The food safety impact of Salt and Sodium reduction initiatives

Abstract

Excessive or high salt or sodium intake is known to cause hypertension and other diseases. Within the UK voluntary targets for salt reduction have been set and laid out in the Secretary of State responsibility deal. This review considers the options available to food manufacturers to enable them to reduce salt and the potential food safety risks associated with those options. Gaps in research and knowledge within the areas of information supplied to food manufacturers, alternative solutions for salt replacement and the food safety impact of salt reduction are discussed.

Keywords

Salt reduction, food safety, sodium reduction, hurdle systems, pathogen survival

Introduction

Salt has been known to be used since the year 2000BC to provide microbiological stability to foods and to add or enhance flavour profiles.[1] The function of salt as a preserving property made it very valuable in earlier history and it was often used as a trading commodity and, although the processes in which it is used have changed over time, salt is still a commonly used component of food for preservation, as a processing aid and for taste.[1] This short review aims to investigate current knowledge and guidance on salt reduction for food manufacturers, specifically focussing on potential food safety concerns and highlighting current knowledge gaps.

Salt may be vacuum extracted, mined from rock or evaporated from salt water and food grade salt will be washed in brine, filtered, dried and screened before sale.[2] Salt is made of two components, 40% sodium and 60% chloride and it is the sodium component that is of concern for health. The terms salt reduction and sodium reduction tend to be used interchangeably in the literature and so this article will use both terms in line with the information reviewed. The body requires sodium, mainly for regulating extracellular fluid volumes, but cannot produce it and it therefore has to obtain it through food intake.[3] In early human development salt would have been obtained through sources such as seaweed and, as hunting and farming increased, the salt requirements would be met through consumption of basic meat and dairy products.[4] Today three quarters of our daily salt intake comes through the food we buy and up to 50% of this may be from combinations of breakfast cereals, biscuits, cakes and bread.[5]

Drive to reduce sodium. In Europe salt consumption peaked during the 19th Century to 18g per day when it was common for large quantities of salted fish and meat to be eaten.[4] Salt intake is normally estimated via measurement of urinary sodium excretion levels and urinary sodium excretion was estimated to be 9.5g/day in 2000-2001. Following further assessment of urinary sodium levels in 2008 the average adult population salt intake was estimated to be 8.6g per day.[5, 6] Based on the data provided by these surveys, the Department of Health, in the responsibility salt deal targets, recommends that intake be reduced to no more than 6g of salt per day as it is known that elevated sodium intake contributes to hypertension and in turn cardiovascular disease.[7, 8] Salt has also been suggested to be the cause of other illnesses such as bone density diseases, gastric cancer and kidney stones but there is not a definitive link to these conditions.[9]

In this context salt targets originally set by the Food Standards Agency (FSA) in 2006 were reviewed and adjusted by the Department of Health in 2010 and 2012.[10, 11, 12]. The Secretary of State responsibility deal on public health has asked businesses to sign up to the voluntary pledge[13] to reduce sodium levels in food and these are now defined in 2017 targets.[12] These targets include 28 food group categories (Table 1) and there is clearly a substantial formulation change for some of these groups of products.[12] A follow-up urinary sodium survey will be conducted in 2014 with results expected to be published in 2015 by the Department of Health.[14] This survey should help to demonstrate how progress by food manufacturers towards these salt targets is impacting salt consumption in the UK population.

Although salt is used in food preservation to aid inhibition of microorganisms, non-fatal exposure to salt may allow some microorganisms to increase the risk of causing illness.[15, 16] Long term salt stress of Enterohaemorrhagic *E. Coli* (EHEC) has been found to increase attachment potential of the organism to the body's epithelial cells.[15] Therefore usage levels for microbiological control must be carefully established.

Table 1: Summary of FSA 2012 versus 2017 Salt Reduction Targets. [12]
'Processing average' (average p), Range of products average (average r),

Main Product Category	Sub categories (where relevant)	RESPONSIBILITY DEAL TARGET FOR 2012 (g salt or mg sodium per 100g)	RESPONSIBILITY DEAL TARGET FOR 2017 (g salt or mg sodium per 100g)
1. Meat Products	1.1 Bacon	2.88g salt or 1150mg sodium (average p)	2.88g salt or 1150mg sodium (average p)
	1.2 Ham/other cured meats	1.63g salt or 650mg sodium (average p)	1.63g salt or 650mg sodium (average p)
	1.3 Fresh Sausages	1.13g salt or 450mg sodium (maximum)	1.13g salt or 450mg sodium (average r) 1.38g salt or 550mg sodium (maximum)
	1.3.2 Cooked sausages and sausage meat products	1.5g salt or 600mg sodium (maximum)	1.38g salt or 550mg sodium (average r) 1.7g salt or 680mg sodium (maximum)
	1.4 Meat Pies 1.4.1 Delicatessen, pork pies and sausage rolls	1.13g salt or 450mg sodium (maximum)	0.98g salt or 390mg sodium (average r) 1.13g salt or 450mg sodium (maximum)
	1.4.2 Cornish and meat-based pasties	1.0g salt or 400mg sodium (maximum)	0.9g salt or 360mg sodium (average r)

