The effect of partial substitution of NaCl with KCl on the physicochemical, microbiological and sensory properties of Akkawi cheese

Rabih Kamleh,a Ammar Olabi,b* Imad Toufeili,b Hamza Daroub,b Tarek Younisa and Rola Ajib a

Abstract

BACKGROUND: Studies have shown a direct relationship between increased dietary sodium intake and chronic diseases such as hypertension, cardiovascular disease and osteoporosis. Potassium chloride is the most widely used salt substitute for sodium chloride in different processed foods. Akkawi cheese, commonly consumed as fresh cheese, has a semi-hard curd, chalky color, firm texture and salty flavor. The effect of partial replacement of NaCl with KCl on the chemical, textural, microbiological and sensory characteristics of fresh and mature Akkawi cheese was investigated.

RESULTS: Salt treatment (NaCl reduction) had a significant effect on pH, lactic acid, sodium and potassium contents of cheeses. Texture profile analysis revealed a significant effect of salt treatment on adhesiveness, chewiness and hardness of cheese. All tested microorganisms increased with storage but in general did not differ between salt treatments, specifically between control (100% NaCl) and (70% NaCl, 30% KCl) samples. Descriptive analysis showed that salt treatment had a significant effect on bitterness, crumbliness and hardness, whereas the age of cheese was significant for color and fermented flavor. Salt treatment had no effect on acceptability variables for all experimental 2-week Akkawi samples.

CONCLUSION: The above results suggest that a 30% substitution of NaCl by KCl (70% NaCl, 30% KCl brine) is acceptable.

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Keywords: Akkawi; potassium chloride; sensory; salt

INTRODUCTION

White brined cheeses are widely consumed in the Eastern Mediterranean and neighboring countries.1 Akkawi cheese originated in the Levantine city of Acre and is widely produced and consumed in Lebanon, Syria, and Cyprus.2 Akkawi cheese is commonly consumed as fresh cheese. Traditionally, it is made from pasteurized sheep’s, goat’s, cow’s, or buffalo’s milk, depending on availability, and is characterized by having a semi-hard curd, a white chalky color, a firm texture and a salty flavor.2–3 NaCl is an essential component of brined cheeses including Akkawi; it enhances taste and firmness, decreases bitterness and water activity, and contributes to its preservation.3–6 In addition, NaCl has a major effect on cheese composition, microbial growth, enzymatic activities and biochemical changes.7 Storage of Akkawi cheese in brine solution is a critical step for preserving its quality and for safety.

However, several studies have shown a direct relationship between increased dietary salt (sodium) intake and hypertension, cardiovascular disease, osteoporosis and kidney stone formation.5 Therefore, the reduction of sodium intake is a major public health concern to be addressed worldwide. The recommended maximum daily intake of 2.3 g sodium5 is exceeded in most populations due to increased consumption of processed foods, which have been estimated to contribute to approximately 75–80% of the total sodium intake.10 Many studies have shown that dairy products, specifically cheeses, contribute by a perceptible amount to daily sodium dietary intake.7 However, a decrease in NaCl content in cheese without replacing it with another salt adversely affects cheese quality.11

Potassium chloride is the most widely used salt substitute to reduce the levels of sodium chloride in different processed foods.12 Increasing the potassium intake by 30–45 mmol d−1, out of the 120 mmol recommended intake versus the current 72 mmol US average intake,13 results in numerous health benefits, including the prevention of renal diseases, reduction of blood pressure, urinary calcium excretion, kidney stone formation, osteoporosis, diabetes and decreasing mortality from cardiovascular diseases.14 Several studies have shown that partial or complete replacement of sodium by potassium in cheeses is successfully achievable, in terms of sensory and physical properties, as has been reported

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pressed curd were placed in plastic containers and covered with
as described in Kamleh
protein, moisture, lactic acid, cheese pH, sodium and potassium
Chemical analyses for cheese samples were conducted for fat,
Chemical analysis below were conducted.

thetext and tables, correspond to samplesthathad been stored for
ent brine solutions. The fresh samples in this work, as reported in
study investigating the effect of NaCl replacement with KCl on the
physicochemical, microbiological and sensory characteristics of
Akkawi cheese.24 Despite the comprehensive and thorough nature of
this latter study, especially with respect to chemical, physical and
microbiological assessments, it lasted for only 30 days, and did not
include either hedonic testing or a full-fledged quantitative
sensory descriptive analysis, but rather relied on intensity mea-
surements of five descriptors. Also, the microbiological focus in the
previous work26 was on the survival of probiotic and lactic acid
bacteria rather than the growth of spoilage microorganisms. In
addition, previous work on partial substitution with KCl in ripened
cheeses, which are significantly more flavorful than ripened white
ces, or even in Halloumi cheese, which is a white ripened
cheese with a totally different rubbery texture, may not shed light
on the outcome of this substitution in Akkawi cheese. Accordingly,
the objective of this study was to determine the effect of partial
NaCl substitution with KCl, in Akkawi cheese (stored in 100 g kg⁻¹
brine/total salt content), on the physicochemical, microbiological
and sensory properties of the product.

