Journal of Elementology ISSN 1644-2296

Wachowska M., Adamczak M. 2019.
Role of sodium and possibilities of reducing its content in ripened cheeses.
J. Elem., 24(2): 511-524. DOI: 10.5601/jelem.2018.23.4.1673

RECEIVED: 7 May 2018
ACCEPTED: 3 November 2018

REVIEW PAPER

ROLE OF SODIUM AND POSSIBILITIES OF REDUCING ITS CONTENT IN RIPENED CHEESES*

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Abstract

Although ripened cheeses are a valuable source of essential nutrients in the human diet, they also contain significant quantities of Na and supply dietary sodium. However, a high concentration of Na can induce lifestyle diseases, e.g. cardiovascular diseases, stroke, cancer and osteoporosis. The World Health Organization (WHO) recommends an intake of < 5 g per day of dietary NaCl and < 2 g per day of Na. Consumer habits should be changed in addition to reducing the content of NaCl by changing the technology of cheese production. The role of NaCl in cheese production does not enable its complete elimination, as this would result in significant deterioration of the quality of cheeses. This paper reviews research into the reduction of Na content in cheeses maintaining their high quality to be acceptable by consumers. It elaborates on the effect of the reduction in the NaCl content of cheeses on the processes of proteolysis and lipolysis as well as on the survivability of microorganisms. The possibilities for the use of NaCl blended with other salts, e.g. KCl, which can replace NaCl up to 25-50%, was presented. The attempts to use flavour enhancers as well as food flavourings in order to improve the consumer acceptability of cheeses were analysed and difficulties in finding substitutes to table salt due to its unique salty taste and effects on the course of microbiological and enzymatic processes were highlighted. The role of NaCl in the technology of cheese production is complex, requiring a multivariate analysis, and the reduction in NaCl content in cheeses or the replacement of NaCl by other additives do not solve the problem of a high concentration of Na in the human diet.

Keywords: salting, salt substitutes, cheese, NaCl, KCl.

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* This research was supported by the Ministry of Science and Higher Education of Poland as part of statutory activities.

INTRODUCTION

Sodium (Na) is a natural component of food raw materials and an additive used in food production, which can be added during the culinary preparation of dishes. Most foods are naturally low in sodium chloride (NaCl) and Na additives almost completely account for the excessive consumption of Na throughout the world (Gutiérrez 2013).

In industrialised countries, the main source of Na in foodstuffs is NaCl, commonly referred to as table salt. It considerably affects the taste of food products and is one of the cheapest and most commonly used food additives (Albarracín et al. 2011, Busch et al. 2013). In addition, table salt has preservative properties, reduces the value of water activity (a_w) and affects enzymatic activity as well as the durability and texture of products.

Consumers search for products which are convenient and easy to prepare; unfortunately, such products usually contain significant amounts of Na. Intake of an excessive amount of Na may be the cause of many diseases, e.g. hypertension, stroke, stomach cancer, kidney stone disease, osteoporosis, asthma and diabetes mellitus (Karppanen, Mervaala 2006, Liem et al. 2011, Mitchell et al. 2011).

According to the World Health Organization (WHO), the daily NaCl intake should not exceed 5 g. NaCl intake in developed countries is 25 times higher than minimally required for an adult, and 75% of table salt originates from processed food products (Albarracín et al. 2011). A significant reduction in the current salt intake requires a shift in two key domains: commercial foods and consumer behaviour. A lower NaCl concentration in food products could be achieved by producing high quality reformulated products which are safe and accepted by consumers; another option is to reduce NaCl consumption by raising the awareness of NaCl consumption (Zandstra et al. 2016). The reduction in Na intake can be achieved by lowering the NaCl content of products as well as by using NaCl substitutes or implementing far-reaching changes in manufacturing processes. As part of the implementation of guidelines on the reduction in table NaCl content of food, World Salt Awareness Week has been celebrated annually for the past eleven years (http://www.worldactiononsalt.com/awarenessweek/).

Since the role of NaCl in the technology of cheese production is complex and the salty taste of cheese is one of its characteristics, a reduction in the NaCl content of cheeses or replacement of NaCl by other additives is a considerable challenge, requiring a multivariate analysis.

