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Consumer acceptance of reformulated food products: A systematic review and meta-analysis of salt-reduced foods

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ABSTRACT

Food product reformulation is promoted as an effective strategy to reduce population salt intake and address the associated burden of chronic disease. Salt has a number of functions in food processing, including impacting upon physical and sensory properties. Manufacturers must ensure that reformulation of foods to reduce salt does not compromise consumer acceptability.

The aim of this systematic review is to determine to what extent foods can be reduced in salt without detrimental effect on consumer acceptability.

Fifty studies reported on salt reduction, replacement or compensation in processed meats, breads, cheeses, soups, and miscellaneous products. For each product category, levels of salt reduction were collapsed into four groups: <40%, 40–59%, 60–79% and ≥80%. Random effects meta-analyses conducted on salt-reduced products showed that salt could be reduced by approximately 40% in breads [mean change in acceptability for reduction <40% (−0.27, 95% confidence interval (CI) −0.62, 0.08; $p = 0.13$)] and approximately 70% in processed meats [mean change in acceptability for reductions 60–69% (−0.18, 95% CI −0.44, 0.07; $p = 0.15$)] without significantly impacting consumer acceptability. Results varied for other products.

These results will support manufacturers to make greater reductions in salt when reformulating food products, which in turn will contribute to a healthier food supply.

KEYWORDS
Salt; sodium; reformulation; reduction; consumer acceptability; food; review

Introduction

Excess dietary sodium has long been recognized as contributing to increased blood pressure, and risk of cardiovascular and renal diseases (Cook et al., 2007; Elliott & Brown, 2007; He & MacGregor, 2010; Jones-Burton et al., 2006; Suckling et al., 2010; Yang et al., 2011). In most countries, daily sodium intake is in excess of recommendations and requirements, with recent reports estimating an average daily intake of 4000 mg/d (range 1500–6000 mg/day), twice that of the World Health Organisation (WHO) recommended 2000 mg/day for adults (Powles et al., 2013; WHO, 2012). In industrialized countries processed foods contribute up to 75% of dietary sodium, predominantly via sodium chloride (hereafter, referred to as salt or NaCl), followed by a much lesser proportion from discretionary salt use or that which is naturally occurring (Brown et al., 2009). Results from national dietary intake surveys suggest that across Westernized countries the products which contribute the most to daily salt intake are similar: cereals and cereal products rank highest, contributing up to 50% of daily salt in some countries (Doyle & Glass, 2010), with breads providing the most salt from this category (Australian Bureau of Statistics, 2014; Bates et al., 2014; Elliott & Brown, 2007; Health Canada, 2010). Other major sources include meat and meat products, milk and milk products, soups, and other foods including sauces, condiments and snack products (Webster et al., 2014). In some Asian countries sources of salt differ considerably, with salt added in cooking a major contributor to intake alongside condiments such as soy sauce, pastes and powders, preserved and fermented products (i.e., fish, fruits, vegetables) and region-specific foods such as miso soup and salted products (Anderson et al., 2010; WHO, 2011).

Reducing salt intake has long been recognized as an effective intervention to reduce the burden of non-communicable diseases. A global target of 30% reduction in population salt intake by 2025 has been set (WHO, 2012), and many countries are now implementing strategies to achieve reductions in salt intake at the population level (Trieu et al., 2015; Webster et al., 2014; Webster et al., 2011; World Action on Salt & Health; WHO, 2013). Food product reformulation is identified by WHO as one of the key pillars for salt reduction, and is a strategy which is particularly effective in countries where the majority of salt is consumed via processed foods (WHO, 2007). In 2014, 83 countries had salt reduction initiatives in place or planned, with 59 of these already working with the food industry to reduce salt in foods, and 38 establishing sodium content targets (Webster et al., 2014). To date, industry-led initiatives, many voluntary, have reported success in reducing salt by an

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average of 25% (range 5–81%) across a range of product categories (Webster et al., 2014), with some countries observing health gains such as reduction in cardiovascular risk and associated morbidity and mortality attributed to decreased salt intake (He et al., 2014; National Heart Foundation of Australia, 2012).

