

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.

1

2 **Keywords**

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

5 Introduction

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

13 Salt may be vacuum extracted, mined from rock or evaporated from salt water and food grade salt
14 will be washed in brine, filtered, dried and screened before sale.² Salt is made of two components,
15 40% sodium and 60% chloride and it is the sodium component that is of concern for health. The
16 terms salt reduction and sodium reduction tend to be used interchangeably in the literature and so
17 this article will use both terms in line with the information reviewed. The body requires sodium,
18 mainly for regulating extracellular fluid volumes, but cannot produce it and it therefore has to obtain
19 it through food intake.³ In early human development salt would have been obtained through
20 sources such as seaweed and, as hunting and farming increased, the salt requirements would be
21 met through consumption of basic meat and dairy products.⁴ Today three quarters of our daily salt
22 intake comes through the food we buy and up to 50% of this may be from combinations of breakfast
23 cereals, biscuits, cakes and bread.⁵

24 **Drive to reduce sodium.** In Europe salt consumption peaked during the 19th Century to 18g per day
25 when it was common for large quantities of salted fish and meat to be eaten.⁴ Salt intake is normally
26 estimated via measurement of urinary sodium excretion levels and urinary sodium excretion was
27 estimated to be 9.5g/day in 2000-2001. Following further assessment of urinary sodium levels in
28 2008 the average adult population salt intake was estimated to be 8.6g per day.^{5,6} Based on the
29 data provided by these surveys, the Department of Health, in the responsibility salt deal targets,
30 recommends that intake be reduced to no more than 6g of salt per day as it is known that elevated
31 sodium intake contributes to hypertension and in turn cardiovascular disease.^{7,8} Salt has also been
32 suggested to be the cause of other illnesses such as bone density diseases, gastric cancer and kidney
33 stones but there is not a definitive link to these conditions.⁹

34 In this context salt targets originally set by the Food Standards Agency (FSA) in 2006 were reviewed
35 and adjusted by the Department of Health in 2010 and 2012.^{10, 11, 12.} The Secretary of State
36 responsibility deal on public health has asked businesses to sign up to the voluntary pledge¹³ to
37 reduce sodium levels in food and these are now defined in 2017 targets.¹² These targets include 28
38 food group categories (Table 1) and there is clearly a substantial formulation change for some of
39 these groups of products.¹² A follow-up urinary sodium survey will be conducted in 2014 with results
40 expected to be published in 2015 by the Department of Health.¹⁴ This survey should help to
41 demonstrate how progress by food manufacturers towards these salt targets is impacting salt
42 consumption in the UK population.

43 Although salt is used in food preservation to aid inhibition of microorganisms, non-fatal exposure to
44 salt may allow some microorganisms to increase the risk of causing illness.^{15,16} Long term salt stress
45 of Enterohaemorrhagic *E. Coli* (EHEC) has been found to increase attachment potential of the
46 organism to the body's epithelial cells.¹⁵ Therefore usage levels for microbiological control must be
47 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)
	<u>4.2.2 Cottage cheese - plain and flavoured</u> 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 <u>Other processed cheese</u> 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)	1.48g salt or 590mg sodium (average r) 1.68g salt or 670mg sodium (maximum)
		Salted butter 1.68g salt or 670mg sodium (average p)	
	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)

49 The process of sodium reduction has been successful to date. One reason for this is that food intakes
50 have changed in the last fifteen years and this has aided the reduction of sodium in the diet. Bread,
51 one of the major foodstuffs associated with regular sodium intake, has reduced in consumption
52 level from 819g per person per week in 1996 to 621g in 2011 as more people eat possibly linked to
53 the rise in the number of people purchasing breakfast cereal snacks during this period.¹⁷ Overall
54 sodium intake from sodium within foods reduced from 3.25g per person in 2001 to 2.72g in 2012.¹⁸
55 In addition to consumers changing their eating habits, food manufacturers have been making
56 formulation changes to meet the requirements of the pledge. This has been supported by projects
57 such as SALUX, an EU project for sharing best practices between small and medium enterprises
58 (SMEs) following reformulation.¹⁹ In addition, in the drive to further reduce levels of salt
59 consumption, catering services are also being asked to reduce salt usage for foods consumed out of
60 the home.²⁰ Mandatory limits using the FSA traffic light system are also in place for hospital
61 caterers.²¹

