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WSS-18-081: Challenges of Removing Salt as a Sodium Reduction Solution for Foods

Paper Track: Salt and Health

Abstract: Research suggests a direct correlation between dietary sodium intake and blood pressure, with the effect being more pronounced for individuals with prehypertension or hypertension. Therefore, various governmental and health organizations recommend dietary sodium intakes that are lower than what is typically consumed to help decrease hypertension, a risk factor for cardiovascular disease. To help reduce sodium in the food supply, various geographies have introduced governmental regulations or voluntary guidelines for sodium targets in key food categories. In addition, market insights suggests consumers are seeking foods that are lower in sodium. As a result, many food manufacturers are publicly committing to reduce sodium in their products.

The first step in reformulating foods to a lower sodium target is to identify the sources of sodium in the formula. Many sodium-containing ingredients, such as sodium bicarbonate, have specific functional roles in food applications. Salt (sodium chloride) is unusual in that it has many roles including microbial management, protein and texture modifications, and taste. As a result, salt is widely used in food products (e.g. meats, bakery products, and cheeses) and is the greatest source of sodium in the food supply chain. No other single ingredient can replace all the functional roles of salt in foods, which creates many technical challenges for food product developers.

To demonstrate the functional roles of salt in food products, various meats, cheeses and bakery products were made using various levels of salt and potassium chloride (KCl) as a substitute for salt. Reducing salt content in hams without KCl replacement creates a product that has a shorter shelf-life and less protein fiber alignment, which results in loss of moisture (juiciness, product yield) and texture. Using partial replacement of salt with KCl can help bring back texture of cheeses, but its bitterness flavor can be detected in mozzarella cheese. In breads, removing salt leads to excess gas production due to uncontrolled yeast fermentation and less gluten development, which leads to large gaping holes in the loaf. KCl can help control fermentation and develop gluten, but has limitations at high usage levels due to taste. Salt also contributes to the expansion of extruded cereal and snack products. In conjunction with sensory testing, advanced analytical methods, such as X-Ray tomography, may be used to help understand the role of salts in food on a molecular level. Removing salt from an extruded cereal formula alters the air cell size distribution and wall thickness, which impact the taste and texture of the product.

Key words: salt, sodium reduction, microbial management, protein modification, sensory

Introduction

To remain relevant in the market and top of mind with the consumers, food manufacturers routinely develop new or reformulate existing products that meet their needs. Recent consumer trends include clean label, natural ingredients, higher in protein and fiber, or lower in calorie, sugar, fat and sodium. In addition, government and non-government organizations encourage food manufactures to provide consumers with healthier food options to help minimize potential health issues, such as hypertension and diabetes. As a result, food scientist are challenged with formulating products that must meet consumer's expectations for taste, while trying to preserve other product attributes (e.g. product yield, shelf life), maintain food safety and minimize introduction of complicated manufacturing processes.

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When faced with the challenge of formulating foods to meet a desired sodium content, product developers must focus on each sodium containing ingredient and the functional role it has on the overall product attribute. There are many sodium containing ingredient in foods including preservatives (e.g. sodium lactate, sodium propionate, salt), emulsifiers (e.g. disodium phosphate), leavening agents (sodium bicarbonate), flavoring agents (monosodium glutamate, acid salts), salt and the food itself (e.g. meat, milk). With the exception of salt, most of the sodium-containing ingredients have very specific functional roles.

Salt (sodium chloride) is the ingredient that contributes the most sodium in processed foods (Mattes and Donnelly, 1991). As a result, salt is generally the first ingredient that food scientist will lower in order to achieve the desired sodium target. Removing salt can help reduce sodium. However, salt is unique in that it creates many attributes that help define foods (e.g. flavor, texture, shelf life, food safety), which makes it a very powerful tool for food scientist. Changes in these attributes, can limit the amount of salt that can successfully be removed from the formula.

Functional Role of Salt in Foods

Salt is known to control microbial fermentation, modify structural changes of protein, impact product yield, promote color formation and most importantly to the consumer, impact flavor (salty and flavor enhancement). Table 1 summarizes the functional roles of salt in various food applications.