Given the increasing momentum of food product reformulation initiatives, there are important factors to be taken into consideration when reducing salt content of foods. First, salt has varying roles in the preservation, flavor and structure of food products (Albarracín et al., 2011; Buttriss & Benelam, 2010; Doyle & Glass, 2010; Liem et al., 2011). Reducing salt alters the composition of food products and therefore manufacturers need to ensure that achieving the target concentration does not compromise the safety and quality of the product (Doyle & Glass, 2010). Second, reducing salt has the potential to disrupt the sensory profile of food—including its taste, texture, aroma and appearance—which may reduce consumers' overall liking and purchase intent for a product (Bi, 2010; Liem et al., 2011; Rowe et al., 2011), resulting in potential economic losses for the manufacturer (Australian Government—Department of Health, 2012; Bautista-Gallego et al., 2013). Prior to investing considerable resources into producing reformulated food products, it is in manufacturers' interests to ensure that comparable acceptance can be demonstrated between the original and reformulated product (Stone et al., 2012). Measuring the degree of liking or acceptance for a product takes place during the research and development phase, with results used to determine the feasibility of progressing with reformulation (Stone et al., 2012). While several studies have investigated consumer acceptance of salt-reduced products via affective testing, there has been no comprehensive review of this topic to date. The aim of this paper is therefore to systematically review the literature on consumer acceptance of reformulated food products with a focus on salt reduction, and to determine the extent to which salt can be reduced while maintaining comparable acceptability.

Methods

Search strategy

Studies comprising investigation of consumer acceptability of salt-reduced food products were identified via electronic database search of Medline, PubMed, the Cochrane Library, Science Direct, Web of Science and Scopus. Studies were limited to English language human studies, with no date restrictions imposed. The initial search took place in June 2014, and was updated in March 2015. Searches were conducted on title, abstract and/or keywords as per the capacity of each database using the following terms: (consumer* OR customer*) AND (salt OR sodium OR NaCl) AND (reformulat* OR reduc* OR replac* OR substitut*) AND (accept* OR assess* OR preference OR sensory OR hedonic OR liking OR taste OR evaluat*). Where available, the option to search for similar terms was unchecked. Reference lists of included studies were hand searched for additional relevant articles.

Study selection

Eligible studies were those which investigated overall consumer acceptability/liking of food products reformulated to reduce salt, using a consumer panel comprising members untrained in sensory analysis. No demographic restrictions were placed on panellists (e.g., age, gender, nationality). The National Heart Foundation of Australia's definition of reformulation was used to identify suitable studies (National Heart Foundation of Australia, 2012). Studies within the primary production or catering/food service sectors were excluded. Products modifying one or more nutrients alongside salt reduction (e.g., increased fiber, reduced fat) were excluded, as changes in preferences could not be attributed to salt reduction alone (Ghawi et al., 2014), however studies of salt reduction combined with substitution or flavor compensation were retained and considered separately.

Mean change in overall acceptability/liking and level of salt reduction were the primary outcome measures for the review and statistical analyses.

Data extraction

All articles from electronic searches were imported into an EndNote X7 library, and any duplicate papers removed. Initial screening was conducted by one author (RJ) to eliminate obvious ineligible references (i.e., book chapters, articles not in English, non-human studies). Titles and abstracts were then screened independently by two authors (RJ, EM) for eligibility. Full-text manuscripts of potentially eligible studies were obtained and assessed against eligibility criteria by the same two authors. If consensus was not reached following discussion, a third author (JB) reviewed these manuscripts and a decision was made as to inclusion of the study. Further advice was sought from an industry expert in the event that uncertainties remained. Agreed reasons for rejection of studies were recorded.

A piloted data extraction form was used to enter data pertaining to participants/panellists, study design, product reformulation strategy, measure of consumer acceptability and study outcomes. Data were extracted independently by a Research Assistant from 25% of studies to ensure consistency. Further information was required for 43 studies, for which their authors were contacted. The requested information was provided for 20 of these studies, while authors of the remaining 23 studies either could not be contacted, did not respond, or were unable to provide details.

The percentage of salt reduction was calculated based on reported concentrations of NaCl in original and reformulated product variants. For studies where NaCl concentrations were not available, reported sodium (Na) concentrations were used to estimate percentage salt reduction.

Quality assessment

Risk of bias was assessed based on Cochrane guidelines for assessing risk of bias in cross-over studies (Higgins & Green, 2011) and advice from an expert in sensory analysis (RC) regarding quality indicators in sensory research. The cross-over study design most closely resembled most of the studies included, given that participants acted as their own control and assessed both regular and reduced-salt products. Three quality indicators were used: (1) Food samples presented in random order, (2) Panellists external to the manufacturer/company, and (3) Panellists blinded to the nature of product modification.