THE USE AND ROLE OF NACl IN CHEESE PRODUCTION

With the exception of the Domiati cheese, cheeses are salted after coagulation and having obtained the curd. Depending on the type of cheeses produced and the required table salt content of the finished product, different salting methods are used, e.g. dry salting for Cheddar, surface dry salting for blue-type cheeses and brine salting for Gouda. Morever, combined salting methods are also sometimes used (GUINNE 2004).

The NaCl concentration in cheeses may vary greatly and is determined by the tradition and consumer preferences. It usually ranges from 0.5-0.7% (w/w) in sour quarks to approx. 6% (w/w) in Domiati cheese (GUINEE 2004). HASHEM et al. (2014) analysed the NaCl content of cheeses sold in supermarkets in the United Kingdom and demonstrated that 8 out of 23 cheese types were characterised by a NaCl content higher than 2 g 100 g^{-1} cheese, e.g. Halloumi and imported blue cheese contained 2.71 g 100 g^{-1} of cheese. Only three types of cheese contained less than 1 g NaCl 100 g^{-1} product. AGARWAL et al. (2011) also found high variability of the Na content in cheeses manufactured by different producers in the United States, and demonstrated that the Na content declared on the label rarely reflected the actual Na content in cheeses.

Table salt serves numerous functions in cheeses, as it imparts taste and aroma, determines the course of fermentation and the sourness of the product, removes excess whey to provide a firmer texture and, in certain cases, contributes to the development of the rind, regulates the activity of many enzymes (including proteolytic and lipolytic enzymes which are of key importance to the quality of cheeses) and contributes to the proper course of the processes associated with ripening. NaCl also regulates the value of water activity (a_w), and thus determines the growth of microorganisms (JOHNSON et al. 2009, EL-BAKRY 2012, TAYLOR et al. 2017). Each type and brand of cheese is characterised by a specific NaCl content, which determines their particular quality features. A low NaCl content enables the development of the propionic acid bacteria in Swiss-type cheeses (Emmentaler 0.7% NaCl), while in the Gouda cheese and other semi-hard or hard cheeses, table NaCl helps reduce the risk of butyric fermentation (BISIG 2017). Several ways to reduce the NaCl content of cheeses have been used, such as increasing the water content of the product and reducing the fat content (PHAN et al. 2008), using KCl as well as KCl and NaCl blends (IWAŃCZAK et al. 1995, AYYASH, SHAH 2013, CARMI, BENJAMIN 2017), using emulsifiers in the production of potassium-containing processed cheeses (JOHNSON et al. 2009) or odour-induced saltiness enhancement, e.g. cheese or sardine aroma (LAWRENCE et al. 2011).

POTENTIAL USE OF TABLE SALT SUBSTITUTES IN CHEESE PRODUCTION

The perception of salty taste is attributed to the Na^+ cation in 70-85% and to the Cl^- anion in 30-15% (Albarracin et al. 2011, Feltrin et al. 2015). Table salt intensifies and modifies the taste of foodstuffs (Durack et al. 2008, Doyle, Glass 2010, Mitchell et al. 2011), e.g. addition of NaCl enhances the sensation of sweet taste while masking metallic or bitter aftertastes. If less NaCl is added, food becomes less tasty and even described as "tasteless". The salty taste is sensed by humans only when table salt is dissolved. Rapid dissolution of table salt can therefore enhance the sensation of the salty taste, which consequently enables the use of less NaCl while maintaining the intensity of perceived saltiness (Beck et al. 2012). It was demonstrated that the rate of dissolution of table salt crystals and the intensity of the perception of the salty taste depend on their size, since smaller NaCl crystals dissolve more rapidly and the salty taste is perceived faster. In addition, it is important to intensify the salty taste with the use of NaCl in an appropriate form of crystals, e.g. in the form of flakes or dendrites, which enables the reduction in the Na content of food products while maintaining the required intensity of the salty taste (Mitchell at al. 2011, Busch et al. 2013) – Figure1. Depending on the crystallisation conditions, different shapes and sizes of salt crystals are produced. If evaporation is performed in a vacuum pan, it produces a concentric or cubic form of crystalline salt (Figure 1*a*). If low levels of sodium ferrocyanide decahydrate or sodium ferrocyanide are added, it interrupts crystal formation and small cubes