62 Besides the pressure of reducing salt, food manufacturers are also being asked to prevent waste²²
63 and this is often done by taking steps to maintain or increase shelf life. All major grocery retailers
64 are now signed up to the Courtauld commitment, a voluntary agreement managed by WRAP (Waste
65 and Resource Action Programme) who are funded by the EU and UK governments and work in
66 partnership with major UK businesses, trade organisations and local authorities.²³ Consequently
67 where shelf-life extension is being considered as a means of combating waste, and this may be

68 combined with salt reduction objectives, consideration must be given to any new food safety
69 hazards this may introduce to a product during its shelf life.

70 **Uses of Salt in Food**

71 **Salt use for flavour.** Salt can be used to enhance the flavour in many products.²⁴ Major modifications
72 to salt levels may cause consumers to dislike a product as flavours within foods can counteract each
73 other and sweet flavours can reduce the perception of saltiness.²⁴ This may be a limiting factor in
74 persuading manufacturers to reduce salt in products. However, gradual reduction of salt allows the
75 consumer to adapt to the taste and accept the new flavour profile²⁴ and a series of small, step-wise
76 reductions over time has been shown to limit rejection by consumers.⁶ Blais et al²⁵ report that it
77 takes approximately 8 weeks for palates to adapt to lower salt concentration and, in addition, study
78 participants rejected previous higher salt diets.²⁵

79 Since salt unevenly distributed throughout a product, i.e. bursts of saltiness, can provide the same
80 perception of homogeneous salt distribution to the palette,²⁴ trials have been conducted using
81 layering of salt and more recently encapsulated salt.^{26, 27} Encapsulated salt is salt covered with a
82 coating, often vegetable oil, and it was developed to prevent salt from interacting with the food
83 matrix during processing and thus prevent quality degradation. Encapsulated salt could be
84 formulated with varying particle sizes to create smaller or larger pockets of saltiness and this
85 method is thought to be more applicable to industrial food manufacture.²⁴ Both layering and
86 encapsulation can achieve consumer acceptance of a lower salt concentration but will only provide

87 the microbial protection of the lesser salt level. Potentially areas without homogenous salt
88 distribution may be at risk of pathogen growth.

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

96 **Salt use for preservation.** Salt is typically used as an additional hurdle in a preservative matrix rather
97 than a standalone preservative.³¹ Manufacturers of bakery ingredients, preserves, pickles,
98 margarines and spreads have stated salt was specifically added for its preservative or
99 microbiological control.³¹ Meat products are reliant upon salt and Sodium components to aid food
100 preservation in combination with nitrates and nitrites.³² However, in a survey reported by Brady in
101 2002 food manufacturers specified that the main constraints to reducing Sodium were flavour
102 profile and cost; food safety was not recorded as a restrictive factor.³¹ It is possible that at the time
103 manufacturers were unable to recognise safety issues until the reformulated recipe had been
104 developed and this may indicate lack of available information or knowledge as to the function of
105 salt within the product or a lack of thorough product risk assessment during reformulation projects.

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

111 **Salt and microorganisms.** When risk assessing preservation of foods, manufacturers need to
112 consider pathogens as well as the more obvious or visible spoilage organisms. Food safety issues
113 have been created when formulations of established products have been changed. A notable
114 incident occurred in the UK in 1989 when the manufacturers of a Hazelnut puree, used in Hazelnut
115 yoghurt, changed the recipe from sugar to Aspartame and therefore changed the water activity of
116 the product. The product did not have a low pH and the heat treatment applied was insufficient to
117 destroy *Clostridium botulinum* spores. All of these combined factors resulted in the growth of
118 *Clostridium botulinum* producing type B toxin in the puree.³⁴ As a result of the growth of the
119 microorganisms and toxin production one person died and a further twenty six people became ill.³¹
120 Although not related to salt reformulation, this incident demonstrates the requirement for thorough
121 risk assessment, by competent and knowledgeable individuals, during any product reformulation,
122 with appropriate action taken to render the formulation and/or process safe. In a similar way,
123 reduction of salt may increase the available water within a food matrix and increase the risk of
124 growth of microorganisms. The Food Standards Agency considered the consequences of its salt

