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Chapter 11

SALT IN CHEESE: HEALTH ISSUES, REDUCTION, REPLACEMENT AND RELEASE

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ABSTRACT

Many chronic diseases are associated with excessive salt intake (NaCl) such as hypertension, strokes, osteoporosis, kidney stones and cardiovascular diseases (CVD). World Health Organisations highly recommended to food manufacturers to reduce the salt in their products. Therefore, reduction of salt in foods becomes an important issue. Cheeses contribute highly to the daily intake of salt. Reduction of salt in cheese has been investigated using different techniques. Simple salt reduction in cheeses without substitution with other salts has been applied. Most of studies reported several issues related to saltiness perception, cheese texture and safety. Salt (NaCl) replacement, second technique, with other salts (potassium chloride, magnesium chloride and calcium chloride) has been proposed as an alternative to simple techniques. Substitution of NaCl with other salts has proved its ability to maintain the safety and quality of cheeses; however, minor issue related to sensory properties needs further investigation. The mechanism of salt release in cheese is an important factor that needs further investigation in order to improve saltiness taste in low-salt cheeses. This chapter provides scientific and valuable information about: roles of salt in cheese, salt and health issues, salt reduction techniques and summarize the studies have been published, so far, in terms of salt release.

Keywords: Salt reduction, salt replacement, salt release

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1. INTRODUCTION

From historical time, salt played an important role in human life. Roman and ancient Egyptians and Middle Eastern people were pioneers in using salt because of its food preservation properties (Forbes, 1965). Historically, “natron” was the first name that has been given to salt by Egyptians; natron means divine salt. The Latin name “salarium” was used to refer to the amount of salt that was given to a worker as payment for his job.

Salt (sodium chloride) is an ionic compound mainly comprised of sodium (Na^+) and chloride (Cl^-) ions. Sodium regulates fluid balance in the body and is used in the electrical signaling in the nervous system (Campbell et al., 1993). Salting is one of the common techniques used to preserve foods during storage. Also, salt contributes to food flavor (Silva et al., 2003). The recommended daily intake (RDI) for sodium varies according to stages of life and genders. In general, RDI of NaCl range between 1.18 to 2.36 g per day (Anonymous, 2003). An excessive consumption of salt leads to chronic health issues (Turk et al., 2009).

About 75% of the dietary salt comes from processed foods (Appel and Anderson, 2010). Although addition of salt plays an essential role during food processing, it is currently considered as a main risk factor for disorders related to osteoporosis, kidney stones and hypertension (Buemi et al., 2002; Kotchen, 2005; Massey, 2005; Heaney, 2006). The World Health Organization has recommended food manufacturers to reduce salt content in their food products (WHO, 2007). It has been reported that dairy products contribute 10% of the RDI, which is mainly contributed cheeses at about 90%. In UK, cheeses contribute to the daily sodium intake to the tune of 7.8%, 9.2% in France, 8.2% in the USA and 5% in Australia (Anonymous, 2003; Meneton et al., 2009; Anderson et al., 2010). Therefore, it is highly recommended to reduce salt content in cheeses to concur with WHO recommendation. The current review discusses the challenges encountered in reducing salt in cheeses and replacing salt with salt substitutes without compromising quality of the product or shelf life. Also, the review briefly revises the role of salt in cheese and salt absorption.

1.1. Roles of Salt in Cheeses

Salting is an important step in cheese manufacturing of all major cheese groups. Salt in cheese plays two major roles: (i) it preserves the cheese and (ii) contributes to the quality of the cheese (flavour and texture). Generally, salt is added to cheese to control the growth of lactic acid bacteria and to prevent undesirable microbial growth and consequently off-flavour (Rowney et al., 2004). Although salt does not act directly as an antimicrobial agent, however, it has the ability to reduce the water activity (a_w) in foods (Albarracín et al., 2011). Water activity of cheeses ranges from 0.99 in non-salted Quarg to 0.92 in Parmesan cheese.

The growth of lactic acid starter bacteria and so-called non-starter lactic acid bacteria (NSLAB) are also affected by salt concentration in cheeses. In dry-salted cheeses such as Cheddar cheese, acid production (decrease in pH) is inhibited by the addition of salt, hence more residual lactose remains in the curd. The residual lactose is utilized by NSLAB that are normally more salt resistant than lactic acid starter bacteria at early stages of ripening (Guinee and Fox, 2004).

Salt also plays an important role on texture of cheeses. Salt has an effect on hydration of casein and consequently on the water binding capacity of the casein matrix (Guinee and O'Kennedy, 2007). Adding salt to cheese curd at low concentration (0.1 – 2.5%) would increase the casein hydration, while at higher concentrations decrease it and consequently hardening the cheese (Guinee and Fox, 2004).

Several studies have reported that salt concentration affects the activity of the proteolytic enzymes (coagulant, indigenous milk enzymes, LAB enzymes) in cheeses. The increase in salt concentration in cheese would decrease the water activity which in turn reduces the enzymes activity (Fox and McSweeney, 1996; Upadhyay et al., 2004; Grummer and Schoenfuss, 2011).

1.2. Salt Absorption and Diffusion into Cheeses

1.2.1. Methods Of Salting Cheeses

There are three major methods for salting the cheese curd: I) **Dry salting:** direct addition of dry salt to cheese curd followed by mixing at the end of manufacture, e.g. Cheddar and cottage. II) **Surface dry salting:** rubbing of dry salt into the surface of the moulded curds, e.g. blue-type cheeses. III) **Brine salting:** soaking of moulded cheese in brine solution, e.g. Feta, Edam and Gouda.

1.2.2. Mechanism of Salt Absorption and Diffusion in Cheeses

1.2.2.1. Brine-Salted Cheeses

After placing a moulded cheese in brine, a net movement of Na^+ and Cl^- ions from the brine into the cheese will occur as a result of the osmotic pressure. This is due to difference in NaCl concentration between the brine and the cheese moisture. As a response to the osmotic pressure, moisture would migrate from the cheese center towards the surface. On the other hand, Na^+ and Cl^- ions would migrate from cheese surface to the center. The size of Na^+ and Cl^- pair is about twice of that of H^+ and OH^- pair. This results in more uptake of water than salt.