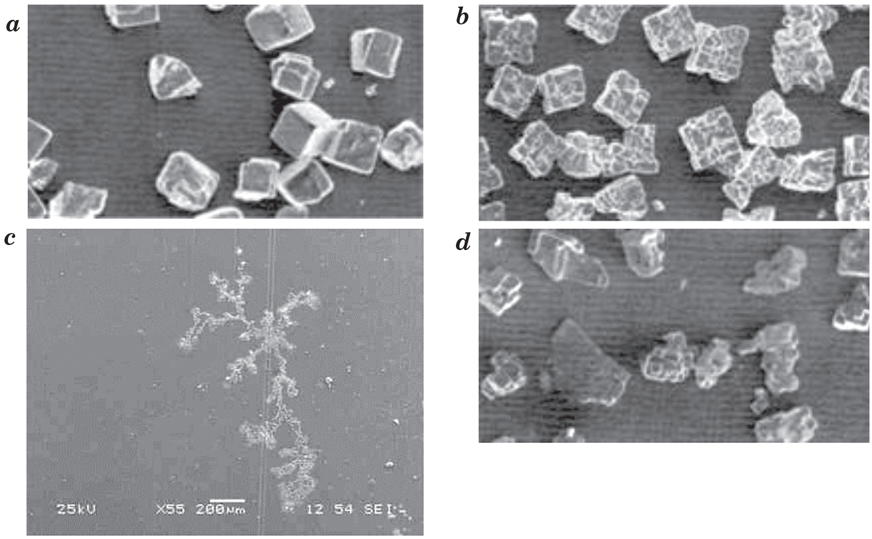

Fig. 1. Different forms of salt crystals: *a* – cube, *b* and *c* – dendritic, d – grainer salt (Barringer 2013, https://odyb.net/food-cooking/type-salt-bath-himalayan-sea-fleur-de-sel/)

aggregate into large cubes which have a porous structure (Figure 1*b*, *c*). Another shape of salt is produced if crystallization proceeds on a surface (the Grainer process) – Figure 1*d*).

Finding an appropriate NaCl substitute in cheese making is very difficult as potassium or calcium lactate are not characterised by the salty taste, while $CaCl_2$ (due to the content of Ca^{2+} ions) accelerates casein coagulation, which excludes this compound as an NaCl substitute in the dairy industry (Feltrin et al. 2015). An analysis of the saltiness profile of $MgCl_2$ demonstrated that it is characterised by the salty taste only for a short time, and afterwards acquires an undesirable bitter taste, which is even more intense than caused by the addition of KCl, while LiCl, despite resembling table salt, exhibits toxic effects on the human body (da Silva et al. 2014).

Other potential NaCl substitutes are characterised by lower saltiness; for instance, it was calculated that in order to obtain saltiness equivalent for 1% (w/w) of the NaCl content of cream cheeses, the addition of either 2.5% potassium chloride or 2.56% monosodium glutamate or 2.98% potassium phosphate was required (da Silva et al. 2014). Due to the low salting effect, the use of the above NaCl substitutes in the production of quarks would contribute to an increase in the costs of the process. However, the salting effect depends not only on the chemical properties of NaCl substitutes, but also on their interaction with the food product matrix (Kuo, Lee 2014) – Table 1.

Table 1

Potencies of NaCl substitutes relative to the NaCl in different products
(Souza et al. 2013, da Silva et al. 2014, Feltrin et al. 2015)

NaCl substitute	Relative salting effect*		
	NaCl in water (0.75%)	NaCl in cream cheese (1.0%)	NaCl in butter (1.0%)
Potassium chloride	74.75	83.33	83.33
Monosodium glutamate	59.52	39.06	31.59
Potassium phosphate	60.48	33.56	33.32
Magnesium chloride	Nd	40.00	nd
Potassium lactate	4.96	nd	nd
Calcium lactate	11.40	nd	nd

* Potency of NaCl substitute was calculated as the ratio between NaCl concentration and the equivalent concentration of substitute; nd – no data

A reduction in the NaCl concentration is likely to affect consumer acceptability of a food product, primarily due to the resulting unacceptable taste (Møller et al. 2013; Czarnacka-Szymani, Jezewska-Zychowicz 2015) and changes to the texture and aroma (Liem et al. 2011, Busch et al. 2013) – Table 2. A variety of blends are used which contain, apart from a reduced NaCl concentration, other salts and/or components, e.g. flavour enhancers (yeast extracts, monosodium glutamate or hydrolysed vegetable proteins),