Microbial Management

In general, foods are a good source of nutrients that can support the growth of spoilage organisms and pathogens under certain environmental conditions. Presence of spoilage organisms can impact the quality of the food product, leading to a decrease in shelf-life and increase in food waste. Presence of pathogens (e.g. *Escherichia coli O157*, *Salmonella* spp., *Lysteria monocytogenes*) can lead to food borne illnesses by the organism itself or through the toxins that it produces. In certain fermented food applications, such as natural cheeses and some meats and vegetables, the presence of organisms are critical for the desired taste, texture and preservation of the food. Considering formulations that includes sodium reduction, the food scientist must first consider the impact to food safety. It is a delicate balance in order to create an environment where the desired organisms thrive while minimizing or eliminating the presence of undesirable spoilage organisms and pathogens.

Historically, salt was recognized as a powerful tool for preserving foods. In the presence of water, salt dissociates into sodium and chloride ions. The association between water and the ions decreases the water activity (Aw) in foods, resulting in less water availability for the microorganisms (Betts et. al., 2007). The inability of sodium and chloride to pass freely through the microbial cell wall results in an increase in osmotic pressure. Water begins to migrate out of the microbial cell to help mitigate the change in osmotic pressure and leads to a series of catastrophic events, such as damage to the cell wall. The presence of salt also impacts the ionic strength, which can alter the conformational structure of enzymes leading to a decrease in enzyme activity. Ultimately, the presence of salt at high levels lead to a decrease in microbial growth or microbial death (Brewer, 2000). The detrimental salt level required to impact survival is microorganism dependent. In general, most bacteria require Aw > 0.9 in order to survive, whereas yeast and molds are in the range of 0.6 – 0.8 range.

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Table 1. Functional Role of Salt in Various Food Applications

Food Application	Functional Role of Salt

Meat[1]	• Extraction and solubilization of soluble protein (myosin)
	• Water, meat and fat binding (emulsification)
	• Increase product yield
	• Control growth of spoilage organisms, pathogens and desired microorganism (microbial management)
	• Sensory attributes
	  ○ Salty taste/flavor enhancement
	  ○ Textural changes

Cheese[2]	• Salty taste/flavor enhancement
	• Control growth of spoilage organisms, pathogens and desired microorganism (microbial management)
	• Impacts enzyme activities
	• Curd syneresis – implications for
	  ○ Moisture reduction
	  ○ Water activity
	  ○ Microbial management
	• Physical changes in cheese proteins
	  ○ Texture
	  ○ Solubility and conformation

Bakery; breads, crackers, cookies[3]	• Salty taste/flavor enhancement
	• Control yeast fermentation (gas production)
	• Artisan appearance in topical applications
	• Impacts protein (gluten) development
	  ○ Air cell structure
	  ○ Texture

Snacks and cereals[4]	• Salty taste/flavor enhancement • Carrier for seasonings • Flavor and color formation (Maillard reaction) • Expansion of grains (cereals, snacks) • Texture in extruded products
Fermented vegetables[5]	• Control growth of spoilage organisms, pathogens and desired microorganism (microbial management) • Texture • Salty taste/flavor enhancement

[1] Feiner, 2006
[2] Guinee and Fox, 2004
[3] Cauvain and Young, 2001
[4] Moraru and Kokini, 2003; Ainsworth & Plunkett, 2006; Reiniccus, 2007
[5] Guillermo et al., 2000

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In developing food formulations and determining operation conditions, many factors (hurdles) are put in place to minimize or eliminate microbial growth as a measure for food safety. Typical hurdles used in food manufacturing include pasteurization (time/temperature), pressure, pH, Aw, salt, salt acids and organic acids. Mathematical models are used to determine the effect of the hurdles on *Lysteria monocytogenes* in ready-to-eat meats (Mejlholm, et al., 2010). To demonstrate the effect of salt on the shelf-life of roasted deli chicken, a model was used to evaluate microbial growth time and lag time at three different sodium levels. Salt levels were adjusted to achieve the sodium content and three levels of sodium were evaluated; control (910 mg/100 g), 25% sodium reduction (670 mg/100 g) and 50% sodium reduction (470 mg sodium/100 g) (Cargill, 2015). As shown in Table 2, the control (full sodium) had the greatest impact on extending the growth time to increase the microbial count from log 2 to log 4, indicating the importance of salt as a tool for extending product shelf life. Similarly, the control had the greatest impact on extending the lag time before exponential growth.