Due to the complexity of the cheese matrix, an impeded diffusion process of salt (inward) and water (outward) movements through the cheese during brining would occur (Geurts et al., 1972). Guinee and Fox (1983) and Simal et al. (2001) reported that NaCl is naturally moving at the rate of 0.2 cm^2 per day [diffusion coefficient in cheese moisture (D)]. However, it may differ from about 0.1 to 0.45 cm^2 per day according to cheese composition and brining conditions comparing to 1.0 cm^2 per day (D) in pure water at 12.5°C.

The movements of Na^+ and Cl^- ions from a high concentration spot to low concentration throughout the cheese are impeded by: (i) fat globules and protein aggregates which causes the ions to move through a complex routes to migrate from a region to another. (ii) the pores of the protein matrix which mechanically affect the Na^+ and Cl^- ions by sieving. It resembles the restricted movement of a sphere through a pipe with different diameters, which at its smallest is comparable to that of the sphere. (iii) the high viscosity of cheese moisture (∼1.27 times more than pure water at 12.5°C) which contains dissolved substances that restrain the movement of Na^+ and Cl^- ions by collision and by their charged fields.

1.2.2.2. Dry-Salted Cheeses Such as Cheddar Cheese

The mechanism of absorption is basically the same as that occurs in brine-salted cheeses. The dry salt would slowly dissolve in surface moisture of the curd pieces. This causes a contrary flow of whey from the center of the pieces to the surface which may associate with dissolving of the remaining salt crystals. Large surface area to volume ratio of the curd results in very rapid uptake of salt (10–20 min for milled Cheddar curd) during dry salting (Turhan and Gunasekaran, 1999; Simal et al., 2001).

2. National Guidelines for Salt Intake

Sodium is an important cation needed to maintain extracellular volume, serum osmolality as well as active transport of molecules across cell membranes. Sodium is found in most foods as sodium chloride, generally known as ‘salt’. The Australian National Health and Medical Research Council (Anonymous, 2003) has developed a nutrient reference values for Australia and New-Zealand including recommended dietary intake (RDI) for all nutrients. The RDI for sodium at different life stages and genders are presented in Table 1. These RDIs are similar to those recommended in the USA (Otten et al., 2006). Table 1 shows that RDI of NaCl is the same for both men and women at 1.18 to 2.36 g per day.

Table 1. The recommended daily intake of sodium (mg/day) and the equivalent amount of salt (g/day) for different life stages and genders[1]

Age (years)	Sodium mg/day		NaCl g/day	
Children & Adolescents	Recommended	Upper Level	Recommended	Upper Level
1 - 3	200 – 400	1000	0.51 – 1.02	2.56 (9 – 17 mmol)
4 - 8	300 – 600	1400	0.76 – 1.53	3.59 (13 – 26 mmol)
9 - 13	400 – 800	2000	1.02 – 2.05	5.13 (17 – 34 mmol)
14 - 18	460 – 920	2300	1.18 – 2.36	5.89 (20 – 40 mmol)
Adults (+18)				
Men	460 – 920	2300	1.18 – 2.36	5.89 (20 – 40 mmol)
Women	460 – 920	2300	1.18 – 2.36	5.89 (20 – 40 mmol)

[1] Nutrient Reference Values for Australia and New-Zealand (NHMRC, 2005).

Several studies and worldwide organisations reports showed that the actual daily intake of sodium is greater than the RDI (Elliott and Brown, 2006; WHO, 2007). Elliott and Brown (2006) reported that the daily sodium intake is in excess of 100 to 200 mmol per day especially in Asian communities. The UK dietary and nutritional survey of adults showed that the daily salt intake was 11 g in men and 8.1 g in women which is nearly 5 times that of RDI (Hoare et al., 2003). Excessive salt intake is highly correlated with various chronic diseases, such as hypertension, stroke heart and renal failure (Alderman, 2006; He and MacGregor 2007; Cappuccio 2012).

2.1. Dietary Sodium and Health Issues

2.1.1. Salt and Hypertension

Hypertension is a term that is used to describe a high blood pressure condition. According to the seventh Joint National Committee on prevention, detection, evaluation, and treatment of high blood pressure, healthy individuals have a blood pressure of approximately 120/80 mmHg, while individuals with blood pressure ≥ 140/90 mmHg are classified as hypertensive (Chobanian 2003). Individuals with blood pressure greater than 120/80 but lower than 140/90 mmHg are considered as pre-hypertension (Chobanian et al., 2003). Epidemiological studies, treatment trials, and animal studies have provided evidences of the positive correlation of sodium intake and hypertension. Thus, an excessive intake of sodium is highly correlated with hypertension (Kotchen, 2005; He and MacGregor, 2007; Penner et al., 2007). The clinical impact of hypertension is wide, varying from damage to blood vessels, through to stroke or myocardial ischemia. Uncontrolled elevation of blood pressure (malignant hypertension) can also lead to renal failure, heart failure and blindness (O'Shaughnessy and Karet 2006).

2.1.2. Salt and Cardiovascular Diseases (CVD)

Cardiovascular diseases (e.g. heart attack, heart failure and stroke) are major death causes in the world. World Health Organisation (WHO) reported that 30% of total death incidences in 2005 were due to CVD. Moreover, the report showed that this level will increase by 17% by 2015 (WHO, 2005). Numerous epidemiological studies have shown that hypertension is a major risk factor that causes CVD (Alderman, 2006; He and MacGregor, 2007; Penner et al., 2007). The lifespan risk of developing hypertension is more than 90% in an average lifespan. This combined with the evidence that increased salt intake is positively correlated with CVDs, there is a strong need for a population-based approach in reducing hypertension (Penner et al., 2007).