			1.0g salt or 400mg sodium (maximum)
	1.4.3 Other meat-based pastry products including pies and slices, canned and frozen products	0.75g salt or 300mg sodium (maximum)	0.68g salt or 270mg sodium (average r) 0.75g salt or 300mg sodium (maximum)
	1.5 Cooked uncured meat	0.75g salt or 300mg sodium (maximum)	0.68g salt or 270mg sodium (maximum)
	1.5.2 Reformed whole muscle	1.0g salt or 400mg sodium (maximum)	0.9g salt or 360mg sodium (maximum)
	1.5.3 Comminuted or chopped reformed meat	1.5g salt or 600mg sodium (maximum)	1.35g salt or 540mg sodium (maximum)
	1.6 Burgers and Grill Steaks	**1.6.1 Standard burgers and grillsteak products** 0.75g salt or 300mg sodium (maximum)	0.75g salt or 300mg sodium (average r) 0.88g salt or 350mg sodium (maximum)
		1.6.2 Speciality and topped burgers and grillsteaks 0.88g salt or 350mg sodium (maximum)	
	1.7 Frankfurters, hotdogs, and burgers	1.38g salt or 550mg sodium (maximum)	1.38g salt or 550mg sodium (average r)

	1.7.1 Canned frankfurters, canned hotdogs and canned burgers only		1.75g salt or 700mg sodium (maximum)
	1.7.2 Fresh chilled frankfurters	1.63g salt or 650mg sodium (maximum)	1.5g salt or 600mg sodium (average r) 1.88g salt or 750mg sodium (maximum)
2. Bread	2.1 Bread and rolls	1.0g salt or 400mg sodium (average r)	0.9g salt or 360mg sodium (average r) 1.13g salt or 450mg sodium (maximum)
	2.2 Bread and rolls with additions	1.2g salt or 480mg sodium (average r)	1g salt or 400mg sodium (average r) 1.13g salt or 450mg sodium (maximum)
	2.3 Morning goods - yeast raised	0.75g salt or 300mg sodium (average r) 1.0g salt or 400mg sodium (maximum)	0.73g salt or 290mg sodium (average r) 0.88g salt or 350mg sodium (maximum)
	2.4 Morning goods - powder raised		1.13g salt or 450mg sodium (average r) 1.25g salt or 500mg sodium (maximum)
3. Breakfast Cereals	3.1 Breakfast cereals	0.61g salt or 244mg sodium (average r)	0.59g salt or 235mg sodium (average r) 1.0g salt or 400mg sodium (maximum)

		1.125g salt or 450mg sodium (maximum)	
4.Cheese	4.1 Cheddar and other similar "hard pressed" cheeses	1.8g salt or 720mg sodium (average r)	1.75g salt or 700mg sodium (average r) 2g salt or 800mg sodium (maximum)
	4.2 "Fresh" cheeses 4.2.1 Soft white cheese	0.55g salt or 220mg sodium (average r) 0.75g salt or 300mg sodium (maximum)	0.5g salt or 200mg sodium (average r) 0.68g salt or 270mg sodium (maximum)
	4.2.2 Cottage cheese - plain and flavoured Includes all plain and flavoured cottage cheese.	0.55g salt or 220mg sodium (average r) 0.63g salt or 250mg sodium (maximum)	0.5g salt or 200mg sodium (average r) 0.53g salt or 210mg sodium (maximum)
	4.3 Mozzarella	1.5g salt or 600mg sodium (average p)	1.35g salt or 540mg sodium (average p)
	4.4 Blue cheese UK produced blue cheeses only	2.1g salt or 840mg sodium (average p)	2.0g salt or 800mg sodium (average p)
	4.5 Processed Cheese 4.5.1 Cheese spreads	1.63g salt or 650mg sodium (average r) 2.25g salt or 900mg sodium (maximum)	1.63g salt or 650mg sodium (average r) 1.8g salt or 720mg sodium (maximum)

	4.5.2 Other processed cheese Includes all sliced cheese and 'string' type cheese with emulsifiers. Excludes stringed cheese without emulsifiers (see category 4.1 Cheddar).	2.0g salt or 800 mg sodium (average r)	1.7g salt or 680 mg sodium (average r) 2.0g salt or 800 mg sodium (maximum)
5. Butter	5.1 Salted butters and buttery spreads	**Regional butter** 2.0g salt or 800mg sodium (average r) Salted butter 1.68g salt or 670mg sodium (average p)	1.48g salt or 590mg sodium (average r) 1.68g salt or 670mg sodium (maximum)
	5.2 Lightly salted butter	1.13g salt or 450mg sodium (average p)	1.13g salt or 450mg sodium (average p)
6. Fat spreads	6.1 Margarines/other spreads	1.13g salt or 450mg sodium (average r) 1.63g salt or 650mg sodium (maximum)	1.06g salt or 425mg sodium (average r) 1.38g salt or 550mg sodium (maximum)
7. Baked Beans	7.1 Baked beans in tomato sauce without accompaniments	0.63g salt or 250mg sodium (maximum)	0.56g salt or 225mg sodium (maximum)
	7.2 Baked beans and canned pasta with accompaniments	0.75g salt or 300mg sodium (maximum)	0.68g salt or 270mg sodium (average r) 0.73g salt or 290mg sodium (maximum)