Table 2

The effect of NaCl substitution in cheeses on their sensory evaluation

Cheese type	Substance type/ reduction in Na content	Sensory evaluation result	References
White salted cheese	Na:K ratio (1:3.4) (w:w)	harder and more fracturable cheese, low bitterness	AL-OTAIBI et al. (2016)
São João cheese	cheeses formulated with (3:1) or (1:1) (w:w) NaCl/ /KCl blends	hardness increased significantly while cohesiveness decreased significantly with the increasing substituting amount of KCl, positive sensory analysis of a reduced-Na cheese	SOARES et al. (2016)
Prato cheese	replacing 40% of NaCl with the following salt substitutes: KCl, Sub4salt®, and Salona™	no significant differences were observed in the physicochemical characteristics, pH, proteolysis indexes, melting capacity, and texture profile; the overall acceptance of the reduced Na cheeses was similar to the control	COSTA et al. (2018)
Requeijão cremoso processed cheese	50% Na reduction, 80% fat reduction and potentially prebiotic xylooligosaccharide	physicochemical, rheological, and sensory characteristics similar to the full-fat product with regular NaCl content	FERRÃO et al. (2018)

which facilitate the reduction of Na levels in food products without affecting their taste. It should be noted that despite the considerable progress in the production of these preparations, many products, including cheeses obtained with their addition, do not always meet consumer expectations.

A modification in the salting method enabled a reduction in the Na content by 32% in relation to traditionally salted cheeses (AL-OTAIBI, WILBEY 2006). The solution involved the addition of whey to the cheese obtained from milk following the ultrafiltration of salt (whey salts product, Valio Ltd, Finland).

Numerous tests were carried out to reduce the NaCl content of cheeses by using KCl for salting. It was demonstrated that an NaCl and KCl blend induced a higher perception of the salty taste than when these salts were used separately (NARSI et al. 2013). Studies aimed at the replacement of NaCl with KCl focused on both very popular cheeses like mozzarella (AYYASH, SHAH 2013, THIBAUDEAU et al. 2015), gouda, camembert (IWAŃCZAK et al. 1995) as well as cheeses typical for various countries, e.g. tzfat in Israel (CARMI, BENJAMIN 2017), telemea in Romania (ANGHELOIU et al. 2016), akkawi originating from Palestine (KAMLEH et al. 2015, GANDHI, SHAH 2016) and Spanish cheese Queso Fresco (VAN HEKKEN et al. 2017). It was found that KCl could usually replace from 25% to 50% of NaCl in these cheeses, and its higher concentrations resulted in a bitter, metallic aftertaste (KARAGÖZLÜ et al. 2008, Kumar, Kanawjia 2012, Soares et al. 2016). It should be emphasised that the effect of reducing the Na content to 120 mg in a serving of cheese (which would enable labelling these products as low-Na food) was not always obtained.

However, the cheeses made with a blend of NaCl and KCl are characterised by a Na to K ratio of 0.7-1.0, which is very favourable to humans, and by a higher nutritional value of protein compared to cheeses salted only with NaCl (Iwańczak et al. 1995).

It was also detected that cheeses made by various producers with a reduced content of Na^+ by 60% and with added KCl were characterised by different sensory and chemical properties. The salts, e.g. KCl-1 and premier KCl 8799 (Cargill Inc.), had a larger average size of particles than KCl-2, modified potassium chloride 14510 (Nu-Tek Products Inc.), i.e. 386 μm and 253 μm, respectively. These salts also differed in the active acidity of 5% aqueous solutions, i.e. the active acidity of KCl-1 was 7.80, while that of KCl-2 was 3.30. The sensory properties of the cheeses were also dependent on the composition of both potassium sources, i.e. KCl-1 contained phosphate tribasic and KCl-2 contained rice flour.

While using KCl as an NaCl substitute, it should be noted that K may affect a number of transformations responsible for the formation of chemical compounds which determine the taste and aroma of cheese. According to Ganesan and Brown (2014), 133 metabolic pathways of lactic acid bacteria can be activated and approximately 20 pathways inactivated by K^+, e.g. potassium ions are activators of 40 enzymes and inhibitors of 25 enzymes of the metabolic pathways of lactic acid bacteria. These metabolic transformations are primarily associated with sugar metabolism, the production of lactic acid and biosynthesis and degradation of amino acids. The visualisation of the effect of the cations on the metabolic pathways of lactic acid bacteria enables the prediction of changes occurring in a cheese with a modified composition of salts during ripening.