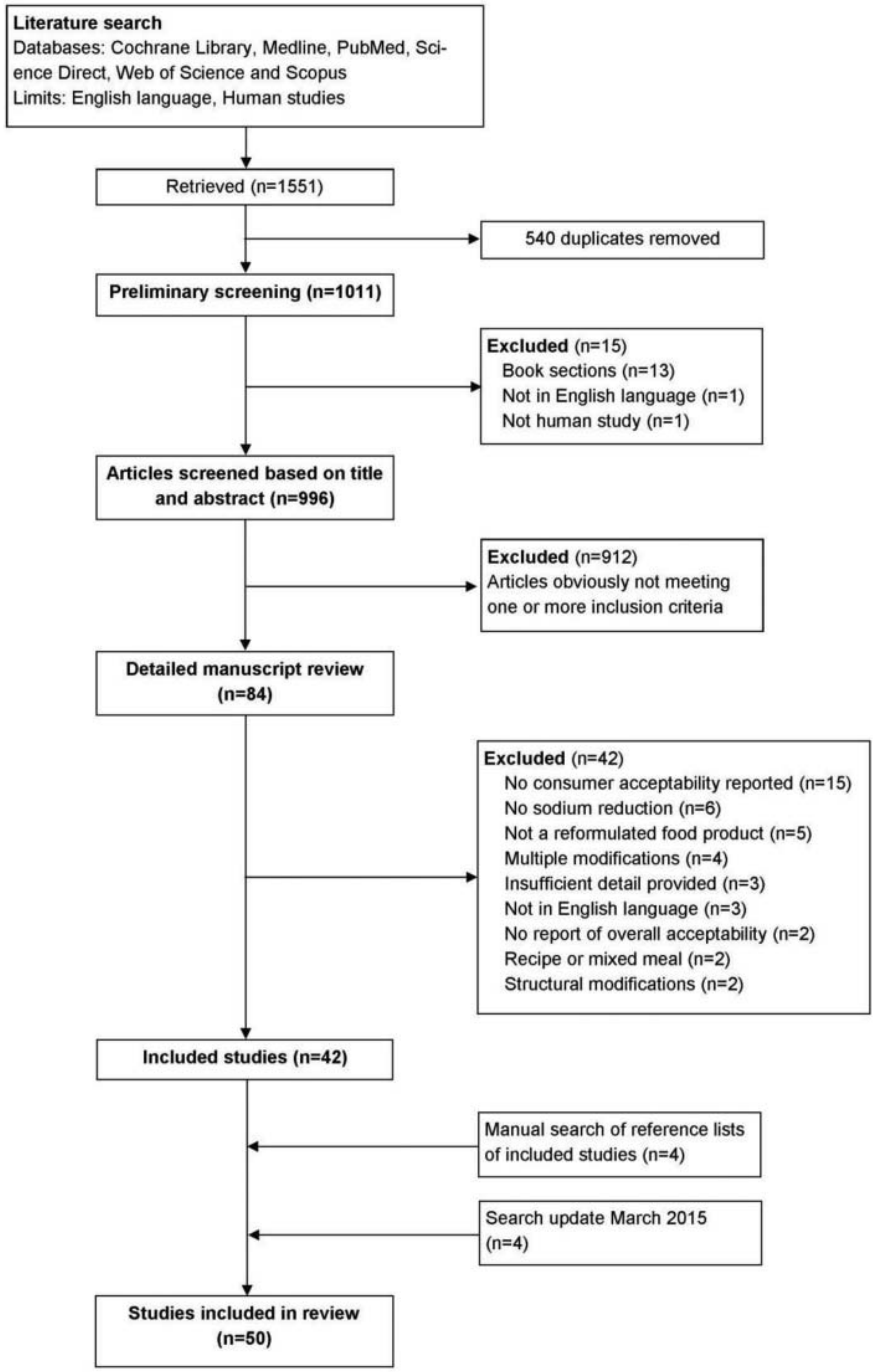

Figure 1. PRISMA diagram.

Data synthesis and analysis

Thirty-seven studies were eligible for meta-analysis, in that they: (1) investigated overall consumer acceptability of salt-reduced products; (2) provided estimates of mean difference in overall acceptability before and after salt reduction; and (3) there were at least two studies from the same product category in two or more reduction groups. When available, a measure of variability was also extracted, but if not provided it was imputed according to methods outlined by the Cochrane Collaboration (Higgins & Green, 2011). With the exception of processed meats and cheeses where potassium chloride (KCl) partially replaced NaCl, and where there were sufficient studies to conduct separate meta-analyses, salt replacement and flavor compensation were excluded from statistical analyses as methods varied between studies and could not be directly compared. Miscellaneous products were also excluded from analyses due to the variation in product types.