8. Ready meals and meal centres	8.1 Ready Meals and Meal Centres	0.63g salt or 250mg sodium (average r) 1.13g salt or 450mg sodium (maximum)	0.63g salt or 250mg sodium (average r) 0.95g salt or 380mg sodium (maximum)
9. Soups	9.1 Soups (as consumed)	0.58g salt or 230mg sodium (average r) 0.73g salt or 290mg sodium (maximum)	0.53g salt or 210mg sodium (average r) 0.63g salt or 250mg sodium (maximum)
10. Pizzas	10.1 All Pizzas (as consumed)	**Pizzas (as sold)** 1.0g salt or 400mg sodium (average r) 1.25g salt or 500mg sodium (maximum)	1.0g salt or 400mg sodium (average r) 1.25g salt or 500mg sodium (maximum)
11.Crisps and snacks	11.1 Standard potato crisps	1.38g salt or 550mg sodium (average r) 1.63g salt or 650mg sodium (maximum)	1.31g salt or 525mg sodium (average r) 1.45g salt or 580mg sodium (maximum)
	11.2 Extruded and sheeted snacks	1.88g salt or 750mg sodium (average r) 2.5g salt or 1000mg sodium (maximum)	1.7g salt or 680mg sodium (average r) 2g salt or 800mg sodium (maximum)
	11.3 Pelleted snacks	2.25g salt or 900mg sodium (average r)	2.13g salt or 850mg sodium (average r) 2.88g salt or 1150mg sodium (maximum)

	11.4 Salt and Vinegar products	2.13g salt or 850mg sodium (average r) 3.0g salt or 1200mg sodium (maximum)	1.88g salt or 750mg sodium (average r) 2.5g salt or 1000mg sodium (maximum)
12. Cakes, pastries, fruit pies and other pastry-based desserts.	12.1 Cakes	0.5g salt or 200mg sodium (average r) 1.0g salt or 400mg sodium (maximum)	0.43g salt or 170mg sodium (average r) 0.7g salt or 280mg sodium (maximum)
	12.2 Pastries	0.5g salt or 200mg sodium (average r)	0.35g salt or 140mg sodium (average r) 0.45g salt or 180mg sodium (maximum)
	12.3 Sweet Pies and other shortcrust or choux pastry based desserts	0.33g salt or 130mg sodium (maximum)	0.25g salt or 100mg sodium (average r) 0.33g salt or 130mg sodium (maximum)
13. Bought Sandwiches	13.1 Sandwiches with high salt fillings	1.0g salt or 400mg sodium (average r)	0.9g salt or 360mg sodium (average r) 1.5g salt or 600mg sodium (maximum)
	13.2 Sandwiches without high salt fillings	0.75g salt or 300mg sodium (average r)	0.68g salt or 270mg sodium (average r) 0.88g salt or 350mg sodium (maximum)
14. Table Sauces	14.1 Tomato ketchup	1.83g salt or 730mg sodium (maximum)	1.7g salt or 680mg sodium (maximum)

	14.2 Brown sauce	1.5g salt or 600mg sodium (maximum)	1.2g salt or 480mg sodium (maximum)
	14.3 Salad cream	1.75g salt or 700mg sodium (maximum)	1.58g salt or 630mg sodium (maximum)
	14.4.1 Mayonnaise (not reduced fat/calorie)	1.25g salt or 500mg sodium (maximum)	1.25g salt or 500mg sodium (maximum)
	14.4.2 Mayonnaise (reduced fat/calorie only)	1.88g salt or 750mg sodium (maximum)	1.7g salt or 680mg sodium (maximum)
	14.5 Salad dressing	1.75g salt or 700mg sodium (maximum)	1.5g salt or 600mg sodium (maximum)
15. Cook-in and Pasta Sauces, thick sauces and pastes	15.1 All cook in and pasta sauces (except Pesto and other thick sauces and pastes)	0.83g salt or 330mg sodium (average r)	0.75g salt or 300mg sodium (average r) 0.93g salt or 370mg sodium (maximum)
	15.2 Pesto and other thick sauces	1.5g salt or 600mg sodium (average r) 2.0g salt or 800mg sodium (maximum)	1.38g salt or 550mg sodium (average r) 1.63g salt or 650mg sodium (maximum)
	15.3 Thick pastes	5.0g salt or 2000mg sodium (maximum)	3.25g salt or 1300mg sodium (average r) 3.75g salt or 1500mg sodium (maximum)
16. Biscuits	16.1 Sweet Biscuits	0.68g salt or 270mg sodium (average r) 1.13g salt or 450mg sodium (maximum)	0.55g salt or 220mg sodium (average r) 0.95g salt or 380mg sodium (maximum)

	16.2 Savoury biscuits	**Savoury biscuits, unfilled** 1.38g salt or 550mg sodium (average r) 2.0g salt or 800mg sodium (maximum) **Savoury biscuits, filled** 1.25g salt or 500mg sodium (maximum)	1.3g salt or 520mg sodium (average r) 1.75g salt or 700mg sodium (maximum)
17. Pasta	17.1 Pasta and noodles, plain and flavoured	0.38g salt or 150mg sodium (maximum)	0.5g salt or 200mg sodium (average r) 0.88g salt or 350mg sodium (maximum)
18. Rice	18.1 Rice (unflavoured), as consumed	0.2g salt or 80mg sodium (maximum)	0.18g salt or 70mg sodium (maximum)
	18.2 Flavoured rice, as consumed	0.45g salt or 180mg sodium (average r) 0.63g salt or 250mg sodium (maximum)	0.45g salt or 180mg sodium (average r) 0.58g salt or 230mg sodium (maximum)
19. Other cereals	**19.1 Other cereals** Includes ready-made pastry, Yorkshire puddings, dumplings, batter and crumble mix, taco shells, flan cases, vol au vent cases, tempura batter, Chinese pancakes and pizza bases.	0.63g salt or 250mg sodium (maximum)	0.55g salt or 220mg sodium (average r) 0.63g salt or 250mg sodium (maximum)

