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Salt Reduction in a Model High-Salt Akawi Cheese: Effects on Bacterial Activity, pH, Moisture, Potential Bioactive Peptides, Amino Acids, and Growth of Human Colon Cells

Akanksha Gandhi and Nagendra P. Shah

Abstract: This study evaluated the effects of sodium chloride reduction and its substitution with potassium chloride on Akawi cheese during storage for 30 d at 4 °C. Survival of probiotic bacteria (Lactobacillus acidophilus, Lactobacillus casei, and Bifidobacterium longum) and starter bacteria (Streptococcus thermophilus and Lactobacillus delbrueckii spp. bulgaricus), angiotensin-converting enzyme-inhibitory and antioxidant activities, and concentrations of standard amino acids as affected by storage in different brine solutions (10% NaCl, 7.5% NaCl, 7.5% NaCl+KCl [1:1], 5% NaCl, and 5% NaCl+KCl [1:1]) were investigated. Furthermore, viability of human colon cells and human colon cancer cells as affected by the extract showing improved peptide profiles, highest release of amino acids and antioxidant activity (that is, from cheese brined in 7.5% NaCl+KCl) was evaluated. Significant increase was observed in survival of probiotic bacteria in cheeses with low salt after 30 d. Calcium content decreased slightly during storage in all cheeses brined in various solutions. Further, no significant changes were observed in ACE-inhibitory activity and antioxidant activity of cheeses during storage. Interestingly, concentrations of 4 essential amino acids (phenylalanine, tryptophan, valine, and leucine) increased significantly during storage in brine solutions containing 7.5% total salt. Low concentration of cheese extract (100 μg/mL) significantly improved the growth of normal human colon cells, and reduced the growth of human colon cancer cells. Overall, the study revealed that cheese extracts from reduced-NaCl brine improved the growth of human colon cells, and the release of essential amino acids, but did not affect the activities of potential bioactive peptides.

Keywords: Akawi cheese, bioactive peptides, Caco-2 cell line, human colon cell line, salt reduction

Introduction

Sodium chloride (common salt, NaCl) is an important food additive and it contributes to the taste, texture, and enhanced shelf life of the food product (Albarracin and others 2011). Increased intake of NaCl is associated with increased risk of hypertension, osteoporosis, and kidney stones, thus there has been a need to reduce the NaCl intake (Buemi and others 2002; Kotchen 2005; Massey 2005; Heaney 2006). Dairy products, particularly brined cheeses, contribute to increased sodium intake. However, as NaCl significantly impacts the textural and sensory properties of cheese, it is difficult to completely remove it from the product. Recent studies have shown that salt concentration (ratio of sodium chloride and potassium chloride) affects the bacterial cell membrane, viability (Gandhi and others 2014; Gandhi and Shah 2015) and proteinase activity (Ayyash and others 2013a) of common dairy bacteria. It is therefore critical to evaluate the effects of varying salt concentrations (sodium and potassium chloride) in brine solution, which impacts the activity of bacteria in cheese.

The effects of reduction or substitution of NaCl in certain cheeses have been extensively studied (Katsiari and others 1997; Mistry and Kasperson 1998; Ayyash and others 2013b). Although the study by Katsiari and others (1997) showed no significant changes in composition, texture, and sensory properties, a study by Ayyash and Shah (2011) has revealed changes in small peptides in cheeses made using partial substitution of NaCl with KCl. In general, the type of cheese, osmotic tolerance of bacteria and salting period, are among the factors that determine the properties of the product (Gobbetti and others 1999; Floury and others 2009). Furthermore, with the increasing use of probiotic bacteria in cheeses (da Cruz and others 2009), it is important to evaluate the effects of salt stress on survival of probiotic organisms in food matrix.

Middle Eastern brined cheeses are mostly rennet-coagulated and are categorized based on addition of and type of starter culture. In general, most of the Middle Eastern cheeses are chalky white in color, possess very mild odors and, have a strong salty and acidic taste (Tamime 2008). Among the various varieties of Middle Eastern cheeses, Braided cheese is a hard cheese, Halloumi cheese is semi-hard to hard type and, Akawi and Nabulsi have been classified as semi-hard cheeses. A common characteristic of most Middle Eastern cheeses is a high salt content (Abd El-Salam and Alchianidis 2004). Akawi cheese, which is commonly consumed in Lebanon, Jordan, Palestine, and Syria, is conventionally brined for 1 mo in 10% brine solution. There is limited information on the effects of reduction of NaCl and substitution with KCl in Middle Eastern Cheeses (Ayyash and others 2012), and this is the 1st study evaluating the effects of salt reduction on release of potential bioactive peptides and amino acids using Akawi cheese as a model for high-salt cheeses.