125 reduction programme on food safety by commissioning research on the risk of pathogen growth:
126 Stringer and Pin conducted a microbial modelling study and concluded that the safety of each
127 reformulated food should be evaluated on case by case basis.³⁵ These findings were discussed by
128 the Advisory Committee on Microbiological Safety of Food (ACMSF, an independent advisory
129 committee to the FSA) and it was suggested products should not be reformulated with lower salt
130 levels until a hazard analysis had been carried out and that industry should not rush into making
131 changes to salt levels without considering the impact of salt reduction on the microbiological safety
132 of the specific product.^{36, 37} At the same time the difficulties of small producers in making practical
133 use of FSA information on salt reduction while ensuring products with modified salt levels were
134 microbiologically safe was highlighted³⁶ and further guidance has since been provided in some
135 sectors.³⁸

136 In a review of more recent food poisoning data, several pathogens have been able to enter or persist
137 within the food chain. It is thought that 45,000 cases of illness may have been caused by
138 contaminated food within the EU during 2008, *Campylobacter* and *Salmonella* species were cited as
139 significant contributors.³⁹ In the United States between 2000 and 2008 non-typhoidal *Salmonella*,
140 *Campylobacter* species, *Staphylococcus aureus*, *Clostridium perfringens* and *Listeria monocytogenes*
141 feature in the list of pathogens causing foodborne illnesses and deaths.⁴⁰ The Electronic Foodborne
142 and non-Foodborne Gastrointestinal Outbreak Surveillance System (eFoss) found *Salmonella*
143 species to be predominantly the cause of illness in food service and institutional / residential settings

144 during 2009.⁴¹ Between 1992 and 2010 the Health Protection Agency (HPA) gathered information
145 that linked foodborne outbreaks most commonly to poultry meat, composite products, red meat,
146 raw shell eggs, desserts, cakes and confectionery food groups, the majority of which are targeted
147 for sodium reduction as shown in table 1.⁴² Potentially, unless salt, which may alone or in
148 combination act as an antimicrobial hurdle, is suitably substituted with an alternative hurdle, an
149 increasing trend in cases may occur in the future and this underlines the need for careful
150 assessment. Potential alternative hurdles include not only formulation factors but also changes to
151 processes and alternative packaging technologies such as modified atmosphere or vacuum
152 packaging. However, food safety risk assessment needs to be done on the holistic
153 product/process/packaging system as failure to consider any one element could increase the risk of
154 foodborne illness. For example, if packaging atmospheres are modified to extend shelf life and this
155 creates anaerobic conditions then, without further adequate hurdles, this may promote the growth
156 of anaerobic pathogens such as *Clostridium botulinum*, which can cause serious illness and even
157 fatalities.⁴³

158

159 **Salt action on microorganisms.**

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

163 Equilibrium relative humidity, more commonly termed available water or water activity (aw). Where
164 no other humectants are present, a solution containing 16.5% salt is required to achieve a water
165 activity value of 0.90.¹ The lowest water activity for pathogen growth is for *Staphylococcus aureus*
166 at 0.86, most pathogens will grow above a water activity level of 0.90 (Table 2).⁴⁴ Table 3 shows the
167 typical water activity of a number of food groups and it is clear to see that all could have the
168 potential of supporting growth of pathogens if inhibitive conditions were not present.
169

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

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

170

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

171

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

187 The impact of salt as an antimicrobial alone has been shown to have varying efficacy. Harper and
188 Getty found that 2% salt was effective at inhibiting *Listeria monocytogenes* growth in ground beef
189 but had no effect on growth in Pork or Turkey demonstrating that across the board generic controls
190 within food groups may not be possible.⁵¹ Changes in salt levels between 3.66% and 1.39% did not