Table 2. Effect of Sodium Reduction on Microbial Growth in Theoretical Meat Model[1, 2]

Percent Sodium Reduction (mg sodium/100 g meat)	Growth Time (days) from Log 2 to Log 4 [2,3]	Lag Time (days) [2, 3]
0 (910)	70-100	31-89
25 (670)	65-93	28-83
50 (470)	58-84	25-75

[1]Cargill, Inc., proprietary research, [2]Opti.Form® Listeria Control Model 2007 (Mejlholm, 2010),
[3]First and second value at 99% and 95% confidence, respectively.

In cheese production, one of the functional roles of salt is to control the growth and metabolism of desired, and undesired, microorganisms (Johnson et al., 2009). Higher salt cheeses (e.g. blue, parmesan and cheese) have salt contents in the range of 2.5 to 3.5% salt, whereas lower salt cheeses are between 0.9 to 1.2% salt. In the case of blue cheese, the high level of salt supports growth of *Penicillium roquefortii*, the mold responsible for its distinctive flavor. In the case of Swiss cheese, lower salt levels are required to allow *Propionibacterium* to produce the desired gas to help form the distinguishing holes or eyes of that cheese (Johnson et al., 2009). Considering the specific salt content required for classes of cheese varieties, reducing salt or adding salt substitutes as a means to reduce sodium will create challenges for the cheesemaker. In addition, Standards of Identities must be followed to produce specific natural cheeses, which generally allow only four ingredients (milk, enzymes, cultures and salt) and the salt must be within a specified range (Code of Federal Regulations, 2017).

Similar to cheese production, salt is used to control fermentation in yeast leavened breads, in order to produce the desired visual and textural effect. By way of experiment, white breads were made in the presence and absence of salt to demonstrate the effect of salt on proofing time (time required to reach a certain bread volume), which is an indication carbon dioxide production rate by yeast (Cargill, 2010). In addition, potassium chloride was used in the formulation to compare its effect on fermentation to salt on a weight or molar basis. Figure 1 suggests that salt had a greater impact at slowing down the rate of gas formation, as indicated by the longer proofing times, than in the absence of salt or presence of potassium chloride (weight and molar basis). At first glance, the faster proofing times may seem beneficial from a manufacturing perspective, however, they are other quality factors to consider. Important to

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bread manufacturing is the quality of the protein development. If gas production rate is too rapid, the gluten protein is not fully developed and cannot contain the gas, resulting in uneven sized air cells (Figure 2). This visual effect may be may be desirable in may artesian breads, but not in conventional white sandwich breads.

Figure 1. Effect of Salt (NaCl) and Potassium Chloride (KCl) on Bread Proof Time (Volume Height)

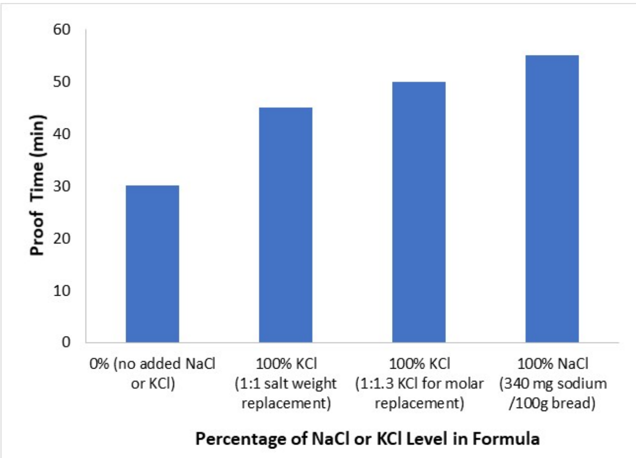
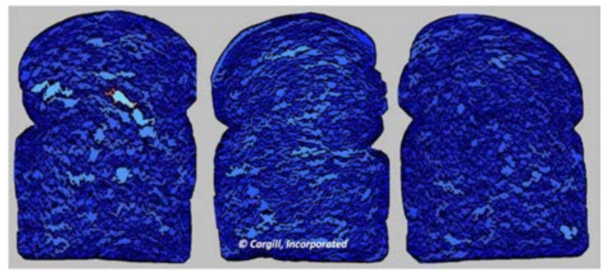


Figure 2. Effect of Salt (NaCl) Level on Air Cell Distribution (C-Cell) in White Bread.