Fermented milk products like yogurt and cheese are well known for their bioactive properties. The release of these peptides is affected by proteolysis during ripening or brining of cheese. The
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Brine concentration may influence the bacterial activity and proteolysis, and in turn, the properties of the peptides released. Cytochemical studies have shown that milk-derived peptides can affect the viability and growth of cancer cells (Hartmann and Meisel 2004). It is therefore important to evaluate the effect of these peptides on the growth of colon cells. In this study since the cheese (prepared with 3 potential probiotic bacteria and 2 starter bacteria) was brined for 1 mo, we wanted to investigate whether these milk-derived peptides released during brining might impact the colon cell growth, and thus a comparative study on growth of normal and cancerous colon cells was performed. To the best of our knowledge, no study has evaluated the comparative effect of cheese extracts on the normal and cancerous human colon cells. The objectives of this study were to evaluate the effects of NaCl reduction with and without potassium chloride substitution on survival of probiotics, moisture content, pH, and formation of potential bioactive peptides (angiotensin-I converting enzyme (ACE)-inhibitory and anti-oxidant) and release of amino acids in Akawi cheese. The effect of cheese extracts on the growth of normal human colon cell line (CCD 841) and human colon cancer cell line (Caco-2) was also evaluated for selected cheese extracts.

Materials and Methods

Bacteria cultivation

Streptococcus thermophilus MS (ST), Lactobacillus delbrueckii sp. bulgaricus ASC 859 (LB), Lactobacillus acidophilus CSCC 2400 (LA), Lactobacillus casei ASCC 290 (LC), and Bifidobacterium longum CSCC 5089 (BL) were obtained from Australian Starter Culture Collection (Dairy Innovation Australia Ltd., Werribee, Vic., Australia). Bacterial cultures were stored in sterile de Mann Rogosa Sharpe (MRS) broth (Becton Dickinson and Co., Franklin Lakes, N.J., U.S.A.) supplemented with 20% glycerol at –80 °C. Each bacterium was activated as a pure culture by 1% inoculation from Kowloon Dairy, Hong Kong. The milk was tempered at 40 °C and ST, LB, LA, LC, and BL were added at 1.5% (vol/vol) each and mixed thoroughly for 2 min. Milk was coagulated after 45 min by addition of diluted (1:15) chymosin (15 mL per 5 L milk; Kosher Halal Chymax Plus; Chr. Hansen Pty Ltd., Bayswater, Vic., Australia). After 40 min, the curd was cut into cubes (1 cm³) using cheese knife and was allowed to settle for 15 min. The whey was drained and curd cubes were transferred to cheesecloth for further removal of whey for 20 min. Curd pieces were wrapped in cheesecloth in small portions (~200 g) and pressed (20 kg weight per 400 g curd) for 90 min at ambient temperature using a cheese press (Mad Millie, Auckland, New Zealand). Cheese blocks (semi-circular with 10 cm diameter × 2 cm thickness) were then placed in 5 different brine solutions (wt/vol): 10% NaCl (batch A), 7.5% NaCl (batch B), 7.5% (NaCl + KCl, 1:1) (batch C), 5% NaCl (batch D), and 5% (NaCl + KCl, 1:1) (batch E) at 1:5 cheese brine ratio and stored at 4 °C for 1 mo. Samples were taken for analysis at 0 (fresh cheese), 10, 20, and 30 d of storage. The experiment was repeated in triplicate.

Survival of bacteria

For evaluating the survival of bacteria, grated cheese (12.5 g) was blended into 112.5 mL of peptone water (0.15% wt/vol). Serial dilutions were made and each type of bacteria was enumerated on appropriate agar as described below (Tharmaraj and Shah 2003; Dave and Shah 1996; Lapierre and others 1992). Anaerobic conditions, when required, was maintained using anaerobic jars and GasPak anaerobe container system (Becton Dickinson and Co.). Gram staining was carried out and colony morphology was closely monitored to ensure the growth of a pure culture. Streptococcus thermophilus MS were enumerated on M17 agar (Becton Dickinson and Co.) and aerobically incubated at 37 °C for 36 to 48 h. Lactobacillus delbrueckii sp. bulgaricus 859 were enumerated using pH-modified (pH 5.2) MRS agar plates and incubated anaerobically at 40 °C for 48 h. Lactobacillus acidophilus was enumerated on MRS agar supplemented with sorbitol (10% wt/vol; Sigma Aldrich, St. Louis, Mo., U.S.A.) and Lactobacillus casei on MRS agar supplemented with vancomycin (2 mL of 0.5 mg/mL vancomycin per liter of media; Sigma Aldrich), and both were incubated anaerobically at 37 °C for 48 h. Bifidobacterium longum was enumerated on MRS agar supplemented with sodium propionate (3% wt/vol; Sigma Aldrich) and lithium chloride (2% wt/vol; Sigma Aldrich) and the plates were incubated anaerobically at 40 °C for 36 to 48 h.