20. Processed puddings Excludes mousses, crème caramel, jelly, rice pudding, ready to eat custard and custard powder as these contain no added salt (the sodium present is that naturally occurring in the ingredients only) Jelly crystals are also excluded for technical reasons.	20.1 Dessert mixes, as consumed	0.5g salt or 200mg sodium (maximum)	0.45g salt or 180mg sodium (maximum)
	20.2 Cheesecake	0.35g salt or 140mg sodium (maximum)	0.28g salt or 110mg sodium (average r) 0.35g salt or 140mg sodium (maximum)
	20.3 Sponge-based processed puddings	0.5g salt or 200mg sodium (average r) 0.75g salt or 300mg sodium (maximum)	0.43g salt or 170mg sodium (average r) 0.63g salt or 250mg sodium (maximum)
	20.4 All other processed puddings	0.18g salt or 70mg sodium (average r) 0.3g salt or 120mg sodium (maximum)	0.18g salt or 70mg sodium (average r) 0.28g salt or 110mg sodium (maximum)
21. Quiche	21.1 Quiches Includes all quiches and flans.	0.75g salt or 300mg sodium (maximum)	0.55g salt or 220mg sodium (average r) 0.68g salt or 270mg sodium (maximum)

22. Scotch Eggs	22.1 Scotch eggs	0.88g salt or 350mg sodium (maximum)	0.78g salt or 310mg sodium (maximum)
23. Canned Fish	23.1 Canned tuna	1.0g salt or 400mg sodium (average p)	0.9g salt or 360mg sodium (average p)
	23.2 Canned salmon	0.93g salt or 370mg sodium (average p)	0.8g salt or 320mg sodium (average p)
	23.3 Other canned fish	0.93g salt or 370mg sodium (average r)	0.85g salt or 340mg sodium (average r) 1.5g salt or 600mg sodium (maximum)
24. Canned vegetables	24.1 Canned and bottled vegetables	0.13g salt or 50mg sodium (maximum)	0.13g salt or 50mg sodium (maximum)
	24.2 Canned processed, marrowfat and mushy peas	0.45g salt or 180mg sodium (maximum)	0.45g salt or 180mg sodium (maximum)
25. Meat alternatives	25.1 Plain meat alternatives	0.7g salt or 280mg sodium (maximum)	0.63g salt or 250mg sodium (maximum)
	25.2 Meat free products	0.93g salt or 370mg sodium (average r) 1.5g salt or 600mg sodium (maximum)	0.9g salt or 360mg sodium (average r) 1.25g salt or 500mg sodium (maximum)
	25.3 Meat-free bacon	2.13g salt or 850mg sodium (average r)	1.88g salt or 750mg sodium (maximum)

26. Other processed potatoes	26.1 Dehydrated instant mashed potato, as consumed	0.18g salt or 70mg sodium (maximum)	0.15g salt or 60mg sodium (maximum)
	26.2 Other processed potato products	0.49g salt or 195mg sodium (average r) 0.75g salt or 300mg sodium (maximum)	0.46g salt or 185mg sodium (average r) 0.69g salt or 275mg sodium (maximum)
27. Beverages	27.1 Dried Beverages, as consumed	0.15g salt or 60mg sodium (maximum)	0.15g salt or 60mg sodium (maximum)
28. Stocks and gravies	28.1 Stocks, as consumed	New target for 2017	0.75g salt or 300mg sodium (average r) 0.95g salt or 380mg sodium (maximum)
	28.2 Gravy, as consumed	New target for 2017	0.95g salt or 380mg sodium (average r) 1.13g salt or 450mg sodium (maximum)

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The process of sodium reduction has been successful to date. One reason for this is that food intakes have changed in the last fifteen years and this has aided the reduction of sodium in the diet. Bread, one of the major foodstuffs associated with regular sodium intake, has reduced in consumption level from 819g per person per week in 1996 to 621g in 2011 as more people eat possibly linked to the rise in the number of people purchasing breakfast cereal snacks during this period.[17] Overall sodium intake from sodium within foods reduced from 3.25g per person in 2001 to 2.72g in 2012.[18] In addition to consumers changing their eating habits, food manufacturers have been making formulation changes to meet the requirements of the pledge. This has been supported by projects such as SALUX, an EU project for sharing best practices between small and medium enterprises (SMEs) following reformulation.[19] In addition, in the drive to further reduce levels of salt consumption, catering services are also being asked to reduce salt usage for foods consumed out of the home.[20] Mandatory limits using the FSA traffic light system are also in place for hospital caterers.[21]

Besides the pressure of reducing salt, food manufacturers are also being asked to prevent waste[22] and this is often done by taking steps to maintain or increase shelf life. All major grocery retailers are now signed up to the Courtauld commitment, a voluntary agreement managed by WRAP (Waste and Resource Action Programme) who are funded by the EU and UK governments and work in partnership with major UK businesses, trade organisations and local authorities.[23] Consequently where shelf-life extension is being considered as a means of combating waste, and this may be combined with salt reduction objectives, consideration must be given to any new food safety hazards this may introduce to a product during its shelf life.