191 affect the growth of *Listeria monocytogenes* in Liver pate.¹⁶ Similarly reducing salt from 1.8% to 0.7%
192 in cheddar cheese between the pH levels of 5.1 and 5.7 did not allow growth of *Listeria*
193 *monocytogenes* or *Salmonella* species; decline of the organisms was noted in all conditions but more
194 prominently at a lower pH.⁵¹ Ellin Doyle and Glass also note that, based on work by McClure et al.
195 on gradient plates, *Listeria monocytogenes* becomes more sensitive to salt in acidic conditions.^{52, 53}
196 *Campylobacter* species are capable of survival in chilled environments but do not increase in
197 number, an addition of 1.5% sodium chloride to minced chicken did not significantly reduce
198 *Campylobacter jejuni* over 14 days at 4°C and therefore, in chilled storage, salt level may not be
199 impactful or significant.^{54, 55} Ellin Doyle and Roman suggested *Campylobacter jejuni* may tolerate
200 higher levels of salt when it is growing within its optimum temperature range (30-45°C) which would
201 suggest that salt will not be an effective antimicrobial if *Campylobacter* contaminated chicken was
202 temperature abused after chilled storage.⁵⁵

203 Proteolytic *Clostridium botulinum* has been shown to survive in up to 10% salt solution and
204 *S. aureus* can survive in even higher concentrations of salt, although will not produce the enterotoxin
205 unless above a water activity value of 0.90 in otherwise ideal conditions.⁵² These data sets indicate
206 salt is not the primary antibacterial hurdle for these organisms. The death rate of Gram negative
207 organisms (*E. Coli* species, *Salmonella* Typhimurium) was found to be greater than Gram positive
208 (*L.monocytogenes*, *S.aureus*) when the antimicrobial properties of Sodium Chloride were challenged
209 on natural sheep casings (used for sausages) and this is most likely due to plasmolysis of the Gram

210 negative cells; *Clostridium perfringens* spores, naturally designed to resist challenges from its
211 environment, were unaffected by the presence of salt.⁵⁶

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

222

223 **Salt as a hurdle.** Sodium salts will commonly be used as part of a hurdle preservation system; each
224 system will typically be bespoke for the product it is protecting, however in general the exact
225 mechanism of action of many hurdle systems is poorly understood. Data are needed on optimum
226 levels of various sub-lethal stress-inducing ingredients and processes to predict the efficacy of
227 hurdle technology against specific pathogens in different food systems. A number of organisms
228 have been studied to understand the impact of specific hurdles (Table 4). These trials provide

229 further evidence to suggest that salt reduction impact will be specific to each individual product and
 230 not a generic risk and therefore much more research is required not only to broaden the scope of
 231 products and organisms but to compare findings in laboratory broths to food matrices.

232

233 **Table 4 Examples of Research into Efficacy of Hurdle Systems and Processes including Salt**
 234

Organism/tested effect	Hurdle system	Findings	Reference
<i>E. coli</i>	Mixture of sodium chloride, nitrite and phosphates	In a laboratory medium, phosphates did not inhibit the growth of pathogenic <i>E. Coli</i> unless in a mixture with Sodium chloride and nitrite, the efficacy of which improved at lower temperatures and a lower pH value.	58
<i>Listeria monocytogenes</i> , <i>Clostridium perfringens</i> 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 <i>Listeria monocytogenes</i> than filtered nitrite.	53, 59
Non proteolytic <i>Clostridium botulinum</i>	Nitrite, nitrate and sodium chloride.	Efficacy of Sodium Chloride on the control of outgrowth of non proteolytic <i>Clostridium botulinum</i> in Rainbow Trout was positively affected by the presence of nitrite and nitrate, demonstrating a similarity to the work on meat and nitrite.	60
<i>E. Coli</i> , <i>S.aureus</i> and <i>Bacillus cereus</i> .	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 <i>E. Coli</i> , <i>S.aureus</i> and <i>Bacillus cereus</i> . 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
<i>Campylobacter</i> spp.	Tri-sodium phosphate as a washing treatment	When using Sodium in washing treatments, <i>Campylobacter</i> species loading on chicken carcasses has been shown to be reduced by 1.7log/g after immersion in tri-Sodium phosphate	54
<i>L.monocytogenes</i>	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 <i>L.monocytogenes</i> 80% CO ₂ was required to prevent growth, whereas 25% CO ₂ restricted growth when other hurdles were at their optimum levels. Growth of <i>L.monocytogenes</i> occurred in 4% Salt at 80% CO ₂ at 4°C, but not at 8% salt.	63