Determination of sodium, potassium, and calcium contents

Sodium, potassium and calcium contents in cheeses were determined using inductively coupled-plasma optical-emission-spectrometry (PE Optima 8300; PerkinElmer, Mass., U.S.A.; software WinLab32 version 5.1.3.0550) according to Ayyash and others (2012) with some modifications. Cheese (5 g, grated) was digested in a mixture of nitric acid and perchloric acid (5:1; Merck, Darmstadt, Germany) on a hot plate until the mixture was a clear solution. The samples were filtered with a 0.22 μm Millipore filter and diluted 100 times before analysis. Sodium, potassium, and calcium concentrations in cheese samples were determined using external standard curves of these 3 elements.

Determination of moisture and pH

Moisture content of cheeses was determined by oven-drying (100 ± 2 °C) method (Oksuz and others 2004). pH of cheese samples was measured after blending 10 g of grated cheese in 10 mL distilled water, using a calibrated pH meter (Model 250A, Orion, Boston, Mass., U.S.A.).

Preparation of water-soluble extracts

Cheese samples (15 g) were homogenized in 15 mL of water with a homogenizer (Ultra Turrax T25, Janke & Kunkel, Staufen im Breisgau, Germany) at 9500 × g for 2 min. The homogenized slurry was centrifuged for 20 min at 4000 × g and 4 °C. The soluble fraction between the upper layer (fat) and the precipitate (casein) was collected and filtered through Whatman No. 4 filter paper. The extracts were centrifuged at 4000 × g for 20 min at 4 °C and filtered through Whatman glass microfiber filter (GF/C) to obtain a clear supernatant (water-soluble extract, WSE). The water-soluble extracts were concentrated by freeze-drying and the freeze-dried WSEs were stored at −20 °C for determination of amino acids, using reversed-phase high performance liquid chromatography (RP-HPLC), ACE-inhibitory activity, antioxidant activity, and the cell line viability assays.
Determination of protein content and proteolytic activity

Protein content in water-soluble extracts of cheeses was measured using Bradford method (Bradford 1976) as described by Apostolidis and others (2007). Briefly, 1.5 mL of Bradford reagent was mixed with 0.05 mL WSE and incubated at room temperature (22 °C) for 5 min after which absorbance at 595 nm was recorded using a UV–VIS spectrophotometer (SmartSpec Plus Spectrophotometer, BioRad, Hercules, Calif., U.S.A.). Protein content was calculated using a standard curve plotted using known concentrations of bovine serum albumin (BSA; Sigma Aldrich).

Proteolytic activity of cheese extracts was determined by o-phthalaldehyde (OPA) method of Church and others (1983) with some modifications as described by Modelišhad and others (2013) and Gandhi and Shah (2014). Briefly, 50 μL of WSE was added to 1 mL of OPA reagent in a cuvette. The cuvette was inverted twice followed by incubation at room temperature (22 °C) for 2 min. Absorbance was recorded at 340 nm using UV–VIS spectrophotometer (Shimadzu Scientific Instruments, Japan).

Peptide profiles of cheese extracts using high performance liquid chromatography

An aliquot (40 mg) of freeze-dried WSE was dissolved in 1 mL solvent A (0.1% trifluoroacetic acid (TFA, Sigma-Aldrich), centrifuged (12000 × g, 10 min) and filtered using 0.22-μm millipore filter. Separation of peptide peaks was performed using RP-HPLC (Model LC-2010A, Shimadzu Corporation, Kyoto, Japan) and Kromasil 5 μ C-18 column (250 mm × 4.6 mm; Phenomenex, Calif., U.S.A.). Eluent B was 60% acetonitrile containing 0.05% TFA. A linear gradient was applied from 0% to 80% eluent B over 90 min. Injection volume was 50 μL and the separation was conducted at 40 °C at a flow rate of 0.5 mL/min, and detection wavelength was 214 nm.