Uses of Salt in Food

Salt use for flavour. Salt can be used to enhance the flavour in many products.[24] Major modifications to salt levels may cause consumers to dislike a product as flavours within foods can counteract each other and sweet flavours can reduce the perception of saltiness.[24] This may be a limiting factor in persuading manufacturers to reduce salt in products. However, gradual reduction of salt allows the consumer to adapt to the taste and accept the new flavour profile[24] and a series of small, step-wise reductions over time has been shown to limit rejection by consumers.[6] Blais et al[25] report that it takes approximately 8 weeks for palates to adapt to lower salt concentration and, in addition, study participants rejected previous higher salt diets. [25]

Since salt unevenly distributed throughout a product, i.e. bursts of saltiness, can provide the same perception of homogeneous salt distribution to the palette,[24] trials have been conducted using layering of salt and more recently encapsulated salt.[26, 27] Encapsulated salt is salt covered with a coating, often vegetable oil, and it was developed to prevent salt from interacting with the food matrix during processing and thus prevent quality degradation. Encapsulated salt could be formulated with varying particle sizes to create smaller or larger pockets of saltiness and this method is thought to be more applicable to industrial food manufacture.[24] Both layering and encapsulation can achieve consumer acceptance of a lower salt concentration but will only provide the microbial protection of the lesser salt level. Potentially areas without homogenous salt distribution may be at risk of pathogen growth.

Salt use as a processing aid. For products to be of an acceptable visual or organoleptic quality salt may be required. The salt in yeasted bread dough is present to prevent over fermentation by the yeasts that if left would cause structural issues in the bread.[28] Similarly the cheese industry uses salt to control fermentation as well as to expel the whey from the curd during processing.[29] The meat industry use salt to tenderise cured meats and in many products salt helps to bind water and prevent its loss during processing.[30] Reduction of salt from these and similar applications may result in greater consumer complaints and the need for further product reformulation.

Salt use for preservation. Salt is typically used as an additional hurdle in a preservative matrix rather than a standalone preservative.[31] Manufacturers of bakery ingredients, preserves, pickles, margarines and spreads have stated salt was specifically added for its preservative or microbiological control.[31] Meat products are reliant upon salt and Sodium components to aid food preservation in combination with nitrates and nitrites.[32] However, in a survey reported by Brady in 2002 food manufacturers specified that the main constraints to reducing Sodium were flavour profile and cost; food safety was not recorded as a restrictive factor.[31] It is possible that at the time manufacturers were unable to recognise safety issues until the reformulated recipe had been developed and this may indicate lack of available information or knowledge as to the function of salt within the product or a lack of thorough product risk assessment during reformulation projects.

Sea salt, often perceived as a healthier option, is less damaging to the cells of microorganisms than a fine salt.[33] Although Sea Salt contains the same level of sodium as refined salt, sea salt may be used in lower quantities due to its strong flavour and it could be hypothesised that this would increase the potential for growth of pathogens; little research evidence exists to confirm this and it is an area requiring further investigation.

Salt and microorganisms. When risk assessing preservation of foods, manufacturers need to consider pathogens as well as the more obvious or visible spoilage organisms. Food safety issues have been created when formulations of established products have been changed. A notable incident occurred in the UK in 1989 when the manufacturers of a Hazelnut puree, used in Hazelnut yoghurt, changed the recipe from sugar to Aspartame and therefore changed the water activity of the product. The product did not have a low pH and the heat treatment applied was insufficient to destroy *Clostridium botulinum* spores. All of these combined factors resulted in the growth of *Clostridium botulinum* producing type B toxin in the puree.[34] As a result of the growth of the microorganisms and toxin production one person died and a further twenty six people became ill.[31] Although not related to salt reformulation, this incident demonstrates the requirement for thorough risk assessment, by competent and knowledgeable individuals, during any product reformulation, with appropriate action taken to render the formulation and/or process safe. In a similar way, reduction of salt may increase the available water within a food matrix and increase the risk of growth of microorganisms. The Food Standards Agency considered the consequences of its salt reduction programme on food safety by commissioning research on the risk of pathogen growth: Stringer and Pin conducted a microbial modelling study and concluded that the safety of each reformulated food should be evaluated on case by case basis.[35] These findings were discussed by the Advisory Committee on Microbiological Safety of Food (ACMSF, an independent advisory committee to the FSA) and it was suggested products should not be reformulated with lower salt levels until a hazard analysis had been carried out and that industry should not rush into making changes to salt levels without considering the impact of salt reduction on the microbiological safety of the specific product.[36, 37] At the same time the difficulties of small producers in making practical use of FSA information on salt reduction while ensuring products with modified salt levels were microbiologically safe was highlighted[36] and further guidance has since been provided in some sectors. [38]

In a review of more recent food poisoning data, several pathogens have been able to enter or persist within the food chain. It is thought that 45,000 cases of illness may have been caused by contaminated food within the EU during 2008, *Campylobacter* and *Salmonella* species were cited as significant contributors.[39] In the United States between 2000 and 2008 non-typhoidal *Salmonella*, *Campylobacter* species, *Staphylococcus aureus*, *Clostridium perfringens* and *Listeria monocytogenes* feature in the list of pathogens causing foodborne illnesses and deaths.[40] The Electronic Foodborne and non-Foodborne Gastrointestinal Outbreak Surveillance System (eFoss) found *Salmonella* species to be predominantly the cause of illness in food service and institutional / residential settings during 2009.[41] Between 1992 and 2010 the Health Protection Agency (HPA) gathered information that linked foodborne outbreaks most commonly to poultry meat, composite products, red meat, raw shell eggs, desserts, cakes and confectionery food groups, the majority of which are targeted for sodium reduction as shown in table 1.[42] Potentially, unless salt, which may alone or in combination act as an antimicrobial hurdle, is suitably substituted with an alternative hurdle, an increasing trend in cases may occur in the future and this underlines the need for careful assessment. Potential alternative hurdles include not only formulation factors but also changes to processes and alternative packaging technologies such as modified atmosphere or vacuum packaging. However, food safety risk assessment needs to be done on the holistic product/process/packaging system as failure to consider any one element could increase the risk of foodborne illness. For example, if packaging atmospheres are modified to extend shelf life and this creates anaerobic conditions then, without further adequate hurdles, this may promote the growth of anaerobic pathogens such as *Clostridium botulinum*, which can cause serious illness and even fatalities.[43]

Salt action on microorganisms.