MATERIALS AND METHODS

Cheese production

The cheeses were produced from cow’s milk as described by Kamleh et al. (2012),27 with one minor difference: pressing the curd
pieces in hoops at 300 KPa for 30 min to allow maximum separa-
tion from the whey. Rectangular blocks (10 cm × 5 cm × 3 cm) of
pressed curd were placed in plastic containers and covered with
different pasteurized brines (100 g kg⁻¹ salt w/w tap water); brine
A (100% NaCl), brine B (70% NaCl; 30% KCl) and brine C (50% NaCl;
50% KCl). Preliminary taste tests were conducted to select NaCl
replacement levels that did not impart noticeable and excessive
bitterness to the cheese. The selected 100 g kg⁻¹ salt level is close
to the levels used in commercial production of Akkawi cheese
(100–120 g kg⁻¹ salt w/w brine). Samples placed in the different
brine solutions were produced in one batch on the same day. The
cheese blocks were stored for 8 weeks at 4 ± 1 °C in the three differ-
ent brine solutions. The fresh samples in this work, as reported in
the text and tables, correspond to samples that had been stored for
48 h in the three corresponding brines. This was applied to allow
for transfer of salts to the cheese blocks before any of the analyses
below were conducted.

Chemical analysis

Chemical analyses for cheese samples were conducted for fat,
protein, moisture, lactic acid, cheese pH, sodium and potassium
as described in Kamleh et al.27 All chemical determinations were
performed in triplicate.

Instrumental texture analysis

Texture profile analysis (TPA) was conducted using a QTS25 tex-
ture analyzer (Brookfield Engineering Labs, Middleboro, MA, USA)
as described in Kamleh et al.27 The test parameters included adhe-
siveness, chewiness, cohesiveness, hardness and springiness.

Microbiological analysis

Counts of total bacteria, lactic acid bacteria, total coliforms,
psychrophilic bacteria and yeasts and molds were conducted accord-
ing to standard procedures28 and as described in Kamleh et al.27
Moreover, total coliforms were enumerated by pour plate tech-
nique using Violet Red Bile Agar and incubating at 35 ± 1 °C for
24 h. All microbiological analyses were performed in duplicate.

Descriptive analysis

Nine judges (two males and seven females, mean age = 26,
range = 20–50) were selected according to their willingness to
participate in the study and their regular consumption of Akkawi
cheese. Descriptive analysis was conducted as described for
Halloumi cheese by Kamleh et al.27 based on the quantitative
descriptive analysis (QDA) approach. Table 1 summarizes the final
list of 11 selected attributes with their definitions, anchor words
and standards used. The panelists attended a total of 10 evaluation
sessions conducted over a period of 5 days. On each test day (fresh,
2 and 6 weeks after storage), they performed two evaluations (one morning
and one afternoon) at least 1 h after their last meal. The samples
were assessed in duplicate evaluations (at every time period),
with all three samples (three salt treatments) served within each
replicate for a total of six samples per day (3 salt treatments × 2
replicates). The sensory evaluation was performed by rating the
intensity of the different attributes on a 15 cm line scale anchored
at 1 cm from the ends with the relevant descriptors (Table 1).29,30
Akkawi samples that were stored in brine C (50% NaCl; 50% KCl)
were assessed fresh and only after 2 weeks of aging, due to appar-
ent changes in their structure and the formation of a slimy layer
on the top at week 4 of maturation, which was attributed to mold
growth as discussed in the microbiological section of the results
and discussion. Akkawi samples stored in brines A (100% NaCl)
and B (70% NaCl; 30% KCl) were assessed fresh and after 2, 4, 6
and 8 weeks of aging. Accordingly, the reported results at all ages
are for A and B samples only.

Hedonic evaluation

A consumer acceptability test was performed only on fresh cheese
samples (at week 0) after 48 h of storage in the three corre-
sponding brines. This test was conducted with 72 panelists (mean
age = 24.3, range = 19–57, SD = 8.1) in a similar manner to the
hedonic test of Kamleh et al.27 The panelists were asked to taste
the three fresh samples in the order indicated, which was counter-
balanced as described in Kamleh et al.,27 and to rate the samples
for appearance, flavor, texture and overall acceptability using the
9-point hedonic scale.31

Statistical analysis

The GLM procedure of SAS® (version 9.02, SAS Institute Inc., Cary,
NC, USA) was used to perform analysis of variance in a similar
manner to the Halloumi work by Kamleh et al.27 The factors in
the model included: salt treatment (brine A (100% NaCl), brine
B (70% NaCl; 30% KCl) and brine C (50% NaCl; 50% KCl)), age
of the cheese (0, 2, 4, 6 and 8 weeks), panelist, replicate and
their two-way interactions. Tukey’s honestly significant difference
(HSD) test was used to separate significant means for the sensory
analyses. Significance was established at P < 0.05. In each part of
the results and discussion section (chemical analyses, descriptive
analysis, etc.), the first part summarizes the significant effects
(P-values) of the main factors and their interactions but these
results are not reported in tables. Mean comparisons are then
discussed in the text and reported in Tables 2, 3 and 4 as well as
Figs 1 and 2. This was done to save on space/redundancy and
minimize the number of tables.
Effect of KCl on Akkawi characteristics