Determination of ACE-inhibitory activity

Angiotensin-converting enzyme (ACE)-inhibitory activity of freeze-dried WSE (5 mL freeze-dried WSE in 1 mL distilled water) was determined by the method of Cushman and Cheung (1971) with some modifications as described by Gandhi and Shah (2014). Briefly, an aliquot (200 μL) of hippuryl-histidyl-leucine (Sigma Chemical Co.) buffer (5 mM Hip–His–Leu in 0.1 M borate buffer containing 0.3 M NaCl, pH 8.3) was mixed with 60 μL of sodium borate buffer and pre-incubated with 20 μL of the sample for 5 min at 37 °C. The reaction was initiated by adding 20 μL of ACE solution (buffer containing ACE at a concentration of 0.1 unit/mL) followed by incubation at 37 °C for 30 min. Hydrochloric acid (250 μL, 1 M) was added to stop the reaction and the solution was then mixed with 1.7 mL of ethyl acetate. The mixture was centrifuged (3000 × g, 10 min 4 °C) and 1.4 mL of the organic phase (ethyl acetate) was transferred to a fresh test tube. The ethyl acetate was evaporated to dryness on a water bath for 30 min at 100 °C. Hippuric acid residue was dissolved in 1 mL of deionized water, and the absorbance of the solution was recorded using a UV–VIS spectrophotometer (Shimadzu Scientific Instruments, Japan) at 228 nm against water as blank. The ACE-inhibitory activity was calculated as follows:

\[
\text{ACE} - \text{inhibitory activity (} \% \text{)} = \left[1 - \left( \frac{C - D}{A - B} \right) \right] \times 100
\]

where A is the absorbance in the presence of ACE and without the ACE-inhibitory component, B is the absorbance without ACE and without the ACE-inhibitory component, C is the absorbance with ACE and the ACE-inhibitory component, and D is the absorbance without ACE and with the ACE-inhibitory component.

Determination of antioxidant activity

The DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity of cheese was determined as described by Abadía-García and others (2013). Briefly, 100 μL of sample (5 mL freeze-dried WSE in 1 mL distilled water) was mixed with 1.1 mL ethanololic solution of DPPH (0.2 mM). Absorbance was measured at 517 nm using a UV–VIS spectrophotometer (SmartSpec Plus Spectrophotometer, BioRad) after 30 min. The results were expressed as a function of trolox concentration.

Quantification of amino acids

Dansylation of free amino acids. Derivatization of amino acids was performed using dansyl chloride as per Le Vo and others (2012) with some modifications. The reaction mixture consisted of 300 μL sample (5 mL freeze-dried WSE dissolved in 1 mL distilled water), 100 μL double-distilled water, 200 μL 1 M sodium bicarbonate buffer (pH 9.8), 200 μL acetonitrile, and 100 μL dansyl chloride (40 g/L in acetonitrile). After incubation at 65 °C for 1 h in dark, 100 μL of 20% (vol/vol) acetic acid was added to stop the reaction. The reaction mixture was centrifuged at 12000 × g for 10 min at 25 °C and the supernatant was filtered using a 0.22-μm millipore filter and stored at −20 °C for HPLC analysis. Calibration curve for a mixture of 20 standard amino acids was prepared using the same method (Wu and Shah 2015).

Detection of amino acids by HPLC. Dansylated amino acids were quantified by RP-HPLC (Model LC-2010A, Shimadzu Corporation, Kyoto, Japan) using a guard column (Phenomenex) and Kromasil 5 μ 100 Å C18 column (250 mm × 4.6 mm; Phenomenex) as described by Wu and Shah (2015). Eluent A was 30 mM ammonium acetate, pH 7.5 and B was acetonitrile. The column was eluted with a linear gradient of 6% to 10% B over 0 to 5 min, 10% to 18% B over 5 to 7 min, 18% to 22% B over 7 to 15 min, 22% to 26% B over 15 to 18.5 min, 26% to 28.5% B over 18.5 to 22.5 min, 28.5% to 30% B over 22.5 to 24 min, 30% to 32% B over 24 to 27.5 min, 32% to 55% B over 27.5 to 40 min, 55% to 50% B over 40 to 45 min, 50% to 6% B over 45 to 55 min and held at 6% B for 5 min. The flow rate of mobile phase was 1 mL/min. Temperature was maintained at 30 °C, injection volume was 20 μL and detection wavelength was 275 nm.

Cell lines

Two cell lines were selected for this study: normal human colon cells, CCD 841 and human colon cancer cells, Caco-2 cells. CCD 841 cells were generously provided by Dr. Tao’s lab in The Chinese University of Hong Kong, Hong Kong, and Caco-2 cells were from the American Type Culture Collection (ATCC).