2.1.3. Salt and Other Harmful Health Issues

Several studies have shown positive association between kidney stones and increased salt intake (Massey, 1995; Lin et al., 2003; Massey, 2005). Stomach cancer is the second death cause compared to other cancer types. Epidemiological studies have shown significantly positive correlation between salt intake and stomach cancer (Joossens et al., 1996; He and MacGregor, 2007). Furthermore studies are shown that bone remodelling is inversely correlated with sodium intake and that there is direct correlation between sodium intake and urinary calcium excretion in healthy elderly men and women. This can lead to bone loss and possibly osteopenia and osteoporosis in individuals with high salt and low calcium intake (Heaney 2006). Therefore, dietary salt reduction is considered a worldwide necessity. Numerous health organisations and epidemiological studies recommend reducing salt intake in order to reduce the risk of chronic diseases especially hypertension (Elliott and Brown, 2006; WHO, 2007).

3. Salt Reduction in Cheeses

There has been an increase in cheese consumption around the world, and cheeses contribute approximately 20% to the daily sodium intake (Guinee, 2004b). This increases the demand for salt-reduced cheeses as a part of the world efforts to reduce salt in food. Because of strong correlation between excessive NaCl consumption and chronic diseases such as hypertension, kidney stone and stroke, several attempts have been made to decrease salt in cheeses without any adverse effects on their characteristics (Flock and Kris-Etherton, 2011).

3.1. Salt Reduction Techniques

3.1.1. Simple Salt Reduction

Numerous studies have been conducted to investigate the effects of salt reduction on cheese characteristics of various types of cheeses. (Table 2) As it has been described before, lowering NaCl concentration affects most characteristics of cheeses. The aim of the most of these studies was to reduce the salt concentration in cheeses with the least impact on flavour, texture and shelf-life. There are different approaches to simply reduce the salt in cheese: 1) reduce the salt in cheeses to the limit that does not adversely affect the quality and taste (Reddy and Marth, 1991), 2) reduce the salt along with adding flavour enhancers to compensate for saltiness (Duran-Meras et al., 1993), 3) adjust the cheese texture to improve the salt distribution inside the cheese in order to have a high salt release (Noort et al., 2010).

Table 2. The Effect of salt reduction on chemical composition of different cheeses

Cheese	Salt %	Moisture %	Fat %	Protein %	pH	References
Cheddar[1]	0.07	38.52±0.83	33.33±0.29	24.21±0.29	-	(Schroeder et al., 1988)
	1.44	34.89±0.76	35.23±0.25	24.78±0.09	-	
Feta	8	49.06±1.65	26.31±2.25	18.22±1.00	4.99±0.05	(Prasad and Alvarez, 1999)
	18	47.90±1.43	25.38±1.31	17.12±1.50	5.08±0.05	
Gaziantep	5	63.30±3.30	19.23±1.00	13.31±0.90	-	(Kaya, 2002)
	25	45.35±1.10	24.46±0.40	17.56±0.50	-	
Dil	3	47.25±0.23	19.25±0.35	24.62±0.78	5.64	(Kilic and Isin, 2004)
	6	47.31±0.06	19.25±0.35	25.09±0.32	5.76	
Cheddar[2]	0	36.14±0.39	31.75±0.30	26.44±0.12	5.22±0.02	(Murtaza et al., 2012)
	2	35.30±0.36	31.74±0.27	26.39±0.16	5.28±0.21	

[1]Cheddar cheese was made using bovine milk.
[2]Cheddar cheese was made using buffalo milk.

The overall acceptability of low-salt cottage cheese with 25, 50, and 75% less salt was examined by Wyatt (1983). A significant drop in the overall acceptability above 50% reduction was reported. Schroeder et al. (1988) investigated the effect of reduction of sodium chloride on sensory, microbiological and chemical properties of Cheddar cheese. The authors evaluated Cheddar cheese containing NaCl ranging from 0 to 1.44%. Cheese quality parameters were analysed over 7 months of storage period. The authors found that proteolysis, growth of lactic acid bacteria and water activity increased in low NaCl cheeses. The overall acceptability of Cheddar cheeses salted between 0.88 to 1.44% was similar. The low salt Cheddar cheese (at 0.73%) received normal acceptability scores (Schroeder et al., 1988). Kelly et al. (1996) reported that the rate of proteolysis in Cheddar type cheese made with different salt levels (0 to 3.3%, w/w) had an inverse relationship with salt concentration. The higher the salt concentration, the lower the proteolysis rate. Kristiansen et al. (1999) examined proteolysis in Danbo-type cheese brined at four different levels of NaCl (0.06, 2.6, 4.3 and 6.4% NaCl) for 96 hours at 16ºC. The authors found that those cheeses brined with high salt concentration had lower proteolysis compared with other cheeses. Physico-chemical properties of Feta cheese brined at 8, 15, and 18% NaCl was investigated by Prasad and Alvarez (1999) during the storage period of 63 days. The authors found that Feta cheeses brined in higher salt concentration became harder (Prasad and Alvarez, 1999).

Kaya (2002) monitored the changes in hardness and colour of Gaziantep cheese kept in brines with different salt concentrations (5%, 10%, 15%, 20% and 25% NaCl) followed by storage for two weeks. Cheeses in 20% and 25% salt solutions showed higher hardness compared with others cheeses. Cheeses in higher concentration of brine showed a change in colour compared to those in lower salt concentration. The texture changes of Dil cheese brined at two salt concentrations (3 and 6% NaCl) during storage for 3 months were examined by Kilic and Isin (2004). At high salt concentration, Dil cheeses showed harder texture compared with cheeses with other salt concentrations. Guven et al. (2006) prepared Beyaz cheese (Turkish white-brined cheese) followed by brining at 12, 14, 16 or 18% NaCl and ripening at 7°C for 9 weeks. Beyaz cheeses brined in 12 and 14% NaCl concentration had higher overall acceptability and flavour scores compared with those made from 16 and 18%. The authors demonstrated that all cheeses were affected by storage period in terms of dry matter, pH values, protein content and hardness. Hamid et al. (2008) made Sudanese white cheese and stored at 7ºC for 8 months in different brine solutions levels (4 - 6% salt concentrations). The authors reported that the microbial growth and proteolysis in cheeses brined in 4% salt concentration showed higher value than those cheeses with 6% salt content. In contrary, the fat and crude protein contents in cheeses with 6% salt were higher. Sensory characteristics of the cheese samples with 6% salt were significantly better compared with those made with 4% salt (Hamid et al., 2008).