Levels of salt reduction were collapsed into four groups: less than 40% reduction, 40–59% reduction, 60–79% reduction and equal to or greater than 80% reduction. These groupings were chosen to be consistent across all product categories while also best representing the differing levels of reduction investigated in individual studies. In instances of studies investigating more

Table 1. Characteristics of included studies.

Author, year Country	Participants *Study design/methods*	Product category	Sodium content (mg Na/100g)*			
			Baseline	Salt reduction only	Salt reduction with salt replacement	Salt reduction with flavour compensation
Adams, 1995 USA	380 (79% male) military & civilian volunteers; mean age 44y *Central location test*	Bread—whole wheat	600	50	—	—
		Bread—oatmeal	490	60	—	—
		Misc—potato chips	160	10	—	—
		Misc—tortilla chips	430	10	—	—
Almli, 2013 Norway	102 (43% male) consumers; age 22–64y *Central location test, blind taste test*	Meat—smoked salmon	1170	—	780 mg	—
Ball, 2002 Australia	107 (33% male) young adults, majority university psychology students; mean age 22y *Cross sectional design*	Soup—pumpkin	343	195; 113; 0	—	195; 113; 0 mg
Bolhuis, 2011 Netherlands	39 university students & employees; age 18–53y *Parallel study design with 3 treatments*	Bread—brown	498	346; 241; 167	—	488; 339; 234′
Braschi, 2009 UK	41 (27% male) research & academic staff; mean age 31y *Randomised single-blind sensory test*	Bread—white	509	—	382; 204; 357; 357; 255	—
Campagnol, 2012 Brazil	80 university students, faculty & staff; age 18–51y *Consumer study*	Meat—fermented sausage	975	—	488	488
Canto, 2014 Brazil	60 university students, faculty & staff; age 18–63y *Randomised block*	Meat—caiman steaks	585	—	293	—
Carter, 2011 USA	34 university students & individuals from surrounding neighbourhood; age 20–35y *Within-subject, repeated measures design*	Soup—chicken broth	663	332; 207; 63	—	332; 207; 62
Carvalho, 2013 Brazil	100 (45% male) untrained consumers *Sensory evaluation*	Meat—marinated beef	780	—	585; 390	—
		Meat—marinated chicken	780	—	585; 390	—
Corral, 2013 Spain	85 untrained consumers *Acceptability test*	Meat—fermented sausage	1053	881	881	—
Corral, 2014 Spain	81 untrained assessors *Sensory analysis*	Meat—fermented sausage	1053	—	790	790
Czarnacka-Szymani, 2015 Poland	100 (48% male) regular cheese consumers recruited via phone; age 16–75y *Consumer panel*	Cheese	593	507; 452	—	—
Drake, 2011 USA	75 (20% male) university students, staff & faculty members; age 18–51y *Crossover design*	Cheese—cottage	245	235; 224; 214	—	—
Ferrante, 2011 Argentina	100 bread consumers, mostly recruited via bakeries *Sensory analysis*	Bread—French	702	468; 234	—	—
Galvão, 2014 Brazil	77 consumers of sliced meat products *Acceptance test*	Meat—turkey ham	761	616; 499	—	—
Ganesan, 2014 USA	120 panellists *Consumer panel, completely randomised block design*	Cheese—cheddar	722	538; 499; 382; 289	—	—
		Cheese—mozzarella	733	527; 464; 351; 289	—	—
Ghawi, 2014 UK	101 university students & staff *Central location test*	Soup—tomato	164	113; 90; 70	—	—
Girgis, 2003 Australia	110 (21% male) hospital staff; mean age 39y *6-week RCT*	Bread—white	780′	585′ (after 5 weeks stepwise reduction)	—	—
Goh, 2011 Singapore	60 (50% male) Chinese consumers recruited via University global address book; mean age 36y *Hedonics & taste intensities sessions*	Misc—salad dressing	780	—	683; 585; 488; 390	—
		Soup—cream of tomato	351	—	324; 293; 265; 234	—
Gomes, 2011 Brazil	100 cheese consumers *Consumer test*	Cheese—Minas fresh	138	—	104; 98; 57	—
Grummer, 2013 USA	117 university students & staff; age > 18y *Consumer acceptability test*	Cheese—cheddar	796	—	273	273 mg
Guàrdia, 2006 Spain	98 (45% male) members from IRTA's panel *Consumer acceptability survey – complete block design*	Meat—sausage	858	—	—	429
Guàrdia, 2008 Spain	239 (50% male) *Complete block design*	Meat—sausage	858	—	—	429
Helleman, 1990 Poland	31 (32% male) employees of food & nutrition institute; mean age 41 years	Bread—wheat	413	246; 98	—	—
		Bread—rye	605	527; 383; 293; 101	—	—
Kamleh, 2012 Lebanon	72 university students, staff & faculty; age 18–57 y (mean 24 y)	Cheese—halloumi	524	—	441; 282	—
Kanavouras, 2005 Mediterranean basin & European Union	39 consumers	Misc—black table olives	6552(in brine)	4992(in brine)	—	—