Caco-2 and CCD cells were cultured in Dulbecco’s modified Eagle’s minimum essential medium (DMEM; Gibco BRL, Life Technologies, Grand Island, N.Y., U.S.A.) and Eagle’s minimum essential medium (EMEM; ATCC, Manassas, Va., U.S.A.), respectively. Both media were supplemented with 10% fetal bovine serum (FBS) and 1% penicillin–streptomycin (10000 U/mL) (Gibco BRL). Cells were incubated at 37 °C in an incubator (US Air Flow, NuAire, U.S.A.) with 5% CO₂. At about 80% confluence, the cells were subcultured by trypsinization using 0.25% trypsin-EDTA (Gibco BRL) and resuspended in fresh media. Caco-2 cells used in this study were between passages 32 and 38, and CCD cells were between passages 11 and 16.
Cell viability assay
Viability of cells was measured using mitochondrial dehydrogenase activity assay with the substrate 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) (van Meeloo and others 2011). Briefly, the cells were subcultured and seeded in 96-well flat bottom plates (Nunc, Thermo Scientific, Suzhou, China) at 2 x 10^4 cells/mL and allowed to grow for 48 h. The cells were then washed with sterile PBS and cultured with antibiotic free media supplemented with varying concentrations (0 to 2000 μg/mL) of freeze-dried water-soluble extracts (WSE) of cheeses (batch A and batch C). The WSE was freshly prepared by dissolving freeze-dried WSE in media in appropriate dilutions. An aliquot (100 μL) of filter sterilized sample (pure media with WSE) or control (pure media with no WSE) was added to each well and incubated for 24 h in the CO2 incubator. The culture media was then inoculated with 10 μL MTT reagent (0.5 mg/mL; Sigma) under dim light and the plates were incubated for 4 h at 37°C in dark. The crystal product formed was dissolved using 100 μL acidified isopropanol and absorbance was recorded at 595 nm using iMark microplate reader (BioRad).

Statistical analysis
All experiments were replicated thrice and all analyses were carried out in duplicate. Data obtained were analyzed using one-way analysis of variance (ANOVA) at 95% level of significance using SPSS statistics software v 20.0 (IBM Corp, Armonk, N.Y., U.S.A.). Tukey's post hoc analysis was performed to further investigate the difference in the means of different cheeses at same storage period. Pearson correlation coefficients were determined in the correlation analyses.

Results and Discussion
Survival of bacteria
Survival of starter and probiotic bacteria was monitored at every 10 d during storage for 1 mo (Figure 1). No significant differences

Moisture content and pH
Moisture content of Akawi cheese was not significantly (P > 0.05) affected by varying NaCl/KCl concentrations up to 20 d of storage (Table 1), although an increasing trend was observed. Similar trend was observed in Cheddar cheese salted with varying concentrations of NaCl/KCl (Hystead and others 2013). However, after 30 d, significant (P < 0.05) difference in batch B and D, which contain only reduced NaCl, was observed. Akawi cheese, like most Middle Eastern brined cheeses is characterized by acidic taste (Tamime 2008). The pH of different batches of cheese was not significantly (P > 0.05) affected by salt concentrations during 30 d storage (Table 1). The moisture content and pH range are different than those reported by Ayyash and others (2012) which may be attributed to several factors such as difference in milk, type of chymosin (Chy Max plus was used in this study), differences in bacterial strains, and addition of another bacterium (B. longum). The pH increased slightly (P < 0.05) during storage for batch C cheese that was stored in brine solutions containing KCl. This

Figure 1—Survival of starter and probiotic bacteria in cheese as affected by NaCl reduction and substitution with KCl during 30 d storage at 4 °C.

*Brine Solutions: 10% NaCl (A); 7.5% NaCl (B); 7.5% NaCl+KCl (1:1) (C); 5% NaCl (D); 5% NaCl+KCl (1:1) (E). *Means within a storage period are significantly different (P < 0.05) from the control (batch A). Values are means ± SE (n ≥ 3). ST, S. thermophilus; LB, L. delbrueckii ssp. bulgaricus; LA, L. acidophilus; LC, L. casei; BL, B. longum.
Table 1—Moisture content and pH of cheeses as affected by NaCl reduction and substitution with KCl during 30 d storage at 4 °C.

<table>
<thead>
<tr>
<th>Storage time (d)</th>
<th>Brine solution*</th>
<th>Moisture content (%)</th>
<th>pH</th>
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<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>10</td>
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<tr>
<td>30</td>
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</table>

Values are means ± SE (n ≥ 3).

*Brine solutions: 10% NaCl (A); 7.5% NaCl (B); 7.5% NaCl+KCl (1:1) (C); 5% NaCl+KCl (1:1) (D); 5% NaCl+KCl (1:1) (E).