In salt the Sodium ions are positively charged and the Chloride ions have a corresponding negative charge, when salt is added to water disassociation occurs until no available Hydrogen atoms remain available in the water. The easiest measure of salt impact upon a food matrix is to determine the

Equilibrium relative humidity, more commonly termed available water or water activity (aw). Where no other humectants are present, a solution containing 16.5% salt is required to achieve a water activity value of 0.90.[1] The lowest water activity for pathogen growth is for *Staphylococcus aureus* at 0.86, most pathogens will grow above a water activity level of 0.90 (Table 2).[44] Table 3 shows the typical water activity of a number of food groups and it is clear to see that all could have the potential of supporting growth of pathogens if inhibitive conditions were not present.

Table 2: Pathogen minimum aw for growth under optimal conditions (i.e. suitable nutrients and temperature).[45]

Pathogen	**aw (min)**
S.aureus	0.86
L.monocytogenes	0.90
Salmonella	0.93
C.botulinum I	0.94
B.cereus	0.95
C.botulinum II	0.97
Campylobacter	0.98

Table 3: Food Types typical aw levels.[44, 46]

Food Type	Typical aw
Cakes, Cereals, Dry Cheese	>0.87
Cured meats, Ham, Salami	0.94-0.96
Crumpets, Pancakes	0.95 – 0.97
Bread	0.96-0.99
Fresh vegetables, meat, milk, fish	>0.98

The antimicrobial effect of salt. In the same way that the human body requires sodium, the cells of microorganisms maintain an osmotic balance by actively transporting ions using ATP driven pumps. Nearly three quarters of the cell's energy is used to maintain these pumps.[47] As salt concentration increases the cell has to work harder to maintain a healthy balance, if the balance is lost the cell will suffer plasmolysis and will dehydrate. Organisms, including *S. aureus*, *E. coli* and *Salmonella* Typhimurium, can have a survival reaction to high stress environments such as a salt solution by seeking out and transporting other solutes such as the trimethylamino acid, Glycine Betamine, to create energy and maintain osmotic balance.[48] When subjected to humectant induced stress, *S. aureus*, *E. coli* and *Salmonella* Typhimurium were found to eventually die off due to issues with substances preventing active transport rather than the cell being depleted on energy.[49] It has been discovered that if the BetL gene of a microorganism can be disrupted it impacts the Glycine Betamine solute transport.[48] Hypothetically if an ingredient was able to function as a BetL disruptor, less salt may have a more antimicrobial effect than if the cell was able to continue to transport Glycine Betamine. This could potentially make the presence of lower levels of salt equally effective as higher levels, and may be an area for further research.

The impact of salt as an antimicrobial alone has been shown to have varying efficacy. Harper and Getty found that 2% salt was effective at inhibiting *Listeria monocytogenes* growth in ground beef but had no effect on growth in Pork or Turkey demonstrating that across the board generic controls within food groups may not be possible.[51] Changes in salt levels between 3.66% and 1.39% did not affect the growth of *Listeria monocytogenes* in Liver pate.[16] Similarly reducing salt from 1.8% to 0.7% in cheddar cheese between the pH levels of 5.1 and 5.7 did not allow growth of *Listeria monocytogenes* or *Salmonella* species; decline of the organisms was noted in all conditions but more prominently at a lower pH.[51] Ellin Doyle and Glass also note that, based on work by McClure et al. on gradient plates, *Listeria monocytogenes* becomes more sensitive to salt in acidic conditions.[52, 53] Campylobacter species are capable of survival in chilled environments but do not increase in number, an addition of 1.5% sodium chloride to minced chicken did not significantly reduce *Campylobacter jejuni* over 14 days at 4°C and therefore, in chilled storage, salt level may not be impactful or significant.[54, 55] Ellin Doyle and Roman suggested *Campylobacter jejuni* may tolerate higher levels of salt when it is growing within its optimum temperature range (30-45°C) which would suggest that salt will not be an effective antimicrobial if *Campylobacter* contaminated chicken was temperature abused after chilled storage.[55]

Proteolytic *Clostridium botulinum* has been shown to survive in up to 10% salt solution and *S. aureus* can survive in even higher concentrations of salt, although will not produce the enterotoxin unless above a water activity value of 0.90 in otherwise ideal conditions.[52] These data sets indicate salt is not the primary antibacterial hurdle for these organisms. The death rate of Gram negative organisms (*E. Coli* species*, Salmonella* Typhimurium) was found to be greater than Gram positive (*L.monocytogenes, S.aureus*) when the antimicrobial properties of Sodium Chloride were challenged on natural sheep casings (used for sausages) and this is most likely due to plasmolysis of the Gram negative cells; *Clostridium perfringens* spores, naturally designed to resist challenges from its environment, were unaffected by the presence of salt.[56]