0% 50% 100% (340 mg sodium/ 100g bread)

Salt Level (% of full control formulation)

Protein Modification

Ionic bonds are one of the interactions that help build the secondary and tertiary structure of a protein or within a protein-protein interaction. In milk, the divalent ion calcium form bridges with phosphate ions to help build structure and stability of casein proteins in solution. The presence of salt (specifically sodium cation) influences the degree of casein-associated calcium, which impact the physical characteristics of the cheese, such as melting upon heating. As a result, the proteins can undergo a conformational changes, which can impact the structure of the protein network. In addition, the exchange between sodium and calcium results in additional hydration of the protein, which can impact the formation and quality characteristic of cheeses, such as texture, rheology and melting characteristics (Guinee and Fox, 2004).

The heating and stretching of curds during the production of pasta-filata style Mozzarella cheese lends to its unique fibrous structure and physical melting (or stretching) characteristics. During the heating and stretching phase, the milk proteins reorganize and align into fibrous structure. In the finished Mozzarella cheese, these fibrous structures are separated by channels or pockets of fat, whey and bacteria (Oberg et al., 1993). The overall microstructure of the cheese can be influenced by many factors, with the primary one being the degree if casein-associated calcium. This degree of association will influence the physical properties of the cheese, such as the flow properties. High levels of calcium association results in cheese that tend to tear more easily, whereas low levels tend to be excessively soft and fluid-like (Kindstedt et al., 2004).

Using scanning and transmission electron microscopy, Paulson et al. (1998) observed more open structure with pockets of serum in unsalted cheese compared to salted cheese. At higher

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magnifications, larger and more distinct protein aggregates were observed for unsalted cheeses, whereas salted cheeses had more homogeneous protein dispersion (less protein aggregates). Comparing serum expression, unsalted cheese had more expressible serum after centrifugation than salted cheese, suggesting more protein hydration for the salted cheese. The melting characteristics of unsalted cheese was also lower than salted cheese further suggesting less protein hydration and protein aggregation with the unsalted cheese.

To determine if other monovalent cation salts could partially replace salt without impacting the functionality of Mozzarella cheese, potassium chloride was used to achieve approximately 30% sodium reduction (Cargill, 2011). After 4 weeks of age, the mean score for acceptability by an expert panel was 3.3 and 5.5 (on a scale of 1 = disliked extremely to 7 = liked extremely) for reduced sodium and control (full sodium) cheeses, respectively. Some panelist called out the bitter and metallic notes, which are typically associated with potassium chloride. The cheeses were baked in a pizza application to denote differences in characteristics such as free oil release, blister color and quantity, stretch (fork test). The most notable differences were in the skinning and the presence of a slight serum expressed in the cheese made with potassium chloride after cutting the pizza.

Meat tissue also contains structural proteins, namely, myofibrils and myofilaments. The addition of salt to ground meats helps extracts and solubilize the myofibrillar proteins. Two theories have been suggested for the changes in the protein structure; either the negatively charged chloride or the positively charged sodium ions from salt associate with the respective positively or negatively charged myofibril surface (Russunen and Plane, 2005). Conformational changes occur in the protein structure, which allow for interaction with fat and water to form a stable emulsion structure that binds muscle fibers to one another. The resulting structure helps increase product yield, texture and flavor in meat products.

To demonstrate the effect of salt on water holding capacity, light microscopy was used to determine the number of intact myofibrils per unit of measure (Cargill, 2013). For comparisons, two deli hams were prepared in the absence and presence of salt (2% w/w) and measured for intact myofibrils. As shown in in Figures 3a and 3b, the changes in salt concentration significantly impacted the myofibril protein swelling and structure. In the presence of salt, the myofibril are intact and exhibit order with approximately 12 myofibrils per 1 mm. The ham sample without salt had no noticeable myofibril swelling and the proteins appear fragmented compared to the ham with salt. Comparing purge results, the ham sample without salt had a significant amount of purge compared to the ham with salt, further supporting the significant contribution of salt towards water holding capacity.