A decrease in the protein levels during ripening of Turkish White cheese was attributed to diffusion of proteolytic difference may be due to higher pH of KCl solution as compared to NaCl solution (Katsiari and others 1997).

Sodium, potassium and calcium contents

Sodium, potassium and calcium contents as determined by optical emission spectrometry are shown in Figure 2. Sodium and potassium contents of cheeses were found to be in accordance with the amount of sodium and potassium, respectively, in the brine solution, that is sodium content in A was highest followed by B, D, C, and E, respectively. The sodium content in cheese was significantly (P < 0.05) lower in batches C, D, and E, as compared to the control after 10 d of storage. After 10 d of storage in brine solutions, the highest sodium content was observed in the control (batch A) 392 mg per 100 g cheese, as compared to batch E which was 118 mg per 100 g. Potassium content was found to be in agreement with the addition of potassium in the brine solution. Significant (P > 0.05) increase was observed in the potassium levels in batch C and E after 10 d of storage in brine-containing KCl. A decrease in the calcium content in all cheese types was observed which might be due to transfer of calcium ions from cheese matrix into the brine solution during storage. However, no significant (P > 0.05) differences were observed in the calcium content within different experimental cheeses beyond 10 d of storage. The decrease in calcium content during brining is attributed to the sodium–calcium interchange or potassium–calcium interchange (Guinee and Fox 1993). It has been reported that addition of 5% sodium chloride in cheese matrix increases the calcium content in the serum (Creamer 1985).

Protein Content, Proteolytic Activity, and Peptide Profile

Protein content in water-soluble extracts of cheese as determined by Bradford method is shown in Figure 3(A). A reduction in protein content in WSE of most types of cheeses was observed after 10 d of storage. This reduction in initial 10 d of storage could possibly be due to the migration of solubilized casein and serum proteins in fresh cheese into the brine solution (Katsiari and others 2000). Another possible cause of protein reduction in WSE could be due to movement of soluble minerals in the cheese during brining, thereby affecting the protein conformations in cheese matrix. During brining in salt, the sodium and the chloride ions migrate from the brine into the cheese matrix due to the osmotic pressure differences in cheese and brine. As a result of this, and to restore osmotic pressure equilibrium, the water (from cheese) containing soluble acids and minerals diffuse out with a flux which is 2 times more than that of NaCl (Guinee and Fox 1993). These dynamic and complex transport systems cause several changes in the composition and texture of cheese during ripening based on several variables (such as brine temperature, cheese to brine ratio, and so on). A decrease in the protein levels during ripening of

Figure 2—Sodium (Na), potassium (K) and calcium (Ca) contents of cheeses as affected by NaCl reduction and substitution with KCl during 30 d storage at 4 °C. *Brine Solutions: 10% NaCl (A); 7.5% NaCl (B); 7.5% NaCl+KCl (1:1) (C); 5% NaCl (D); 5% NaCl+KCl (1:1) (E). *Means within a storage period are significantly different (P < 0.05) from the control (batch A). Values are means ± SE (n ≥ 3).
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products into the brine (Hayaloglu and others 2002), as a result of which the amount of total nitrogen in the brine increases during ripening (Ehsani and others 1999).

The proteolytic activity during storage plays an important role in release of flavor compounds and amino acids. In this study, the properties of the water-soluble cheese extract, which is rich in peptides and amino acids, were evaluated. Cheeses brined in varying salt (NaCl/KCl) concentrations would impact the proteolysis in cheese and thus possibly the amino acids and the activity of the peptides released. It was therefore critical to evaluate the bioactivities (such as antioxidant, ACE-inhibitory, and colon cell viability) in the water-soluble extracts of these cheeses. The increased proteolytic activity (Figure 3B) observed in Akawi cheese WSE, particularly in those brined with lower NaCl concentration, contributed to enhanced production of amino acids in the product (Table 2). The changes in the overall peptide profile of WSE of cheese indicate increased presence of peptides in cheeses brined in lower salt concentration (7.5% and 5%) as compared to those brined in higher total salt concentrations (10%). The peptide profile (Figure 3C) of all stored cheeses showed increased proteolysis as compared to the profile of fresh cheese, which indicated that there was increased proteolysis in cheese during storage. The peak intensities of the peaks in highlighted regions were the most significantly affected by varying salt concentrations of the brine solutions. Batch C (segments S1 to S3, Figure 3C) shows most changes in the number and intensity of peaks as compared to the control, batch A. An obvious increase in the peak at the retention time of 28, 64, 66, 68, and 78 min was observed in batch C as compared with the batch A (control). These changes in peptides are indicative of increased proteolysis in batch C, which was brined with 7.5% NaCl:KCl (1:1).