What is of importance to the production and quality of cheeses is that KCl used in combination with NaCl can be used for salting cheeses without an adverse effect on their microbiological quality (Wachowska 2011, Wachowska, Adamczak 2014, Kamleh et al. 2015, Haddad et al. 2017). The results of many experiments are available, which indicate the possibility of obtaining cheeses with the addition of probiotic strains and, at the same time, salted with an NaCl and KCl blend (Gandhi, Shah 2016, Silva et al. 2017).

EFFECT OF NACL REDUCTION ON PARAMETERS OF CHEESE

Studies on the reduction of NaCl content in various types of cheeses salted using various methods indicate the possibility to reduce NaCl concentration by 20-50% compared to cheeses obtained by a classical technology (Table 3).

It was observed that the reduction in the NaCl content in cheeses contributed to a reduction in whey syneresis (Lu, McMahon 2015), an increase in the value of the water activity in cheese and a reduction in the pH value. A greater increase in the starter microflora and non-starter lactic acid bacteria (NSLAB) at the early ripening stages, which resulted in a more intense course of the proteolysis process, was observed (Rulikowska et al. 2013, Cuffia et al. 2015). The reduction in the NaCl concentration from 4% to 1% (w:w) in a feta-type cheese from milk concentrated by ultrafiltration (UF) resulted in an increase, on day 30 of the ripening, in the content of water-soluble nitrogen compounds from 20.7 to 23.5%TN (water soluble nitrogen, as a % of total nitrogen) (Aly 1995). In the Cheddar cheese, a reduction in the NaCl content from 2.3% to 0.9% contributed to an increase in soluble peptides at pH of 4.6 (pH 4.6-SP), with a simultaneous reduction in the content of total free amino acids, TFAA (69.5-45.7 mmol kg^{-1} cheese) which, according to the authors, is linked to a high risk of the occurrence of the bitter taste in the cheese (Møller et al. 2013). In the Pecorino Romano cheese with a reduced NaCl content, no more intensive course of proteolysis process was noted but a higher pH 4.6-SP and TFAA, respectively 19.87%TN pH 4.6-SP and 3712.5 mg 100 g^{-1} TFAA was demonstrated. In a traditionally salted cheese of 14.77%TN pH 4.6-SP and 3229.1 mg 100 g^{-1} TFAA was determined (Tripaldi et al. 2014).

In UF feta-type cheeses with the NaCl content of 1% and 2% (w:w), a higher total content of volatile fatty acids was observed than in control cheeses containing 4% (w:w) NaCl (Aly 1995). In the Cheddar cheeses, a reduction in the NaCl content from 3% to 0.5% (w:w) resulted in no changes in the intensity of the lipolysis. In all cheeses after 224 days of ripening, the levels of free fatty acids (FFA) ranged from 908 to 1020 ppm (Rulikowska et al. 2013) and similarly, Tarakci et al. (2004) analysed herby cheeses with salt contents of 4%, 5% and 6% (w:w), demonstrated no differences in the course of lipolysis.

Microbiological analysis demonstrated no significant differences between the São João containing 1-4% (w:w) NaCl and with no salt added, in the Total Bacterial Counts (TBC), the count of *Enterobacteriaceae,* coagulase-positive staphylococci as well as yeasts and moulds. Despite the high count of *Enterobacteriaceae*, the authors noted no *E. coli*, *Salmonella spp.* strains in the cheese and identified no *L. monocytogenes*. According to the authors, industrial production of the São João cheeses with the NaCl content reduced to 3% (w:w) is possible without adversely affecting their quality (Soares et al. 2015).

Table 3

Effect of the reduction in the NaCl content in cheeses on their sensory evaluation