Table 1. Terms used in descriptive analysis of Akkawi cheese

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition as worded on score sheet</th>
<th>Anchor words (low–high)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Color of the cheese ranging from chalky white to light ivory</td>
<td>Chalky white – Light ivory</td>
</tr>
<tr>
<td>Fermented odor</td>
<td>Fermented odor of Light Pitas Halloumi&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Not at all – Very</td>
</tr>
<tr>
<td>Milky odor</td>
<td>Odor of heavy cream&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Not at all – Very</td>
</tr>
<tr>
<td>Saltiness</td>
<td>Taste elicited by table salt</td>
<td>Not at all – Very</td>
</tr>
<tr>
<td>Fermented flavor</td>
<td>Fermented flavor of Light Pitas Halloumi&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Not at all – Very</td>
</tr>
<tr>
<td>Milky flavor</td>
<td>Flavor of heavy cream&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Not at all – Very</td>
</tr>
<tr>
<td>Bitterness</td>
<td>Taste elicited by caffeine</td>
<td>Not at all – Very</td>
</tr>
<tr>
<td>Hardness</td>
<td>Force necessary to cut a cube of an Akkawi cheese sample with a metal fork at a 90° angle</td>
<td>Soft – Hard</td>
</tr>
<tr>
<td>Crumbliness</td>
<td>Amount of fracturability of cheese sample after biting it using molars and chewing it three times</td>
<td>Cohesive mass – Crumbly</td>
</tr>
<tr>
<td>Salty aftertaste</td>
<td>Aftertaste elicited by table salt</td>
<td>Not at all – Very</td>
</tr>
<tr>
<td>Bitter aftertaste</td>
<td>Aftertaste elicited by caffeine</td>
<td>Not at all – Very</td>
</tr>
</tbody>
</table>

<sup>a</sup> Light Pitas Halloumi, Nicosia, Cyprus.

<sup>b</sup> Skimmilk (Dairy Day, Bekaa, Lebanon) versus heavy cream (ElleetVire, France).

Table 2. Least squares means of the chemical properties of Akkawi samples (moisture, pH, lactic acid, sodium and potassium) for Salt treatment × Age of cheese interaction (ST × AC)

<table>
<thead>
<tr>
<th>Salt treatment&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Age (week)&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Moisture</th>
<th>Fat&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Protein&lt;sup&gt;d&lt;/sup&gt;</th>
<th>pH</th>
<th>Lactic acid</th>
<th>Sodium</th>
<th>Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>61.03ab</td>
<td>19.50</td>
<td>15.74</td>
<td>6.49ab</td>
<td>0.19e</td>
<td>667a</td>
<td>15h</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>57.20ab</td>
<td>20.25</td>
<td>15.25</td>
<td>6.52ab</td>
<td>0.20de</td>
<td>472bcd</td>
<td>112ef</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>54.33b</td>
<td>19.48</td>
<td>15.39</td>
<td>6.52ab</td>
<td>0.23de</td>
<td>196ef</td>
<td>149cd</td>
</tr>
<tr>
<td>Pooled SD</td>
<td></td>
<td>±2.18</td>
<td>±1.10</td>
<td>±0.34</td>
<td>±0.03</td>
<td>±0.02</td>
<td>±45</td>
<td>±12</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>60.59ab</td>
<td>ND&lt;sup&gt;d&lt;/sup&gt;</td>
<td>ND</td>
<td>6.51ab</td>
<td>0.22de</td>
<td>603ab</td>
<td>22h</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>58.30ab</td>
<td>ND</td>
<td>ND</td>
<td>6.59ab</td>
<td>0.21de</td>
<td>519abc</td>
<td>122def</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>57.64ab</td>
<td>ND</td>
<td>ND</td>
<td>6.57ab</td>
<td>0.25de</td>
<td>258ef</td>
<td>138cde</td>
</tr>
<tr>
<td>Pooled SD</td>
<td></td>
<td>±1.80</td>
<td>±0.03</td>
<td>±0.02</td>
<td>±5</td>
<td>±6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>4</td>
<td>59.97ab</td>
<td>25.25</td>
<td>15.79</td>
<td>6.56ab</td>
<td>0.19de</td>
<td>483bcd</td>
<td>76g</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>58.83ab</td>
<td>25.49</td>
<td>16.16</td>
<td>6.65a</td>
<td>0.23de</td>
<td>315def</td>
<td>108f</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>61.87a</td>
<td>26.30</td>
<td>15.16</td>
<td>6.24c</td>
<td>0.36c</td>
<td>186f</td>
<td>177ab</td>
</tr>
<tr>
<td>Pooled SD</td>
<td></td>
<td>±1.83</td>
<td>±1.51</td>
<td>±0.25</td>
<td>±0.03</td>
<td>±0.01</td>
<td>±13</td>
<td>±6</td>
</tr>
<tr>
<td>A</td>
<td>6</td>
<td>56.63ab</td>
<td>ND</td>
<td>ND</td>
<td>6.21c</td>
<td>0.32d</td>
<td>488abcd</td>
<td>75g</td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td>58.37ab</td>
<td>ND</td>
<td>ND</td>
<td>6.43b</td>
<td>0.27d</td>
<td>371cde</td>
<td>119ef</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>59.63ab</td>
<td>ND</td>
<td>ND</td>
<td>5.90d</td>
<td>0.53b</td>
<td>166f</td>
<td>153bc</td>
</tr>
<tr>
<td>Pooled SD</td>
<td></td>
<td>±1.20</td>
<td>±0.06</td>
<td>±0.02</td>
<td>±16</td>
<td>±5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>8</td>
<td>57.97ab</td>
<td>25.18</td>
<td>14.75</td>
<td>5.85de</td>
<td>0.51b</td>
<td>514abc</td>
<td>71g</td>
</tr>
<tr>
<td>B</td>
<td>8</td>
<td>56.43ab</td>
<td>25.35</td>
<td>15.38</td>
<td>6.25c</td>
<td>0.34 cd</td>
<td>445bcd</td>
<td>157abc</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
<td>58.33ab</td>
<td>25.74</td>
<td>14.70</td>
<td>5.71e</td>
<td>0.75a</td>
<td>309def</td>
<td>183a</td>
</tr>
<tr>
<td>Pooled SD</td>
<td></td>
<td>±0.90</td>
<td>±0.79</td>
<td>±0.05</td>
<td>±0.04</td>
<td>±0.04</td>
<td>±75</td>
<td>±9</td>
</tr>
</tbody>
</table>