Other important preservatives used by the food industry, in addition to salt, may also need to be reduced or removed in order to reduce Sodium in finished products. These include sodium benzoate, sodium nitrite and nitrate, sodium lactate, sodium diacetate and sodium propionate. The many and varied uses of these compounds as, for example, preservatives, acidity regulators, antioxidants and sequestrants in a wide range of situations mean that requirements for reduction of sodium would have major impacts across the food industry, with the potential to allow proliferation of food safety hazards if alternative systems are not found. Further research is necessary in this area; however some options look encouraging, e.g. cationic antimicrobial peptides have been found to be primarily effective against Gram-negative organisms and this may be a method, for antimicrobial purposes, of reducing sodium.[57]

Salt as a hurdle. Sodium salts will commonly be used as part of a hurdle preservation system; each system will typically be bespoke for the product it is protecting, however in general the exact mechanism of action of many hurdle systems is poorly understood. Data are needed on optimum levels of various sub-lethal stress-inducing ingredients and processes to predict the efficacy of hurdle technology against specific pathogens in different food systems. A number of organisms have been studied to understand the impact of specific hurdles (Table 4). These trials provide further evidence to suggest that salt reduction impact will be specific to each individual product and not a generic risk and therefore much more research is required not only to broaden the scope of products and organisms but to compare findings in laboratory broths to food matrices.

Table 4 Examples of Research into Efficacy of Hurdle Systems and Processes including Salt

Organism/tested effect	Hurdle system	Findings	Reference
E. coli	Mixture of sodium chloride, nitrite and phosphates	In a laboratory medium, phosphates did not inhibit the growth of pathogenic *E. Coli* unless in a mixture with Sodium chloride and nitrite, the efficacy of which improved at lower temperatures and a lower pH value.	58
Listeria monocytogenes, *Clostridium perfringens* and faecal Streptococci	Nitrite and pH	The efficacy of nitrites against growth was found to be affected by pH level in laboratory broths. Heated nitrite was less effective against *Listeria monocytogenes* than filtered nitrite.	53, 59
Non proteolytic *Clostridium botulinum*	Nitrite, nitrate and sodium chloride.	Efficacy of Sodium Chloride on the control of outgrowth of non proteolytic *Clostridium botulinum* in Rainbow Trout was positively affected by the presence of nitrite and nitrate, demonstrating a similarity to the work on meat and nitrite.	60
E. Coli, *S.aureus* and *Bacillus cereus.*	Sodium nitrite, sodium benzoate, sorbic acid and sodium chloride	Sodium nitrite was found to be the least effective preservative when compared to Sodium benzoate and sorbic acid tested	61

		on gradient plates with pathogenic *E. Coli*, *S.aureus* and *Bacillus cereus.* The nitrite efficacy was not improved by addition of Sodium Chloride.	
Not tested on organisms – nitrite/nitrate distribution only.	Nitrite and Sodium Chloride or Potassium Chloride, Calcium Chloride, or Magnesium Chloride	Replacement of Sodium Chloride with Potassium Chloride, Calcium Chloride, and Magnesium Chloride did not impact the movement of nitrite and nitrate through processed dry cured Hams, therefore a direct salt replacement may not have an antagonistic effect upon the nitrate hurdle.	62
Campylobacter spp.	Tri-sodium phosphate as a washing treatment	When using Sodium in washing treatments, *Campylobacter* species loading on chicken carcases has been shown to be reduced by 1.7log/g after immersion in tri-Sodium phosphate	54
L.monocytogenes	Modified atmosphere packaging (MAP) with pH, temperature and Sodium Chloride combinations – studying impact of reducing salt.	When pH, temperature and Sodium Chloride in laboratory medium were at suitable levels for allowing growth of *L.monocytogenes* 80% CO_2 was required to prevent growth, whereas 25% CO_2 restricted growth when other hurdles were at their optimum levels. Growth of *L.monocytogenes* occurred in 4% Salt at 80% CO_2 at 4^oC, but not at 8% salt.	63

Not tested on organisms – organoleptic shelf life only	Light salting combined with MAP and essential oils	Organoleptic shelf life of sea bream fillets was extended by over a week when light salting was combined with MAP; this was further extended by use of oregano essential oils	64
Microbiological and sensory shelf life	MAP, chilling and Sodium Chloride	Sensory and microbiological shelf life increased in chilled hake slices when stored in MAP and further increased when the fish was pre dipped in Sodium Chloride.	65

In contrast to the positive additive effect anticipated with hurdle technology, the tolerance of EHEC *E. Coli* O157:H7 to salt in Salami and Cider has been found to be increased following mild acid stress.[15] Olsen et al. suggested that addition of Calcium Lactate and Calcium Acetate when tested in Liver pate may actually trigger the stress adaption gene of *Listeria monocytogenes* and therefore increase the risk of the growth of the pathogen.[15] This information would suggest that food manufacturers need to be cautious when adding additional hurdles for control of microorganisms.