El-Bakry et al. (2011) studied the effects of NaCl reduction on cheese functionality, microbiological stability and sensory attributes of imitation cheese (cheese analogue) containing 48% moisture and different salt concentrations (0-1.5%). The authors concluded that reducing salt content in imitation cheese decreased processing times, cheese hardness and microbial stability. However, sensory attributes of imitation cheeses with 50% of salt reduction received the highest acceptability scores. Murtaza et al. (2012) examined the effect of NaCl reduction on production of organic acids in buffalo milk Cheddar cheese salted at 0, 1 and 2% during storage of 120 days. The authors reported that high level of salt decreased the production of organic acids during storage.

The effect of salt reduction on different characteristics of Cheddar cheese was investigated by Sheibani et al. (unpublished data). Cheddar cheeses with three different salt levels [control (2.5%), treatment 1 (2%), treatment 2 (1.5%) and treatment 3 (1%)] were produced and ripened at 4.5°C for 8 weeks. Several parameters including chemical composition, microbial count, proteolysis rate, organic acid production, texture profile and microstructure were analysed. Authors reported significant difference in all measured parameters between all experimental cheeses at the same time of storage (Table 3). The microstructure of Cheddar cheeses became more close and homogenous by end of storage (Figure 2).

Table 3. The effect of salt reduction on proteolysis, microbial growth, hardness and lactic acid of Cheddar cheese during storage for 8 weeks at 4.5°C

Storage (week)	WSN[1]	TCA-SN[2]	TFAA[3]	*L. helveticus* [4]	Hardness	Lactic acid
0	3.86±0.7	3.03±1.2	0.862±0.03	8.72±0.0	12.17±0.4	1.08±0.1
	5.23±1.4	2.35±0.4	0.844±0.02	8.67±0.1	18.11±1.3	1.13±0.0
	5.75±1.4	4.77±0.4	0.940±0.02	8.71±0.0	14.54±0.3	1.13±0.0
	5.86±1.3	3.43±0.9	0.989±0.05	9.21±0.0	13.27±1.7	1.15±0.0
8	14.09±0.6	4.66±0.2	0.819±0.04	9.03±0.1	11.06±0.8	1.27±0.1
	10.92±0.6	4.55±0.3	0.937±0.13	9.01±0.1	13.75±1.2	1.25±0.1
	11.08±0.1	4.98±0.3	0.980±0.01	9.00±0.1	9.94±0.6	1.28±0.1
	12.31±0.4	4.30±0.2	1.184±0.06	9.20±0.1	8.31±0.3	1.28±0.0

[1] WSN: Water soluble nitrogen as percentage of total nitrogen (TN %).
[2]TCA-SN: 12% trichloroacetic acid-soluble nitrogen as percentage of total nitrogen (TN %).
[3]TFAA: Total free amino acids absorbance at 507 nm.
[4] L. helveticus: *Lactobacillus helveticus* (cfu/g).

Simple reduction of salt is the most preferable technique among cheese manufacturers; however, several issues need to be addressed. The increase in bitterness during storage and uncontrolled microbial growth in cheeses are the main issues with the low-salt cheeses. A hypothesis was proposed to improve salt release from cheese to mouth cavity during mastication in order to compensate for low salt taste. Several attempts were made to manipulate the cheese texture and composition with the purpose of enhancing the salt release hypothesis (Guinee and O'Kennedy, 2007; McMahon, 2010).

3.1.2. Salt (NaCl) Replacement

Replacement of sodium chloride with other salts [potassium chloride (KCl); calcium chloride ($CaCl_2$); magnesium chloride ($MgCl_2$)] without adverse impact on the cheese quality would be a good choice during cheese manufacturing. Salt content of Gouda cheese was reduced from 650 to 72 mg/100g and replaced with 283 mg KCl /100g by Martens et al. (1976). The authors reported acceptable sensory properties for cheeses. Replacement of salt with NaCl/$MgCl_2$ mixture in Gruyere cheese showed acceptable taste with a slight bitterness and soft body (Lefier et al., 1987).

Reddy and Marth (1993) salted Cheddar cheese with different NaCl/KCl mixtures (2:1, 1:1, 1:2 and 3:4). Sensory properties were overall acceptable in cheeses made with NaCl/KCl mixtures and similar to control cheese made with only NaCl. However, those cheeses contained lower KCl were preferable. Chemical composition, microbiological quality and texture properties of Cheddar cheeses salted with NaCl/KCl mixtures were similar to the control (Reddy and Marth, 1993). Katsiari et al. (1997; 2000a; b) investigated the effect of partial substitution of NaCl with KCl at different levels (3NaCl:1KCl, 1NaCl:1KCl, and 1NaCl:3KCl) on characteristics of Feta cheese during 180 days of storage. Authors reported no noteworthy differences in all sensory characteristics compared with the control (only NaCl). However, cheese salted with 3NaCl:1KCl received higher acceptability scores than cheeses made with other salt mixtures. Likewise, no significant differences in physico-chemical and microbiological parameters between experimental Feta cheeses were reported (Katsiari et al., 1997; 2000b). Similar study was conducted to examine the effects of partial salt replacement with KCl on Greek Kefalograviera cheese (Katsiari et al., 1998; 2001b; a). Kefalograviera cheeses salted with 3NaCl:1KCl, 1NaCl:1KCl and 1NaCl:3KCl had similar sensory scores compared with the control.