For each variable (column), means within a salt treatment or age of cheese (row) with different letters are significantly different (P < 0.05).

<sup>a</sup> Salt treatment: A, 100% NaCl (control); B, 70% NaCl, 30% KCl; C, 50% NaCl, 50% KCl.

<sup>b</sup> Week 0 corresponds to 48 h of storage in corresponding brine solution.

<sup>c</sup> Fat and protein were only determined at three times given the expectation that is based on previous studies of lack of any major changes with an 8-week period.

<sup>d</sup> ND, not determined.

RESULTS

Chemical analysis

Table 2 summarizes the least squares means of the chemical analyses. Salt treatment (brine solution) had a significant effect (P < 0.001) on pH, lactic acid, sodium and potassium content of the cheese. In addition, age of the cheese had a significant effect on fat content, pH, lactic acid (P < 0.001), potassium and sodium content (P < 0.01) of cheese samples. As expected from the study design, sodium content of the cheese was significantly lower in samples stored in NaCl/KCl brines than in samples stored in pure NaCl brine (treatment A; Table 2). The opposite was true for the potassium content of cheeses. In general, a significant decrease in the sodium content was observed in Akkawi samples aged for 4 and 6 weeks in comparison to fresh samples and those aged for 2 weeks; however, sodium content increased significantly at week 8. Sodium content of cheeses did not differ significantly upon storage for each of treatments B and C; however, for treatment A, sodium decreased significantly at week 4 of maturation when...
compared with fresh samples. Potassium increased significantly in cheeses stored in brine A after week 4 of maturation, whereas in cheeses stored in brines B and C it increased after 8 weeks of storage for B and after 4 weeks for C. In general, salt treatment had no significant effect on moisture, protein and fat content and no significant differences were observed in moisture and protein content during storage. pH of cheeses was significantly lower for treatment C (50% NaCl; 50% KCl) than it was for treatments A (control: 100% NaCl) and B (70% NaCl; 30% KCl) starting week 4. pH did not significantly differ within the same treatment until week 4 for treatment C, week 6 for treatment A and week 8 for treatment B. The opposite trend was true for lactic acid, which was significantly higher in treatment C after 4 weeks. Moreover, there was a significant progressive increase in lactic acid content from week 0 to week 8 for all the treatments.

**Instrumental texture analysis**

Table 3 summarizes the least squares means of the texture analyses. Salt treatment had a significant effect on adhesiveness, chewiness, hardness, and cohesiveness (P < 0.001). The age of the cheese had a significant effect on adhesiveness, cohesiveness and springiness (P < 0.001), chewiness (P < 0.01) and hardness (P < 0.05). A significant salt treatment × age interaction was found for adhesiveness, hardness (P < 0.001), cohesiveness and chewiness (P < 0.05). Adhesiveness of Akkawi samples decreased significantly with storage, in particular after week 6 of maturation. Similarly, all the other physical parameters decreased upon storage: after week 8 of maturation for chewiness and hardness, and after week 6 of maturation for cohesiveness. In general, there were no significant differences between treatments at the same age period with the exception of adhesiveness of fresh samples, which was the lowest for brine A samples; and chewiness and hardness at week 8 of maturation, where the value decreased significantly for brine A cheeses as compared to brine B cheeses.