Many trials have been conducted with partial replacement using Potassium salts in place of sodium. Zarei et al. found that *Listeria monocytogenes* in laboratory broth was slightly more tolerant to the presence of Potassium Chloride than sodium chloride with 11% potassium chloride required for inhibiting growth compared to 9% sodium chloride.[66] They also found that below 25% replacement of sodium chloride for potassium chloride would not impact upon food safety whereas levels of exchange above 50% may allow growth of the organism. Bidlas and Lambert found that exchanging sodium chloride for potassium chloride in laboratory medium did not however impact upon the growth of *Aeromonas* species.[67] A significant amount of research has been conducted and has demonstrated the efficacy of Potassium chloride; however, this may not be an option for sodium chloride replacement as there are concerns that sections of the public may have their health at risk through consumption of potassium salts and that use of potassium chloride retains a high salt flavour whereas salt reduction initiatives aim to allow consumer palates to become used to lower salt flavours.[32, 68, 69] Therefore, it is not current policy to recommend potassium-based alternatives to sodium chloride but this is currently under review at the Department of Health. [69]

Beyond pathogen control some food manufacturers must consider Histamine production as this may cause allergic reactions in some consumers and therefore production in susceptible foods requires control. Histamine production on Trout was found to be inhibited by a solution containing 10% sodium chloride, glucose, ascorbic acid and potassium nitrate; when lactic acid bacteria were added to the brine double the volume of salt was required for the same level of control.[70] This reflects the previous observation that multiple hurdles are not always beneficial.

Options for Replacing Sodium.

A number of methods for sodium reduction are in use, the most common is gradual reduction with consumer adaption over time.[24] It has been suggested that this method could allow sodium reduction of up to 15% and other mineral salts as substitutes may allow 25% reduction where appropriate.[71] Harper found magnesium salts in replacement of sodium within enrichment broths increased the growth of *Listeria monocytogenes*, indicating a further requirement for caution in reformulation processes.[72]

Where greater than 25% sodium reduction is required this may be achieved by salt flavour enhancers but these will not typically offer an antimicrobial effect.[71]

Other ingredients may not be as easily interchangeable with salt. A larger quantity of glycerol or glucose has been found to be required to alter the water activity to obtain the same effect as sodium chloride and therefore a lesser amount of salt, in comparison, is required to inhibit bacterial growth.[33] Potassium chloride is also required in a greater volume to equal the water activity of sodium chloride.[66]

Stollewerk et al. studied the impact of a fast drying process and high pressure on sodium chloride free Chorizo after being inoculated with *Salmonella* species and *Listeria monocytogenes*. Sodium chloride was part replaced by potassium chloride and lactate.[73] The results demonstrated the survival of the organisms in the low acid product after traditional and fast drying followed by chilled storage. The additional hurdle of high pressure was required to assure food safety in low acid Chorizo.

The essential oil compound Eugenol, which can be extracted from a range of essential oils such as clove oil, nutmeg and cinnamon, has been found to reduce the growth of *Listeria monocytogenes* and the efficacy of essential oils was found to be improved by the presence of sodium chloride.[74] At higher concentrations Eugenol was found to have a bactericidal action against *Salmonella* Typhi due to the alteration of the cell membrane.[75] Inactivation of genes has been considered as one of the mechanisms of the antimicrobial effect of essential oils and this may disrupt the cell transport system.[76] As previously suggested this action may be exploited in the future to create an additive that will inhibit microorganism growth, increasing the lag phase by effecting solute transport and aiding the efficacy of reduced salt levels. However, in a food safety review by Ellin Doyle the efficacy of essential oils was highlighted to be limited by fats or other ingredients.[52] The impact of aroma from the essential oil components on flavour must also be considered as a limiting factor for use.

How to reduce salt in a safe manner.

Recent reviews recognise that the drive to reduce sodium may have some impact upon food safety and suggest that each product will need to be evaluated by challenge test.[33, 52] Predictive microbiology databases such as Combase may provide an indication of efficacy but in many cases challenge testing will need to be conducted as product intrinsic parameters may impact the behaviour of salt and / or the microorganisms. Guidance produced primarily for Canadian food manufacturers by CTAC in 2009 describes the options for reducing sodium and links alternative ingredients with taste profiles to aid manufacturers in choice.[77] However of major concern is the fact that this document does not provide guidance on how to establish if a product is safe.

Leatherhead Research have reviewed the technologies available for salt replacement but cannot offer a generic solution for all food groups and again this suggests each product will need to be assessed for safety on a case by case basis.[32] With individual challenge tests typically costing several thousand pounds the initiative could become very expensive for food manufacturers, especially SMEs. There are many papers available investigating food pathogens and sodium interactions; however, there is not one source of information for food manufacturers to use to guide them during a salt reduction exercise. This may become more of an issue in the future, especially as smaller service businesses become under increased pressure to reduce sodium levels.

Even if the available information could be gathered into one database many of the studies conducted have been carried out in laboratory medium rather than a food matrix and the resulting data needs to be verified against each complex food system. *Listeria monocytogenes* has also been studied in depth; this is most likely due to its high incidence of fatality where it has occurred. Sodium reduction in products currently deemed to be a low risk for pathogen growth but regular contributors of sodium to the diet, such as bakery goods, has not been extensively researched. This is of greater concern when some of the additional hurdles manufacturers may consider using to maintain shelf life, such as modified atmosphere packaging, are added to the scenario as their likely impact on different organisms such as anaerobic pathogens is not well understood, and is an area requiring further research.

Conclusions

Insufficient guidance is available for food manufacturers who are tackling salt reduction reformulation. Many individuals are conducting work that examines removal or replacement of salt and its impact upon pathogen survival and growth. Much of this information is in a highly scientific format and not presented in a manner that can aid food manufacturers, particularly SMEs. There is no doubt that some food products will be susceptible to the growth of pathogens should their current formulations be changed, however addition of extra hurdles does not always enhance product safety. Guidance and further research is required to fill knowledge gaps and ensure future food safety.

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