Laborda and Rubiolo (1999) prepared Fynbo (semi-hard Danish cheese) with NaCl/KCl mixture (1:1) and examined the maturation index. The authors concluded that proteolysis of Fynbo cheeses salted with NaCl/KCl mixture were very similar to the control brined only with NaCl. Zorrilla and Rubiolo (1999) examined the sensory properties of Fynbo cheese salted with NaCl/KCl mixtures. The authors reported that the sensory values of Fynbo cheeses salted with NaCl/KCl mixture were typical values in terms of saltiness and firmness compared with the control; however a slight bitterness was noticed in cheeses made with NaCl/KCl mixture.

Guven and Karaca (2001) investigated Turkish white cheese stored in different brines containing 14% of 1NaCl:1$CaCl_2$;1NaCl:1KCl;1NaCl:1$MgCl_2$; or 1NaCl:0.33$CaCl_2$: 0.33KCl:0.33$MgCl_2$ for 12 weeks. Proteolysis and acidity in experimental cheeses at the same storage period showed similar trend compared with the control. However, no evaluation was conducted in terms of sensory properties of the white cheeses stored in different brines.

Ayyash and Shah (2010) investigated the effect of partial substitution of NaCl with KCl on Halloumi cheese brined in 4 different brine solutions at 18% including only NaCl, 3NaCl: 1KCl, 1NaCl: 1KCl and 1NaCl: 3KCl and then stored at 4°C for 56 days. Several variables such as chemical composition, microbiology, proteolysis, organic acids production and texture profile were examined. The authors reported no significant difference between chemical composition, lactic bacterial count, proteolysis and pH values of control and experimental cheeses at the same storage period. Hardness of all Halloumi cheeses was similar to the control. However, a decrease in hardness occurred during storage period. Microstructure of all Halloumi cheeses showed a rough texture containing several voids at earlier storage times. However, the texture became more condensed and compacted by end of storage time (Figure 3).

Similar study was conducted to examine the effect of partial substitution of NaCl with KCl on Nabulsi cheese by Ayyash and Shah (2011b). Nabulsi cheese was made and brined in four different brine solutions at 18%, including only NaCl; 3NaCl:1KCl; 1NaCl:1KCl and 1NaCl:3KCl followed by storage for five months at room temperature. Different parameters were investigated including chemical composition, proteolysis, total microbial count and texture profiles. The authors demonstrated that Nabulsi cheeses brined in NaCl/KCl mixtures had identical chemical composition and texture profiles compared with control. Proteolysis values were higher in cheeses kept in brines containing higher KCl compared with the control. Furthermore, the microbial growth increased significantly during storage for all salt treatments while, hardness decreased during prolonged storage. Microstructure of all experimental cheeses showed smooth texture at the end of storage comparing with the initial storage time (Figure 4).

Ayyash and Shah (2011a) examined the effect of NaCl substitution with KCl on the proteolysis of Halloumi cheese. Halloumi cheeses were produced and salted using 4 different brine solutions (18% w/w), including only NaCl; 3NaCl:1KCl (w/w); NaCl: 1KCl (w/w);

1NaCl:3KCl (w/w) and stored at 4°C for 56 days. There was no significant difference in proteolysis between experimental cheeses salted with various salt mixtures.

Similar study was conducted to examine the effect of NaCl substitution with KCl on proteolysis rate and microbial growth and in Mozzarella cheese by Ayyash and Shah (2011c). Mozzarella cheeses were produced and salted with four different mixtures of salt (only NaCl, 3NaCl:1KCl, 1NaCl:1KCl, and NaCl:3KCl) followed by storage at 4°C for 27 days. Authors reported no significant difference in proteolysis rate and microbial growth between experimental cheeses during the storage. In contrary, there was an increase in proteolysis within a salt treatment.

Grummer et al. (2012) investigated the use of different salt replacers (KCl, $MgCl_2$ and $CaCl_2$) to replace sodium content in cheese aiming to sustain the saltiness and the preservation effects of NaCl in Cheddar cheese. Reduced-sodium cheeses were made by mixtures of NaCl with KCl, $MgCl_2$, or $CaCl_2$ and stored at 4 to 5°C for 6 months. The authors reported that at early stages of storage, water activity (a_w) of reduced-sodium cheeses did not show significant difference as compared to the control. The pH values of all reduced-sodium cheeses, except that with the mixture of NaCl and $MgCl_2$, were lower than those with only NaCl. Treatments containing NaCl/$CaCl_2$ showed the highest hardness values than the other cheeses. Treatments with $MgCl_2$ and modified KCl were generally less hard than with other treatments. Treatments containing $CaCl_2$ and $MgCl_2$ produced considerable off-flavour in the cheeses (bitterness, metallic, unclean, and soapy) as scored by trained panellists.

Table 4. The Effect of salt replacement on proteolysis of different cheeses

Cheese	Storage (d)	SR[1]	WSN[2]	TCA-SN[3]	PTA-SN[4]	TFAA[5]	References
Feta	3	NaCl	13.69±0.45	4.75±0.03	2.04±0.37	0.236±0.05	(Katsiari et al., 2000b)
		1:1	13.17±0.27	5.10±0.22	1.95±0.35	0.251±0.03	
	240	NaCl	22.10±1.00	12.95±0.63	5.24±0.52	0.822±0.11	
		1:1	22.96±0.74	13.76±0.50	5.27±0.54	0.846±0.09	
White	1	NaCl	0.22±0.01	-	-	-	(Guven and Karaca, 2001)
		1:1	0.32±0.05	-	-	-	
	84	NaCl	0.19±0.01	-	-	-	
		1:1	0.29±0.01	-	-	-	
Nabulsi	1	NaCl	1.02±0.02	0.79±0.04	0.39±0.02	-	(Ayyash and Shah, 2011b)
		1:1	1.09±0.09	0.87±0.04	0.39±0.01	-	
	150	NaCl	3.81±0.15	4.38±0.28	2.44±0.06	-	
		1:1	4.05±0.14	3.03±0.05	0.69±0.35	-	
Halloumi	0	NaCl	1.87 ± 0.21	1.43 ± 0.24	0.32 ± 0.02	-	(Ayyash and Shah, 2011a)
		1:1	2.34 ± 0.25	2.27 ± 0.40	0.30 ± 0.05	-	
	56	NaCl	28.86±1.68	2.76 ± 0.25	3.02 ± 0.03	-	
		1:1	27.42±2.57	1.73 ± 0.05	2.97 ± 0.14	-	
Mozzarella	0	NaCl	3.79±0.26	2.95±0.26	0.73±0.06	-	(Ayyash and Shah, 2011c)
		1:1	3.33±0.27	2.58±0.13	0.55±0.03	-	
	27	NaCl	8.55±0.19	6.56±0.42	1.07±0.08	-	
		1:1	7.09±0.49	6.35±0.68	0.80±0.08	-	