**Microbiological analysis**

Counts of total bacteria, psychrophilic bacteria, lactic acid bacteria, total coliforms and yeasts and molds in Akkawi cheese samples

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**Table 3.** Least squares means of the textural properties of Akkawi samples (adhesiveness, chewiness, cohesiveness and hardness) for significant Salt treatment × Age of cheese interactions (ST × AC)

<table>
<thead>
<tr>
<th>Salt treatment&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Age (week&lt;sup&gt;b&lt;/sup&gt;)</th>
<th>Adhesiveness</th>
<th>Chewiness</th>
<th>Cohesiveness</th>
<th>Hardness</th>
<th>Springiness</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>−3.78ab</td>
<td>828abcd</td>
<td>0.840a</td>
<td>395bcde</td>
<td>2.35</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>−12.35f</td>
<td>1034ab</td>
<td>0.830ab</td>
<td>503abc</td>
<td>2.48</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>−10.64def</td>
<td>545bcede</td>
<td>0.836ab</td>
<td>277cdef</td>
<td>2.50</td>
</tr>
<tr>
<td></td>
<td>Pooled SD</td>
<td>±1.22</td>
<td>±27</td>
<td>±0.02</td>
<td>±12</td>
<td>±0.05</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>−7.17bcde</td>
<td>707abdef</td>
<td>0.826ab</td>
<td>352bcdef</td>
<td>2.28</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>−10.86def</td>
<td>921abc</td>
<td>0.830ab</td>
<td>442bced</td>
<td>2.51</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>−10.50def</td>
<td>471cdef</td>
<td>0.843a</td>
<td>245cdef</td>
<td>2.44</td>
</tr>
<tr>
<td></td>
<td>Pooled SD</td>
<td>±1.11</td>
<td>±63</td>
<td>±0.01</td>
<td>±28</td>
<td>±0.10</td>
</tr>
<tr>
<td>A</td>
<td>4</td>
<td>−9.57cdef</td>
<td>761abcd</td>
<td>0.820a</td>
<td>415bced</td>
<td>2.50</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>−1.60a</td>
<td>570bcdef</td>
<td>0.846a</td>
<td>294bced</td>
<td>2.29</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>−11.58ef</td>
<td>746abcede</td>
<td>0.813ab</td>
<td>366bcdef</td>
<td>2.47</td>
</tr>
<tr>
<td></td>
<td>Pooled SD</td>
<td>±0.51</td>
<td>±122</td>
<td>±0.01</td>
<td>±53</td>
<td>±0.05</td>
</tr>
<tr>
<td>A</td>
<td>6</td>
<td>−5.36abc</td>
<td>789abde</td>
<td>0.793abc</td>
<td>457abed</td>
<td>2.00</td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td>−3.32ab</td>
<td>1183a</td>
<td>0.773bcd</td>
<td>701a</td>
<td>2.14</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>−5.02abc</td>
<td>256ef</td>
<td>0.796abc</td>
<td>156ef</td>
<td>2.18</td>
</tr>
<tr>
<td></td>
<td>Pooled SD</td>
<td>±1.00</td>
<td>±254</td>
<td>±0.02</td>
<td>±123</td>
<td>±0.15</td>
</tr>
<tr>
<td>A</td>
<td>8</td>
<td>−0.72a</td>
<td>170f</td>
<td>0.747cd</td>
<td>124f</td>
<td>2.18</td>
</tr>
<tr>
<td>B</td>
<td>8</td>
<td>−1.77a</td>
<td>844abcd</td>
<td>0.713d</td>
<td>559ab</td>
<td>2.10</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
<td>−6.62bcd</td>
<td>362def</td>
<td>0.813ab</td>
<td>203def</td>
<td>1.80</td>
</tr>
<tr>
<td></td>
<td>Pooled SD</td>
<td>±2.01</td>
<td>±126</td>
<td>±0.04</td>
<td>±70</td>
<td>±0.24</td>
</tr>
</tbody>
</table>

For each variable (column), means within a salt treatment or age of cheese (row) with different letters are significantly different (P < 0.05).

<sup>a</sup> Salt treatment: A, 100% NaCl (control); B, 70% NaCl, 30% KCl; C, 50% NaCl, 50% KCl.

<sup>b</sup> Week 0 corresponds to 48 h of storage in corresponding brine solution.