ACE-inhibitory activity

ACE-inhibitory peptides are biologically active peptides that possess antihypertensive properties and have been detected in fermented milk products, released by bacterial proteinases and peptidases during fermentation. In this study, the ACE-inhibitory activity of freeze-dried WSE of Akawi cheese was monitored in different batches during storage (Figure 4). In general, ACE-inhibitory activity was found to be higher in batch D and E, which had the lowest amount of salt concentration. Although at a given storage time no significant differences ($P > 0.05$) were observed in different batches of cheese as compared with the control, highest inhibitory activity (92.56%) was observed in batch E after 30-d storage. No significant changes in ACE-inhibitory activity, in cheeses brined with varying KCl concentrations, were observed by (Ayyash and others 2012). This trend could possibly be due to slow proteolysis continuing during the prolonged storage. These findings indicate that reduction and substitution of NaCl with KCl may not be affecting the release of ACE-inhibitory peptides in Akawi cheese.

Antioxidant activity

Antioxidant activity of freeze-dried WSE of Akawi cheese was estimated by DPPH radical scavenging ability (Figure 5). The antioxidant activity (expressed as $\mu$M equivalence of trolox) was not

![Figure 3](https://example.com/figure3.png)  
Figure 3–Protein content (A), proteolytic activity (B) and peptide profile (C) of WSE of cheeses as affected by NaCl reduction and substitution with KCl during 30 d storage at 4 °C. *Brine Solutions: 10% NaCl (A); 7.5% NaCl (B); 7.5% NaCl+KCl (1:1) (C); 5% NaCl (D); 5% NaCl+KCl (1:1) (E). *Means within a storage period are significantly different ($P < 0.05$) from the control (batch A). Values are means ± SE ($n \geq 3$). WSE: water soluble extract; S1–S3, segments of chromatogram with altered peaks.
Table 2—Amino acid content in cheeses as affected by NaCl reduction and substitution with KCl during 30 d storage at 4 °C.

<table>
<thead>
<tr>
<th>Amino Acid</th>
<th>Batch A*</th>
<th>Batch B*</th>
<th>Batch C*</th>
<th>Batch D*</th>
<th>Batch E*</th>
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<td>10</td>
<td>20</td>
<td>30</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>0.140</td>
<td>0.123</td>
<td>0.099</td>
<td>0.178</td>
<td>0.153</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>0.251</td>
<td>0.196</td>
<td>0.185</td>
<td>0.388</td>
<td>0.287</td>
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<td>Asparagine</td>
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<td>0.079</td>
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<td>Glutamine</td>
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<td>0.145</td>
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<td>0.136</td>
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</tr>
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<td>Arginine + Serine</td>
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<td>0.061</td>
<td>0.057</td>
<td>0.035</td>
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<tr>
<td>Threonine</td>
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<td>0.028</td>
<td>0.030</td>
<td>0.026</td>
<td>0.027</td>
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<tr>
<td>Glycine</td>
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<td>0.040</td>
<td>0.051</td>
<td>0.067</td>
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<tr>
<td>Alanine</td>
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<td>0.027</td>
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<tr>
<td>Proline</td>
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<tr>
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<td>0.070</td>
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<tr>
<td>Methionine</td>
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<td>0.094</td>
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<tr>
<td>Isoleucine</td>
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<td>0.044</td>
<td>0.044</td>
<td>0.047</td>
<td>0.068</td>
</tr>
<tr>
<td>Leucine</td>
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<tr>
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<td>0.060</td>
<td>0.060</td>
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<tr>
<td>Phenylalanine</td>
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<td>0.103</td>
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<tr>
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<td>0.034</td>
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<td>0.048</td>
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</table>

Values are means ± SE (n ≥ 3) and are expressed as g/L.

*Means are significantly different (P < 0.05) as compared to the respective day of control (batch A).