[1] SR: Salt replacement (1:1= 1 NaCl: 1 KCl)

[2]WSN: Water soluble nitrogen as percentage of total nitrogen (TN %).

[3]TCA-SN: 12% trichloroacetic acid-soluble nitrogen as percentage of total nitrogen (TN %).

[4]PTA-SN: 5% phosphotungstic-soluble nitrogen as percentage of total nitrogen (TN %).

[5]TFAA: Total free amino acids absorbance at 507 nm.

In a nutshell, replacement of NaCl with other salt mixtures showed acceptable results without adverse effects on cheese characteristics compared with simple salt reduction (Table 4.). Moreover, among other salts, KCl was found to be the most acceptable salt for partial NaCl replacement. In addition, intake of KCl is not associated with development of hypertension and cardiovascular diseases (Buemi et al., 2002; Geleijnse et al., 2007). However, according to epithelial sodium channel (ENaC) such replacements appear doubtful due to the specificity of sodium ion that is responsible for salt taste (Garty and Palmer, 1997). Sodium chloride replacers such as KCl, $CaCl_2$ and $MgSO_4$ have been applied to replace NaCl or enhance salt taste in a number of cheeses (Van Der Klaauw and Smith, 1995). Although, these compounds may contribute to a salty taste, they may also provide undesirable after tastes such as bitterness, metallic and sharp taste, which limits their usage in cheese manufacturing (Reddy and Marth, 1991; Lawless et al., 2003). Hence, while the use of other cations, particularly potassium, is recommended due to the added health benefit of increasing dietary potassium intake, the concentration at which salt compounds can be used in cheeses will be limited (Lawless et al., 2003).

4. Salt Release from Cheeses

Although, the reduction of salt is a serious concern for public health and food industries; however, the problem of saltiness perception in sodium-reduced food products still exists. Perception of saltiness is one of the main factors of acceptability of a food product. Sodium ion (Na^+) in turn plays the main role in saltiness perception (Rawson and Li, 2007). Reducing the sodium content of food either by using mineral replacer or simple reduction decreases the acceptability and saltiness taste of cheeses. A hypothesis has been proposed to manipulate the cheese composition and texture in order to facilitate Na movements in cheese moisture which in turn will increase the salt release. In other word, the main concept is to increase the speed and amount of salt released from cheese into mouth during chewing. The acceleration of salt contact with the tongue papillae will decrease the feel of low saltiness taste. Hence, salt reduction in cheese would not be an issue in terms of flavour.

4.1. Salt Movement in Cheeses

Immediately after contacting the salt with water, it dissolves and separates into two ions, Na^+ and Cl^-, and surrounds by H_2O molecules (Chang and Cruickshank, 2005).

$$NaCl \rightarrow Na^+ + Cl^-$$

After salting the cheese, Na^+ and Cl^- will migrate from brine or dry salt into cheese moisture and water will move out of the cheese simultaneously. There are two opposite fluxes when cheese is exposed to brine or dry salt: (i) Na^+ and Cl^- ions diffuse into cheese matrix towards the cheese centre and (ii) water in cheese migrates from the cheese centre to the surface (Figure 1). Salt diffusion into cheese varies based on the cheese block size and distance between cheese block centre and surface.

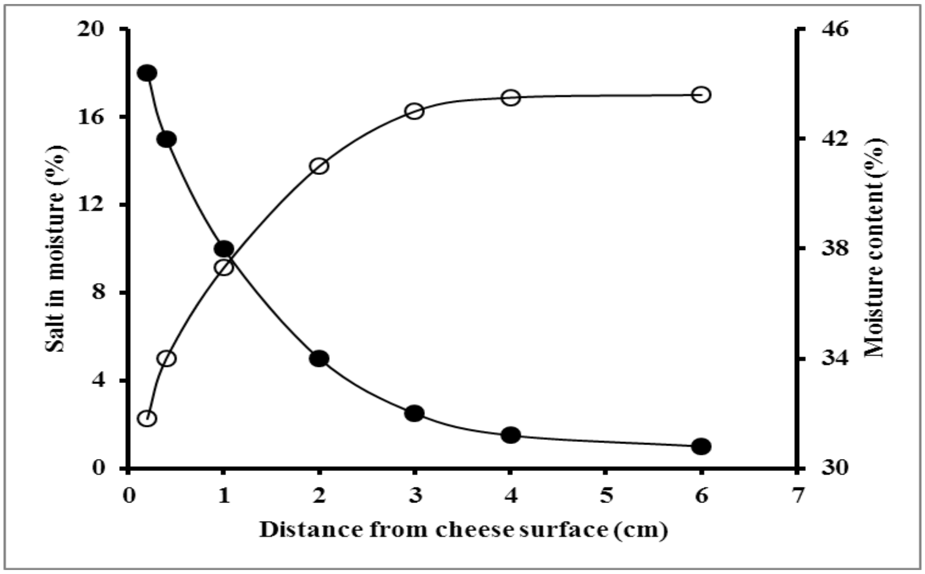
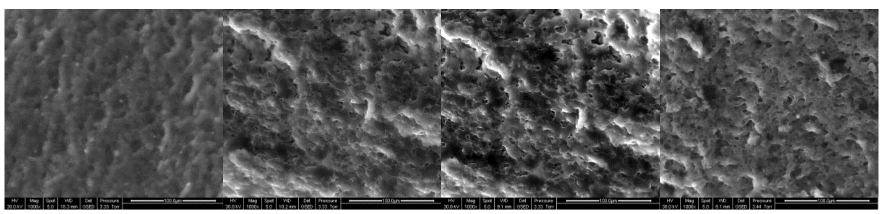


Figure 1. Moisture content (o) and salt-in-moisture (●) in a typical semi-hard cheese as a function of distance from the salting surface (Sutherland, 2003).