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**Table 4.** Least squares means of descriptive analysis attributes of Akkawi samples (rated on a 15 cm line scale) for different salt treatments and ages

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Salt treatment&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Age of cheese (week&lt;sup&gt;b&lt;/sup&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Color</td>
<td>7.05</td>
<td>7.55</td>
</tr>
<tr>
<td>Fermented odor</td>
<td>5.60</td>
<td>5.78</td>
</tr>
<tr>
<td>Milky odor</td>
<td>5.37</td>
<td>6.27</td>
</tr>
<tr>
<td>Saltiness</td>
<td>8.74</td>
<td>8.36</td>
</tr>
<tr>
<td>Bitterness</td>
<td>4.10b</td>
<td>5.19a</td>
</tr>
<tr>
<td>Fermented flavor</td>
<td>4.90</td>
<td>5.42</td>
</tr>
<tr>
<td>Milky flavor</td>
<td>4.99</td>
<td>5.22</td>
</tr>
<tr>
<td>Hardness</td>
<td>6.54b</td>
<td>6.20a</td>
</tr>
<tr>
<td>Crumbliness</td>
<td>6.33b</td>
<td>7.11a</td>
</tr>
<tr>
<td>Salty aftertaste</td>
<td>6.61</td>
<td>6.53</td>
</tr>
<tr>
<td>Bitter aftertaste</td>
<td>4.01</td>
<td>4.52</td>
</tr>
</tbody>
</table>

Means within a salt treatment or age of cheese and within a row with different letters are significantly different (P < 0.05).

<sup>a</sup> Salt treatments: A, 100% NaCl (control); B, 70% NaCl, 30% KCl.

<sup>b</sup> Week 0 corresponds to 48 h of storage in corresponding brine solution.
stored for 8 weeks and in the three different salt treatments are summarized in Fig. 1. All the observed microorganisms increased significantly (P < 0.05) in the control sample (A) and in the other two experimental samples (B and C). Counts of psychrophilic bacteria reached 6.6 log10 CFU g⁻¹, 6.7 log10 CFU g⁻¹ and 7.0 log10 CFU g⁻¹ in treatments A, B and C, respectively, after 8 weeks of storage (Fig. 1). Psychrophilic bacteria were slightly higher in cheeses brined in solution C. At week 8, the total bacterial count (TBC) reached 5.8 log10 CFU g⁻¹, 5.9 log10 CFU g⁻¹ and 7.1 log10 CFU g⁻¹, respectively, in cheeses brined in treatments A, B, and C. TBC differed significantly (P < 0.05), after 2, 4, 6 and 8 weeks of storage, between treatment C and treatments A and B. Total bacterial counts were higher in Akkawi cheeses brined in treatment C (50% NaCl; 50% KCl). Moreover, salt treatment had a significant effect on lactic acid bacteria (LAB) growth (Fig. 1). Total coliforms reached 4.5, 4.7 and 4.8 log CFU g⁻¹ in cheeses stored in treatments A, B and C, respectively, at week 8 (P > 0.05). In general, they did not differ between the control sample (A) and the other treatments (B and C), at the same period of storage (Fig. 1). The substitution of NaCl by KCl did not have a significant effect on the growth of coliforms. Yeast and mold counts varied significantly (P < 0.05) among different treatments and at all ages of cheese. They were higher in treatment C than in treatments A and B.

**Descriptive analysis**

The results of the analyses of variance for the sensory descriptive properties and the least square means of all 11 sensory attributes for treatments A and B (100% NaCl; 70% NaCl, 30% KCl, respectively) and for the five ages of cheese (0, 2, 4, 6, and 8 weeks) are summarized below and in Table 4, respectively. Crumbliness and hardness were rated higher for treatment B and differed significantly from those of treatment A (Table 4). Bitterness had significantly, although slightly, higher ratings for brine B samples, which is expected given the presence of KCl in those samples (Table 4). No significant differences (P > 0.05) existed in all other attributes. Color ratings increased significantly with maturation, indicating that Akkawi samples were becoming more yellowish with aging. In addition, cheese samples had a significantly more intense fermented flavor at week 6 of maturation (Table 4). Salt treatment × age of cheese interaction was significant for color (P < 0.01) and milky odor (P < 0.05). There were no significant differences between the two salt treatments at the same age, except...
DISCUSSION

Chemical analysis

The decrease in sodium and increase in potassium in NaCl/KCl samples observed over time in this work was also obtained by other researchers\textsuperscript{18,21,22,24,26} who tested the effect of partial substitution of sodium chloride with potassium chloride in the processing of Akkawi, white salted, Halloumi, Mozzarella and Minas cheeses. This phenomenon is due to salt diffusion into the cheese matrix, the electrolyte balance between the cheese matrix and the surrounding solution and the lower ionic strength for KCl.\textsuperscript{32} This phenomenon of electrolyte transfer in reduced-salt brined cheeses needs to be further assessed.

Ayyash and Shah\textsuperscript{25} also found that the sodium content of Mozzarella cheese did not differ during storage within a salt treatment. The increase in the potassium content in cheeses stored in brine A during storage is a surprising outcome, since one could expect an increase in potassium level in treatments B and C as obtained by Ayyash and Shah\textsuperscript{24,26} but not for the control (treatment A). However, the original potassium level in the control sample (A) was much higher in the Ayyash study than this work (an estimated 125 mg versus 15 mg 100 g\textsuperscript{-1} cheese, respectively). Interestingly enough, the potassium levels in the control sample of the two studies above, which used similar salt substitution levels, equilibrated at an estimated 66 mg 100 g\textsuperscript{-1} versus 76 mg 100 g\textsuperscript{-1}, respectively, after 4 weeks, which is much closer than the starting potassium levels in the cheese for the two studies. Moreover, Ayyash and Shah\textsuperscript{26} had found an increase in the potassium levels of the control Halloumi cheese (NaCl brine only). This increase was from around 15 mg potassium 100 g\textsuperscript{-1} cheese on day 0 to around 35 40 mg (values estimated from graph) on day 56. The opposite phenomenon was observed by Ayyash et al.\textsuperscript{26} in Akkawi cheese, where the level of potassium in the control cheese decreased from around 115 mg potassium 100 g\textsuperscript{-1} of cheese on day 0 to around 55 mg (values estimated from graph) on day 30. A downward trend were noted in Ayyash and Shah\textsuperscript{22} for the potassium levels in Mozzarella cheese during a period of 27 days, despite the lack of significant differences between the different time periods for