**Means within a batch are significantly different (P < 0.05) as compared to day 10 of the same batch.

Figure 4–Angiotensin converting enzyme-inhibitory activity of WSE of cheeses as affected by NaCl reduction and substitution with KCl during 30 d storage at 4 °C. *Brine solutions: 10% NaCl (A); 7.5% NaCl (B); 7.5% NaCl and KCl (1:1) (C); 5% NaCl (D); 5% NaCl and KCl (1:1) (E).
In changes of amino acid content are shown in the heat map (Figure S1), with red color depicting the lower concentrations and green depicting the higher concentrations. Slight changes were observed in the amino acid profiles of cheeses stored in low salt brine solutions (5%), but significant changes were observed in cheeses stored in 7.5% brine solution. In batch A (10% NaCl), there was no significant difference ($P > 0.05$) on concentrations of most of the amino acids during storage. In cheese stored in 7.5% brine solution (batches B and C), there was significant ($P < 0.05$) increase in concentration of most of the amino acids after 30 d. This could be attributed to an increased proteolytic activity in cheeses stored at 7.5% brine solution, which appeared to enhance the amino acid release. A strong correlation was observed between proteolytic activity and total essential amino acids (EAA) in cheese extract as observed by Pearson correlation coefficient analyses. The correlation coefficient was strongest for batch E (0.998) and batch C (0.996). Nevertheless, a positive correlation was also observed in all other batches of cheese (Pearson coefficient for batches A, B and D was 0.956, 0.855, and 0.720, respectively). The EAA in cheese samples from batch D and E did not increase significantly ($P > 0.05$) during storage. Among EAA, the concentrations of valine, leucine, tryptophan, and phenylalanine increased during storage in most cheeses. This increase correlated to the increased proteolytic activity as observed during storage (Figure 3B). Certain flavor compounds originating from phenylalanine and tryptophan have been detected in cheese (Adda and others 1982) as well as in model systems (Jollivet and others 1994). Release of amino acids plays a significant role in determining the production of flavor compounds in cheese. Furthermore, the increased concentration of amino acids, in particular the essential amino acids, in cheese also contributes to enhanced properties, especially the flavor, of the product. Overall, the study revealed that reduction of NaCl to 5% (batches D and E) does not contribute to significant increase in amino acids during storage. On the contrary, reduction up to 7.5% brine solution (batch B) and 50% substitution with KCl (batch C) aided in enhanced concentrations of amino acids during storage in Akawi cheese.

Effect of water-soluble extract on growth of colon cells

The effect of WSE on the growth of human colon cells and human colon cancer cells was investigated (Figure 6). One of the most reliable and commonly used methods for determining cell viability is based on reduction of tetrazolium salts such as MTT (3-(4,5-Dimethyl-2-thiazoly)-2,5-diphenyl-2H-tetrazolium bromide). The yellow tetrazolium salt, MTT, is reduced by the action of dehydrogenase enzymes in metabolically active cells to generate reducing equivalents such as NADH and NADPH. This reduction of MTT results in formation of a purple colored formazan, which can be solubilized and quantified using a spectrophotometer. The Caco-2 cells are heterogeneous human epithelial colorectal adenocarcinoma cells, and CCD 841 is a cell line of human epithelial colon cells, and both cell lines are adherent in nature.

The WSE of cheese brined in 7.5% NaCl+KCl (1:1) solution was selected for the cell line study as it was found to be the optimum concentration as mentioned previously, and the effects were compared to those of the WSE of cheese brined in 10% NaCl solution (control). Viability of CCD cells was significantly ($P < 0.05$) increased at lower concentrations (50 to 100 $\mu$g/mL) of WSE from batch C. There was no significant change in CCD cells at concentrations ranging from 250 to 750 $\mu$g/mL, beyond which there was a significant ($P < 0.05$) decline in cell viability, which is indicative of the cytotoxic effects of WSE from batch C at high doses (1000 to 2000 $\mu$g/mL). The WSE from control batch (batch A), showed a similar trend, however, the cell viability was higher in those supplemented with WSE from batch C. The lowest cell viability was 88% (compared to the control) at 2000 $\mu$g/mL of WSE from batch C. The WSE from both batches, A and C, had an inhibitory effect on the viability of Caco-2 cells. The viability was significantly reduced at concentrations higher than 75 $\mu$g/mL WSE. At highest concentration (2000 $\mu$g/mL) evaluated, the cell viability was approximately 65% of the cell viability in control (no WSE treatment). Enzymatic hydrolysates from casein have shown inhibitory effect on growth of Caco-2 cells (Phelan and others 2010) at high concentrations (5% to 10% vol/vol). Our results clearly indicated that the WSE from Akawi cheese may...
concentration (7.5%) may improve the functional properties of cheese. The cheese extracts also showed the potential to enhance the growth of human colon cells and to retard the growth of human colon cancer cell. This study paves way for further research on gut-health promoting effects of cheese extracts.

References
Role of salt on bioactivities of cheese . . .


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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher’s website:

Figure S1. Heat map showing change in amino acid during storage in cheeses brined 691 with varying salt (NaCl/KCl) concentrations.
Queries

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