B

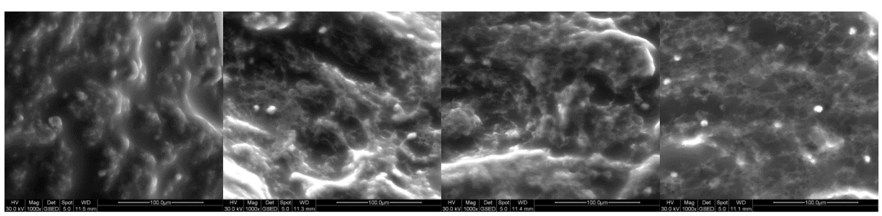


Figure 2. Microstructure of Cheddar cheeses made with 4 levels of NaCl during storage for 8 weeks at 4.5° C (A= week 0, B= week 8).

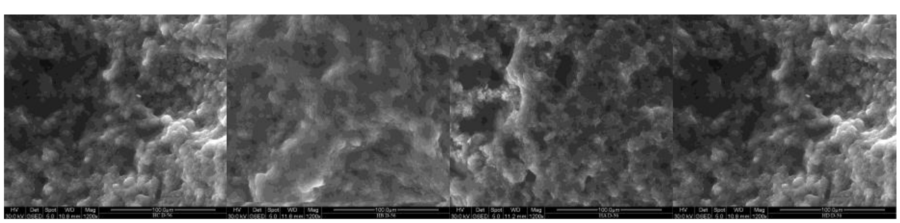


Figure 3. Environmental electron scanning microscopic images of Halloumi cheese microstructure made with 4 different salt replacements (only NaCl; 3NaCl:1KCl; 1NaCl:1KCl and 1NaCl:3KCl) at 18% concentration and stored 56 days at 4°C.

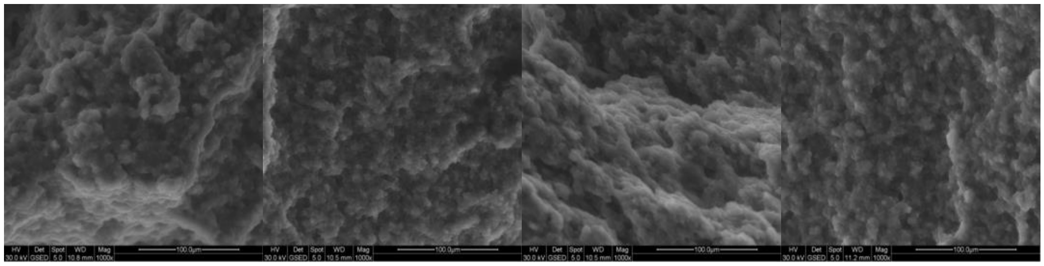


Figure 4. Environmental electron scanning microscopic images of Nabulsi cheese microstructure made with 4 different salt replacements (only NaCl; 3NaCl:1KCl; 1NaCl:1KCl and 1NaCl:3KCl) at 18% concentration and stored 6 month at room temperature.

Diffusion of NaCl into cheese and migration of water out of the cheese is an impeded diffusion process (Geurts et al., 1974; 1980a). Diffusion rate of NaCl in cheese matrix (cm^2) per day called coefficient of diffusion (D^*; cm^2/day) varies between 0.1 to 0.45 cm^2 / day (Guinee, 2004a). There are several components impeding the movements of NaCl ions and H_2O throughout cheese matrix including protein, fat and ash. These components along with many other factors act as a barrier for NaCl and water movements through cheese matrix (Guinee, 2004a; Guinee and Fox, 2004):

a) The mechanical force of outward water flux (migration of amount of water out of the cheese is higher compared with low flux of Na^+ and Cl^+.) might impede the inward Na^+ and Cl^- flux.
b) The Na^+ and water movements inside the cheese matrix are influenced by fat globules and protein mass. Consequently, salt and water will encounter a tortuous path and accordingly slower movement outwards the cheese.
c) The diffusion of Na^+ and Cl^- into cheese and water out of cheese are affected by the complex cheese matrix which exerts a sieving effect.
d) Due to the amount of soluble solids in aqueous phase of cheese compared with pure water, the Na^+ diffusion in cheese moisture would be slower compared with pure water.

4.2. Salt Release in Model Cheeses

The significance of the salt reduction issue and accordingly the release of salt to contribute the normal perception of saltiness in salt-reduced food products triggered the further investigation on mechanism of release of NaCl from different food matrices. Cheese is one of the food products to which a lot of consideration has been given due to its complicated matrix. Several studies have investigated the mechanism of salt release from different model cheese matrices. However, there is lack of information about the mechanism of salt release in real cheese matrix which requires further investigation.

Geurts et al. (1980b) investigated the movement of salt and water during the salting of Gouda-type model cheese. Cylinders of cheese (30cm diameter, height 10 cm) were made with different compositions and placed in contact with brine solution. Authors reported that diffusion of salt in cheese cylinders containing higher fat in dry matter was lower. This might be due to a tortuosity path caused by higher fat content for salt to travel. Similar achievements were obtained in term of Moisture and temperature of ripening. The higher the moisture content in cheese, the higher the diffusion rate.