![Sensory profile of Akkawi samples for different salt treatments aged for 2 weeks. Salt treatments: A, 100% NaCl (control); B, 70% NaCl, 30% KCl; C, 50% NaCl, 50% KCl. *P < 0.05; **P < 0.01.](image)
cheese potassium levels. On another front, sodium levels in the control Mozzarella decreased from around 510 mg 100 g\(^{-1}\) cheese on day 0 to around 420 mg (values estimated from graph) on day 27. This type of phenomenon was true in the sodium levels of brine A of this work. The above phenomena are influenced by factors such as the moisture content and its migration to brine, pH of cheese, salt in moisture levels, proteolysis and casein hydration.

The lack of significant salt effect on moisture, protein and fat content in this work (Table 2) was obtained by several studies\(^6-18\), \(^21\), \(^23\), \(^25\), \(^26\) where salt treatment had no significant effect on the chemical composition (mainly moisture, protein and fat content) of different white pickled cheeses such as Feta, Kefalograviera, Minas, Nabulsli, Halloumi and Akkawi, due to the minimal effect that the salt substitution has on the above components. In addition, no significant differences were observed in moisture and protein content during storage. This trend was also reported by Ayyash and Shah\(^22\) and Reddy and Marth\(^20\) in Mozzarella and Cheddar cheeses, respectively.

Karagözül et al.\(^19\) reported that acidity of white pickled cheese increased significantly with decreasing levels of NaCl. However, opposite results were obtained by Ayyash and Shah,\(^22\), \(^24\), \(^26\) who reported significantly lower pH for cheeses stored in control brine (100% NaCl) than those stored in brines formed of NaCl and KCl mixtures, which was attributed to the higher pH of KCl compared to NaCl. On the other hand, Karagözül et al.\(^19\) and Ayyash and Shah\(^22\), \(^26\) showed that the pH of white pickled cheese, Mozzarella cheese and Akkawi cheese decreased during storage, as obtained in the present study. The decrease in pH of cheese upon maturation has been linked to increased levels of organic acids (such as lactic acid) produced by different microorganisms during storage.\(^26\), \(^33\)

**Instrumental texture analysis**

Al-Otaibi and Wilbey\(^18\) and Gomes et al.\(^21\) reported that cheeses salted with NaCl/KCl mixtures were harder than control cheeses (salted with NaCl alone), similar to findings of this work, and this is mainly due to the modification in protein hydration caused by the higher level of potassium. An increase in hardness is typical for low-fat brined cheeses, as is the case in Halloumi cheese, and is in general conducive to lower acceptability.\(^27\) Al-Otaibi and Wilbey\(^18\) reported no significant effect of salt treatment on the springiness of white salted cheese as obtained by the current study.

The decrease in hardness and chewiness with time was also obtained by several authors\(^16\), \(^17\), \(^21\), \(^23\), \(^25\) who reported a decrease in cohesiveness and hardness of different white cheeses upon storage. These changes have been attributed to an increase in proteolysis with its concomitant weakening of the cheese matrix and the decrease in calcium content of the cheese, which leads to a reduction in the cross-linkage between caseins during storage. Unfortunately, the level of proteolysis was not measured in this work and thus this possible effect cannot be ascertained.

The lack of significant differences between treatments at the same age period was obtained by Ayyash and Shah,\(^23\) who reported that no significant difference was observed among experimental Nabulsli cheeses during most of the storage period, except for slight differences in the texture parameters between experimental cheeses at specific sampling times. Similarly, Ayyash et al.\(^26\) stated that, in general, there were no significant differences among experimental Akkawi cheese at the same storage period for texture parameters, except for occasional differences in cohesiveness and gumminess at certain storage periods (specifically at day 10 and day 30). These occasional differences were attributed to differences in cheese loaves and not due to salt treatment. This above outcome is a positive one given that in general age is the mean indicator of the textural changes rather than salt treatment despite the presence of specific significant salt treatment differences.