Cheese type	The effect of reducing NaCl content of the cheese	The acceptable level of NaCl reduction (%)	References
UF feta-type cheese	bitter taste	50	Aly (1995)
Cheddar	higher bitterness, lower salty intensity	50	Møller et al. (2013)
Irish Cheddar	saltiness, sweetness decreased, bitterness and sulphur increased Onion off-flavour	25	Rulikowska et al. (2013)
Cheddar	lower intensity of the salty and buttery taste	30	Ganesan, Brown (2014)
Mozzarella (low-moisture and low-fat)	a lack of salty flavour (0.7 and 0.9% salt), had lower intensity scores for brothy, sour, umami, sulphur, and buttery flavour attributes	30	Ganesan et al. (2014)
Argentinian sheep milk cheese	noticeable bitter taste	approx. 26	Cuffia et al. (2015)
São João cheese	increase in the bitter taste	25	Soares et al. (2015)
Prato cheese	the salt reduction did not increase the relative intensity of known bitter-tasting peptides; cheeses with 50% NaCl reduction were less firm and less sensory acceptable than the control cheese and the cheese with 25% NaCl reduction	25-50	Baptista et al. (2017)
Half-fat (16%) half-NaCl (0.9%) Cheddar-style cheese	overall, Ca reduction, when used in conjunction with moisture normalisation, proved an effective means of counteracting the adverse effects of fat reduction on texture and cooking properties (higher primary proteolysis, lower secondary proteolysis, higher water-holding capacity on reducing relative humidity	50	McCarthy et al. (2017)
Tybo cheese	the reduction of 30% NaCl content resulted in a cheese similar to a typical Tybo cheese in most respects	30	Sihufe et al. (2018)

An increase in the count of micrococci, staphylococci, proteolytic bacteria, yeasts and moulds in herby cheese with a reduction of NaCl concentration was observed by Tarakci et al. (2004). The count of determined microorganisms could have been affected by the water content of the cheeses and by the value of active acidity of the cheese bulk.

On the other hand, Mehyar et al. (2017) indicated that the use of either chitosan and natamycin or chitosan and lysozyme coatings for the halloumi cheese enabled the regulation of the cheese microflora, which offered the possibility for reducing the concentration of the brine used for salting from 15% to 10% (w:v) NaCl.

Proteolytic and lipolytic processes, as well as microbiological changes in cheeses contribute to the formation of the taste, smell and texture typical for a specific type of cheese. Ganesan et al. (2014) demonstrated that since consumers are able to identify a 30% reduction in the NaCl content of cheeses, it is necessary to gradually reduce the table salt content to increase the acceptance of these cheeses. Moreover, information on a reduced NaCl and fat content in a cheese positively contributes to the choice of this product by consumers (Czarnacka-Szymani, Jezewska-Zychowicz 2015).

Lawrence et al. (2011) studied the effects of the addition of sardine, comté cheese and carrot odours to a model cheese on the perception of its saltiness. Cheeses with the addition of sardine and comté cheese aromas, particularly those with a higher fat content (40% in d.m.), were assessed as being saltier than cheeses with the addition of carrot odour or in control cheeses. While comté cheese flavouring appeared to be more similar to the natural cheese smell, the addition of sardine aroma intensified the salty taste. The results demonstrated that properly selected aromatic compounds could enhance the sensation of the salty taste of products with reduced NaCl levels.

It should be stressed, however, that limitations in the reduction of the NaCl content of cheeses not only result from the lack of acceptance of less salty products, but also from the effects of table salt on the growth and metabolic activity of both the desired and undesirable microflora and on enzyme activity (Johnson et al. 2009). At the same time, the reduction of the NaCl content in food products may result in a significant increase of the risk of human exposure to food pathogens or microorganisms causing food spoilage and, in the authors' opinion, the research carried out in this area is insufficient (Taormina 2010). Stanhewicz et al. (2017) point out that although an Na-rich diet increases oxidative stress in the human body, milk proteins serve an important protective role against a reduction in NO bioavailability.

SUMMARY

A need to reduce NaCl intake remains a global human health problem. The challenge to achieve a 30% reduction in NaCl intake by 2025 is enormous. The group of 10 major products containing large amounts of NaCl includes cheeses. This review has demonstrated a possibility of lowering the NaCl content of cheeses by reducing its addition and using NaCl substitutes. Cheeses with a reduced NaCl content should be acceptable by consumers and characterised by high quality, which is difficult due to the multi-directional effects of NaCl on the quality of products. One promising method is to use an NaCl and KCl blend for salting cheeses. It should be stressed that the average K intake by humans is lower than that recommended in the WHO guidelines (at least 3510 mg day^{-1}), which makes the addition of KCl valuable to consumers while reducing table salt intake. Studies on the modelling of K intake by the replacement of NaCl with KCl in products with an excessive Na content exclude a risk of K overdose for a healthy population of humans (van Buren et al. 2016).

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