Diffusion of salt in Cheddar cheese made and salted with different salt levels (0, 2.8 and 5.6 % NaCl) following by storage at 8°C for 24 weeks, was examined (Morris et al., 1985). Several variables including moisture, salt and pH were measured. Authors concluded that establishment of an equal balance of salt in Cheddar cheese is a very slow process and affects the salt distribution directly. If inadequate distribution of salt occurs initially, it would lead to an improper salt balance throughout the cheese during the ripening period. Moreover, the random positioning of salted curd pieces which forming the structure of the cheese may contribute with the slow balance of salt throughout the cheese. Initially, NaC1 is diffusing from the surface to the center of each piece of curd. This might cause a lack in net NaC1 gradient to form a balance throughout the cheese due to the NaCl balance has been formed inside each curd pieces.

Turhan and Kaletunc (1992) investigated the salt movement in white cheese brined at two brine concentrations (15 and 20% NaCl) and stored at 4, 12.5 and 20°C. Authors concluded that the time, temperature and distribution of salt might affect the salt concentration and the required time to reach ultimate salt concentration in white cheeses and other similar cheeses.

Zorrilla and Rubiolo (Zorrilla and Rubiolo, 1994) made a Fynbo cheese model considering a triple diffusion in axial and radial directions to predict the concentration of NaCl and KC1 during brining. Cheese samples were brined in a KCl-NaCl mixture and stored for 5, 10 and 15 hours. As the brining time increased, the average relative error of the cheese samples showed higher value in cheeses with KC1 comparing to those containing only NaCl.

Similar study was conducted by Jack et al. (1995) to investigate the effect of texture on release of salt from Cheddar cheese during chewing. Different types of Cheddar cheeses (vintage, vegetarian, reduced fat, Scottish mature, etc.) were purchased form market and stored at 4°C. Various parameters were measured including: salt, moisture and sensory evaluation (based on chewing mechanism). Authors reported that the increase in chewing time and ripening time (more effect on texture) would increase the release of salt form cheese.

Simal et al. (2001) investigated the diffusion of water and salt during the ripening of cheese. A diffusional model of Mahon cheese was made and brined in a mixture of 28% NaCl with 1.5% $CaCl_2$ at 12°C. A significant difference was observed in salt concentration between the surface and center of cheese. The difference in salt concentration decreased as the ripening time increased. Authors reported that mass transfer phenomena are affected by internal and external resistance.

Pionnier et al. (2004) investigated the relationships between flavour release oral parameters and perception during consumption of a model cheese. A model cheese was made consisting of fat, protein, volatile and non-volatile compounds to mimic actual cheese structure. In term of contribution to flavour release and oral parameters, no significant difference was detected between different compounds. The authors hypothesized that there are three reasons may explain their results: (i) the authors did not properly evaluate the effect of mixture on those parameters. (ii) No enough replications have been performed. (iii) The mechanism of flavour perception is highly complex and thereby this would increase the difficulties to observe the correlation between flavour release and perception.

Parallel study conducted by Phan et al. (2008) to examine the perception of saltiness during eating model cheeses of different textures using cheese models. Cheeses were made with two levels of shear intensity and two different ratios of fat/water concentration. Several parameters were evaluated including fat/water ratio, salt concentration in saliva, saltiness perception and masticatory parameters for each product. Products made with high shear intensity showed easier salt release in the mouth during mastication. However, the release of salt showed decrease in cheese models containing high fat concentration. Authors reported that there is direct relationship between masticatory parameters, sodium release and saltiness perception. Also, sodium release and saltiness was affected by the water and fat content respectively.

Floury et al. (2009) studied model cheeses with different compositions (dry matter, fat/dry matter and salt) and investigated the effect of different factors (rennet concentration, fat content and pH) on release of salt from these model cheeses. Different variables were measured including salt concentration in saliva and each model cheese, protein and fat content and microstructure. Authors claimed that the pH at renneting stage caused an increase in diffusion coefficient value (D). This might be due to the changes in chemical components in the structure of the casein micelles. In cheese models with the initial salt concentration, the D value significantly decreased which may be due to the compact microstructure. Additionally, the diffusion of the salt was accelerated in some of the cheese models due to the lower protein content which may create a rougher and softer microstructure. In contrast, there was no significant observation on the effect of fat content on salt release form model cheeses.

Similar study investigated the impact of salt and fat reduction on texture and perception of flavour in a model cheese by Saint-Eve et al. (2009). Five different model cheeses with different dry matter content (370 or 440% w/w), fat content (40 or 20% w fat/w dry matter) and salt (NaCl) content (0.5 or 1.5% w/w) were prepared. Various parameters such as sensory and texture properties were analysed. It was reported that the perception of texture and instrumental texture parameters were highly affected by differences in the amount of salt, fat and dry matter. Salt and fat contents showed an effective role in aroma release and perception. However, texture properties of model cheeses showed no effect on salty perception. Also, the perception of saltiness in model cheeses with the low fat and dry matter contents showed an increase.

De Loubens et al. (2011) prepared model cheeses and investigated the effect of mastication on salt release from model cheeses. Authors developed an experimental device for monitoring the salt release from the cheese models into water (saliva) after an equal compression (mastication simulation). They claimed that mastication and accordingly the texture breakdown of model cheeses showed direct contribution to release of salt from model cheeses. Likewise, cheese models with higher fat content showed higher breakability and therefore more release of salt.

The effects of composition and texture on release of salt from a solid lipoprotein model has been studied by Lawrence et al. (2012). Lipoprotein matrices were prepared using milk and different variables including rheological, texture and sensory profiles were measured. Authors found that change in dry matter, salt and fat contents influenced the taste perceptions and texture. The amount of release of sodium showed direct correlation with the moisture content, while fat content was responsible for perception of saltiness. Moreover, the brittleness of lipoprotein models was affected by amount of fat. The higher the fat content, the higher the brittleness and consequently the higher salt release.

To sum up with, the effect of different factors on mechanism of release is obviously important and needs more investigation. However, the impact of these factors on salt release from cheese model matrices would not reveal the reality of these phenomena as model matrices are prepared and manipulated humanly.

There is still lack of information on understanding of both salt release from actual cheese matrices and effective factors. More investigations need to be conducted to unveil more facts regarding this issue.

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