**Microbiological analysis**

The increase in all microorganisms during storage observed in this work was also observed in other white brined cheeses.\(^34\), \(^35\) The psychrophilic counts observed in this study for Akkawi were higher than those reported for artisanal Turkish white cheese,\(^34\) presumably due to differences in processing and brine concentrations. TBC counts were lower than in other white brined cheeses,\(^35\), \(^36\) although a low brine concentration was used in this work (10% salt). Similar results were obtained for LAB counts in terms of differences between brine solutions and lower values than in artisanal white Turkish cheese\(^35\) and in Anevato cheese.\(^37\) In addition, total coliforms were lower than those reported by Öner et al. in artisanal white Turkish cheese\(^35\) and in Anevato cheese.\(^37\) It is known that the quality and acceptability of food products can be affected by the spoilage and fermentation activity of yeast and molds.\(^38\) The slimy texture of cheese blocks in treatment C, observed after 6 weeks of storage, could be related to the high counts of yeasts and molds (6.2 log10 CFU g\(^{-1}\)) and the softer texture of Akkawi cheese compared to Halloumi.\(^27\) As such, the substitution of NaCl by KCl has an effect on their growth. In addition, yeast and mold counts of Akkawi cheese stored in different brine solutions were lower than those reported in Urfa cheese\(^39\) (traditional Turkish white brined cheese) but slightly higher than those in traditional Halloumi\(^27\), Turkish white\(^35\) and Greek\(^37\) cheeses.

**Descriptive analysis**

Al-Otaibi and Wilbey\(^18\) reported that white salted cheeses treated with mixtures of salts (NaCl and KCl) were found to be harder than cheeses treated with NaCl only. The findings of this work were also in agreement with the texture profile analysis summarized above. In addition, Al-Otaibi and Wilbey\(^18\) reported no significant differences between salt treatments for the sensory scores of salty taste as obtained in the present work. Higher bitterness ratings for brine B samples were also obtained by Karagözül et al.\(^19\) and Gomes et al.\(^21\) Both higher hardness and bitterness levels could have a negative impact on acceptability, especially if excessive. In a similar finding, Ayyash et al.\(^26\) reported that no significant differences were observed in creaminess, saltiness and sour-acid among Akkawi cheese for the same storage period. The more intense fermented flavor at week 6 of maturation is thought to be associated with the increase of microorganisms during storage that could lead to the formation of lactic acid along with other organic acids. Papademas\(^40\) and Kaminarides et al.\(^23\) reported a significant increase in acidic flavor of Halloumi cheese during storage.

**Hedonic evaluation**

The lack of significant acceptability differences for salt levels indicated that the original sodium and potassium differences as well as instrumental textural differences did not translate into actual acceptability differences among naïve consumers, at least for the 2-week samples. These findings are encouraging because of their possible implications, i.e. the possibility of producing Akkawi cheese with a 30% salt substitution with minimal to no effect on acceptability. The results are also in line with those reported by
Al-Otaibi and Wilbey,18 who noted that the overall acceptability of white salted cheese was not affected by brining in solutions with different NaCl/KCl ratios. Similar results were also obtained by several studies13,15,17,21,27 which reported no significant differences between the acceptability scores of most sensory attributes of cottage, Kefalovravia, Minas and Halloumi cheeses produced by using NaCl and NaCl/KCl mixtures.

CONCLUSIONS
Salt treatment had a significant effect on pH, lactic acid, sodium and potassium content of cheeses, and it also had a significant effect on adhesiveness, chewiness and hardness of cheese samples. All tested microorganisms increased with storage but in general did not differ between the salt treatments, specifically between the control (100% NaCl) and (70% NaCl, 30% KCl) samples. Descriptive analysis showed that salt treatment had a significant effect on bitterness, crumbliness and hardness, whereas the age of cheese had a significant effect on color and fermented flavor attributes. The partial substitution of NaCl by KCl did not seem to affect the acceptability of Akkawi cheese. However, additional hedonic measurements over time could have assured a more comprehensive assessment of the acceptability of samples. The above results of sensory, chemical, textural and microbiological analyses suggest that a 30% substitution of NaCl by KCl (70% NaCl, 30% KCl brine), instead of the commercial NaCl brine currently used in the cheese industry, is advisable; especially that a relatively moderate brine concentration (100 g kg⁻¹) was used, which could have led to a lower quality at an earlier time compared to the higher brine salt concentrations usually used (120 g kg⁻¹ or even higher sometimes). To our knowledge, this the only study that has assessed the shelf life of Akkawi cheese for a period of 8 weeks and that included assessments of chemical, physical microbiological and sensory parameters (descriptive and hedonic). Additional studies on the shelf life of Akkawi and other cheeses are much needed, owing to the major role that salt plays in cheese preservation, particularly in countries where standardizations are still in process. It would also be interesting to study the effect of additional ingredients on the perceived bitterness and the possibility of using ingredients that would assist in masking this bitterness and thus improving the acceptability of Akkawi cheese stored in NaCl/KCl brine. The latest advances made in the manufacture of salt powder that delivers the same salt intensity with less weight through the production of salt microspheres needs to be investigated in white brined cheeses. The issue of potassium intake of products that have KCl substitution is of crucial importance from a public health perspective and needs to be further investigated, especially with respect to risk assessment of high intake of potassium.

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REFERENCES


