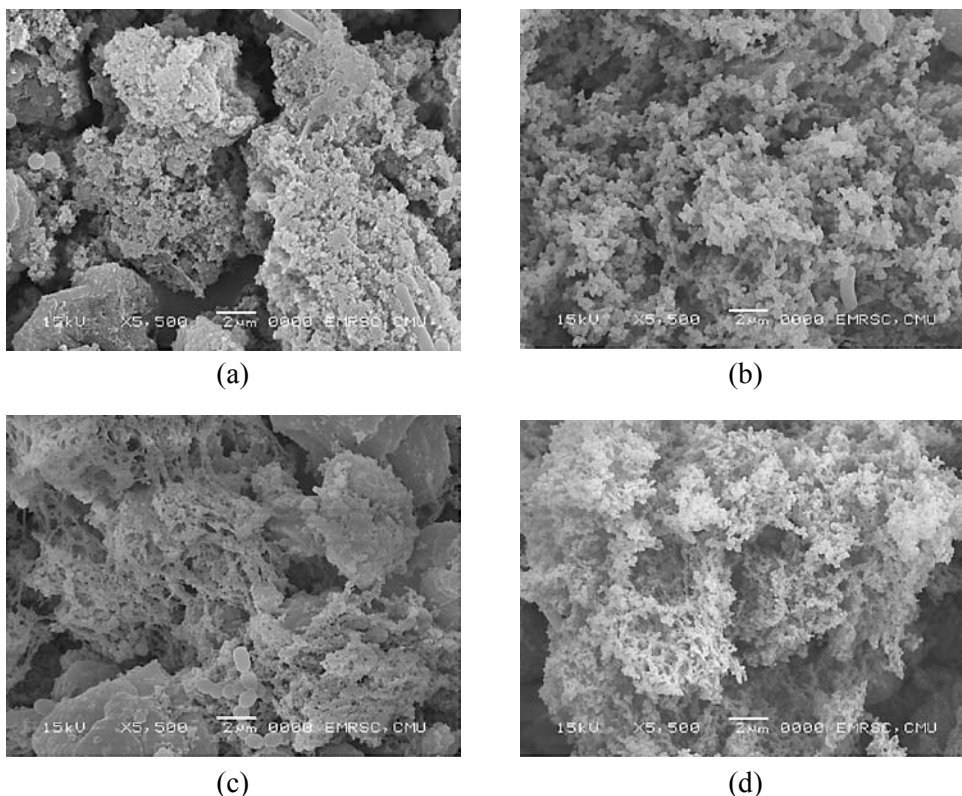


Figure 7. Scanning electron micrographs of corn milk yogurt without protein supplementation (a) and corn milk yogurt supplemented with 4.0% (w/v) sodium caseinate (b), 1.0% (w/v) WPI (c), 4.0% (w/v) sodium caseinate and 1.0% (w/v) WPI (d).

CONCLUSION

Sodium caseinate and WPI significantly affected the production of lactic acid, pH value, counts of *S. thermophilus* and *L. delbrueckii* subsp. *bulgaricus*, color, physical and textural properties, and the microstructure of corn milk yogurts. Lactic acid production, pH values and counts of starter cultures were enhanced by addition of milk proteins. The lightness of the corn milk yogurt increased but the yellow color was lower with increases in sodium caseinate and/or WPI concentration. The yellowness of yogurt decreased with increased WPI concentration while addition of sodium caseinate enhanced the yellowness of yogurt. Water holding capacity and consistency were increased, whereas syneresis was decreased with higher concentrations of sodium caseinate and/or WPI. Whey drainage was mainly reduced by adding sodium caseinate.

The fermented corn milk alone did not produce a yogurt gel. However, fortification of corn milk with only 4.0% (w/v) sodium caseinate enabled the production of corn milk yogurt. At this condition, the yogurt contained the high-

est counts of starter cultures and the lowest whey drainage. Besides, it produced a homogeneous gel network with a small pore size.

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