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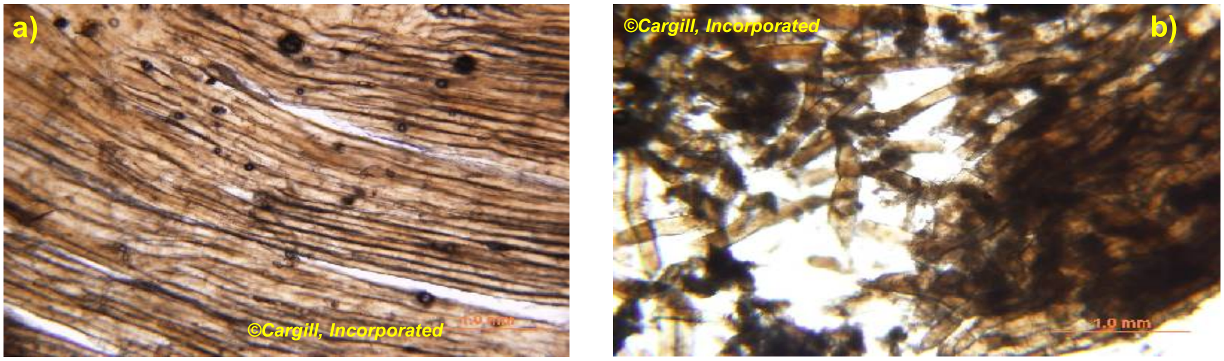
Figure 3. Effect of Salt (0 and 2% w/w) on the Myofibril Protein Swelling and Structure in Deli Hams. a) salt added at 2% (wt/wt), b) no added salt (0% wt/wt).



Similar to cheese and meats, protein modification is also important in grain products, such as breads. As discussed earlier, the formation and strength of gluten (formed from proteins glutenin and gliadin) is important for entrapping gas formed during the fermentation process of yeast-leavened bread. Compared to the absence of salt, the hydration rate of the proteins are less than in the presence of salt, resulting in a decrease of gluten formation (McCann and Day, 2013). However, elongated protein fibril structures were observe in the presence of salt, which results in stronger dough properties.

Sensory Attributes: Salty Taste, Flavor Enhancement, Texture and Quality

According to a consumer survey, 84% state "taste" as the driver of purchase, which has remained to be the number one driver for over a decade (International Food Information Council Foundation, 2017). One of the most recognized functional role of salt in food product by the consumer is its salty taste and flavor enhancement properties. Whether it is prepared in the home or by food manufacturers, salt is added to foods because of the desirable impact in has on the taste and flavor of foods.

Fruits and vegetables are known to contain many types of phytonutrients (e.g. phenols, flavonoids) that are beneficial to health when consumed in the diet (Drewnowski and Gomez-Carneros, 2000). Many of these plant based nutrient are described as bitter, astringent or acrid, which can drive consumption of these nutritious foods down. In addition, cooking vegetables may release some of these bitter tasting compounds, making them less desirable to eat. Therefore, salt is commonly added to vegetables to help mitigate the negative tastes associated with this food group.

In natural cheese production, salt is added to create an environment that allows the desired cultures to thrive and it also impacts the enzyme activity, both which are important for flavor development. Low-salt Cheddar cheeses are generally associated with acid flavor and bitterness (Guinee and Fox, 2004). Lowering the salt level, or Aw, will impact the growth and metabolism of bacteria. To determine if maintaining Aw had any effect on preserving the chemical and microbiological properties, such as proteolysis, lactic acid bacterial count, of lower sodium Cheddar-style cheeses, Grummer et al. (2013) prepared various cheeses using two different sources of potassium chloride (KCl and modified KCl), calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$) as a partial replacement of salt (sodium chloride and reduced

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sodium sea salt). For comparison, full sodium cheeses (controls) were made with salt or reduced sodium sea salt. The pH of the cheeses were lower than the controls except for the KCl and reduced sodium sea salt plus $MgCl_2$ treatments, suggesting less inhibitory effect on the cultures by the other salts ($CaCl_2$, $MgCl_2$, modified KCl). Cheeses made with $CaCl_2$ or $MgCl_2$ had unacceptable off-flavors (bitter, metallic, earthy, unclean soapy), whereas the bitterness and salty flavor attribution of both KCl treatments were similar to the full-sodium control.