<i>Not tested on organisms – organoleptic shelf life only</i>	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

235

236 In contrast to the positive additive effect anticipated with hurdle technology, the tolerance of EHEC
237 *E. Coli* O157:H7 to salt in Salami and Cider has been found to be increased following mild acid
238 stress.¹⁵ Olsen et al. suggested that addition of Calcium Lactate and Calcium Acetate when tested in
239 Liver pate may actually trigger the stress adaption gene of *Listeria monocytogenes* and therefore
240 increase the risk of the growth of the pathogen.¹⁵ This information would suggest that food
241 manufacturers need to be cautious when adding additional hurdles for control of microorganisms.
242 Many trials have been conducted with partial replacement using Potassium salts in place of sodium.
243 Zarei et al. found that *Listeria monocytogenes* in laboratory broth was slightly more tolerant to the
244 presence of Potassium Chloride than sodium chloride with 11% potassium chloride required for
245 inhibiting growth compared to 9% sodium chloride.⁶⁶ They also found that below 25% replacement
246 of sodium chloride for potassium chloride would not impact upon food safety whereas levels of
247 exchange above 50% may allow growth of the organism. Bidlas and Lambert found that exchanging

248 sodium chloride for potassium chloride in laboratory medium did not however impact upon the
249 growth of *Aeromonas* species.⁶⁷ A significant amount of research has been conducted and has
250 demonstrated the efficacy of Potassium chloride; however, this may not be an option for sodium
251 chloride replacement as there are concerns that sections of the public may have their health at risk
252 through consumption of potassium salts and that use of potassium chloride retains a high salt
253 flavour whereas salt reduction initiatives aim to allow consumer palates to become used to lower
254 salt flavours.^{32, 68, 69} Therefore, it is not current policy to recommend potassium-based alternatives
255 to sodium chloride but this is currently under review at the Department of Health.⁶⁹
256 Beyond pathogen control some food manufacturers must consider Histamine production as this
257 may cause allergic reactions in some consumers and therefore production in susceptible foods
258 requires control. Histamine production on Trout was found to be inhibited by a solution containing
259 10% sodium chloride, glucose, ascorbic acid and potassium nitrate; when lactic acid bacteria were
260 added to the brine double the volume of salt was required for the same level of control.⁷⁰ This
261 reflects the previous observation that multiple hurdles are not always beneficial.

262

263 **Options for Replacing Sodium.**

264 A number of methods for sodium reduction are in use, the most common is gradual reduction with
265 consumer adaption over time.²⁴ It has been suggested that this method could allow sodium
266 reduction of up to 15% and other mineral salts as substitutes may allow 25% reduction where

267 appropriate.⁷¹ Harper found magnesium salts in replacement of sodium within enrichment broths
268 increased the growth of *Listeria monocytogenes*, indicating a further requirement for caution in
269 reformulation processes.⁷²

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

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

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

283 The essential oil compound Eugenol, which can be extracted from a range of essential oils such as
284 clove oil, nutmeg and cinnamon, has been found to reduce the growth of *Listeria monocytogenes*
285 and the efficacy of essential oils was found to be improved by the presence of sodium chloride.⁷⁴ At

286 higher concentrations Eugenol was found to have a bactericidal action against *Salmonella* Typhi due
287 to the alteration of the cell membrane.⁷⁵ Inactivation of genes has been considered as one of the
288 mechanisms of the antimicrobial effect of essential oils and this may disrupt the cell transport
289 system.⁷⁶ As previously suggested this action may be exploited in the future to create an additive
290 that will inhibit microorganism growth, increasing the lag phase by effecting solute transport and
291 aiding the efficacy of reduced salt levels. However, in a food safety review by Ellin Doyle the efficacy
292 of essential oils was highlighted to be limited by fats or other ingredients.⁵² The impact of aroma
293 from the essential oil components on flavour must also be considered as a limiting factor for use.

294

295 **How to reduce salt in a safe manner.**

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

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

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

322

323 **Conclusions**

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

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