Some breakfast cereals are known for their characteristic brownish color and toasted flavor. Without salt in the formulation, cereals tend to be pail in color and lack toasted notes. Many of these color and flavor compounds are formed through the Maillard reaction, which rapidly occurs during the extrusion or the drying process (Hill and Ferry, 2006). The Maillard reaction is sensitive to Aw, which can impact the degree of color and flavor formation. Lajoie et al. (1996) studied the impact of salt on color formation in cereals and observed an increase in brown color and decrease in simple sugars at higher salt levels.

Salt can also impact the expansion of extruded cereals and snacks, which can impact the texture of the food product. The expansion process is complex, but begins with nucleation and growth of air bubbles that are trapped within starch/protein matrix that has undergone structural transformations and phase transitions (Moraru and Kokini, 2003). Comparing salt, urea and sodium bicarbonate in an extruded corn cereal, Chinnaswamy (1993) observed the highest expansion ratio with the salt formulation. Using X-ray tomography to measure the air cell wall thickness in expanded corn cereals, which can impact texture, it was observed that thickness is dependent on type of salt (sodium or potassium chloride) and presence of trisodium phosphate (TSP) (Cargill, 2011). Cereals made with KCl had the greatest cell wall thickness, whereas no salt and no TSP had the least.

It has been suggested that through gradual reduction, consumers are more likely not to perceive changes in salty taste. To determine the salt concentration at which panelists noticed a decrease in salty taste (Just-Noticeable Difference, JND), Drake et al. (2011) evaluated salty taste perception in water, cottage cheese, milk-based soup and cheese sauce. The level of first JND observed by the panelist was matrix dependent with water, cottage cheese, soup and cottage cheese being 2, 8, 15 and 14% sodium reduction, respectively. The complexity of the food matrix (e.g. higher fat, protein, minerals) may allow for greater absolute sodium reduction as noted in the cheddar cheese sauce (~180 mg/100g) compared to water (22 mg/100g) sample. Consumer acceptance performed on cottage cheese suggests that no differences between control (no sodium reduction) and up to 8% sodium reduction in overall liking, appearance liking, flavor liking or salty intensity. When presented information that the product may have sodium reduction (priming ballot), Salty taste and Texture liking scores decreased for all samples (control, 4, 8 and 12% reduction) compared to traditional sensory ballots. However, if the health benefit of sodium reduction was also presented with the primary ballot, Salty Taste and Texture Liking scores and purchase intent increased compared to the primary ballot.

Conclusion

Consumers, government and non-government organizations are seeking products that contain lower levels of sodium in the food supply chain to help lower the incidence of hypertension in the population. Salt has many functional roles in foods that can impact sensory or quality

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attributes, such as texture and shelf-life. Many of these roles are interrelated, such as microbial management, flavor formation and texture due to action of key bacteria in cheeses, which adds another layer of complexity to sodium reduction. Salt's impact on salty taste and flavor enhancement is the most challenging for product developers since taste is the number one driver for purchase intent.

Gradual reduction of salt may help re-calibrate the salt sensory pallet to a certain degree. However at some level of salt reduction, taste, flavor and the other functional properties impact the overall desired quality. The level of salt reduction required to impact the other quality attributes will be food product dependent. At too high of a salt reduction, breads, cheeses and meats will begin to lose their texture. Too low of salt in the formulation may result in an increase in acid production, thereby creating more sour taste and an unbalanced overall flavor profile in fermented products (e.g. cheese, meats, vegetables). Presence of spoilage organisms in a low salt environment may result in defects, such as slime formation in deli-meats, earlier than anticipated and shorten the shelf-life of various foods.

No other single ingredients performs all the functional roles of salt. As a result, it will most likely take more than one ingredient or changes in operation conditions to help bring back the attributes consumers desire in their food products. Additional research is required, especially in the area of taste and flavor, to find acceptable solutions for salt when considering salt reduction in foods.

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