Karahadian, 1984 USA	197 consumers from University Dairy Salesroom clientele	Cheese—cheddar	1250	571	95	—
Kremer, 2009 Netherlands	108 (50% male) Caucasian consumers recruited via local recruitment agency; mean age 38 y	Misc—salad dressing	780	—	683; 585; 488; 390	—
		Soup—cream of tomato	351	—	339; 320; 308; 293	—
Kremer, 2013a Netherlands	115 (44% male) participants selected by local recruitment agency; mean age 46 y *n-home use test*	Bread—wholemeal	702 mg^	—	429 mg^	—
Kremer, 2013b Netherlands	89 participants; age 19–65 y *Sensory profiling*	Bread—wholemeal	702*	—	585; 507; 429; 312*	—
		Soup—cream of tomato	351	—	324; 293; 265; 234	—
La Croix, 2014 USA	109 members of University Food Innovation Centre sensory testing database	Bread—50% whole wheat	780*	702; 624; 546*	—	—
Lindsay, 1982 USA	150 (~50% male) clientele of University Dairy Salesroom; age >17 y *Randomised complete block*	Cheese—cheddar	530	430	240	—
Lopez, 2012 USA	180 participants *Randomised complete block with 3 replications*	Meat—marinated broiler	488	390; 293; 195; 98	—	—
McGough, 2012 USA	150 university faculty staff & students, & the general public; age 18–24 y (majority) *Randomised complete block using mixed effects model with 3 replications*	Meat—frankfurter	975	—	878; 780; 683; 488	—
Methven, 2012 UK	40 university students & staff; age 20–55 y (mean 33 y)	Soup	225	165; 110; 0	—	—
Miller, 2014 USA	118 (41% male); age 18–40+ y *Consumer sensory test*	Bread—white pan	720	323; 267	—	—
Mitchell, 2009 Ireland	175 (43% male) staff & students of research centre & visiting personnel; age 19–70years *Blind taste test*	Misc—ready meal (frozen lasagne)	410	—	215	—
Mitchell, 2011 Ireland	90 (56% male) staff & students of research centre & visiting personnel; age 19–70 y *Blind taste test*	Misc—ready meal (chili con carne)	398	—	—	160
Mitchell 2013 Ireland	60 (43% male) staff & students of research centre; age 22–56 y *Blind test*	Soup—vegetable	363	176	—	176
Monterio, 2014 Brazil	60 (32% male) participants from university campus; age 19–48 y *Acceptance test*	Meat—restructured fish steaks	585	—	293	—
Noort, 2012 Netherlands	86 (48% male) participants; age 18–65 y	Bread—white	477	359; 241	—	—
Pietrasik, 2014 Canada	90 participants; age >18 y *Completely randomised design*	Meat—restructured cooked ham	780 - reduction874 - replacement 780 - compensation	468	613; 452	468
Saha, 2009 USA	68 consumers	Meat—marinated broiler	488	390; 293; 195	—	—
Schroeder, 1988 USA	40 (50% male) university students faculty or staff *Consumer test every 30 days of aging period starting at 60 days*	Cheese—cheddar	562	437; 285; 144; 27	—	—
Sofos, 1983 USA	25 participants, majority college students	Meat—frankfurter	975	780; 585	—	—
Tobin, 2012 Ireland	25 participants; age 20–30 y *Sensory evaluation (undertaken in duplicate)*	Meat—frankfurter	1170	975; 780; 585; 390	—	—
Tobin, 2013 Ireland	25 participants; age 20–30 y *Sensory evaluation*	Meat—sausage	936	780; 624; 546; 468; 390; 312	—	—
Vazquez, 2009 Argentina	192 high school students (n = 96; approx. 50% male; age 13–14 y) or adult food service workers (n = 96; 75% male; median age 35 y) *Blind acceptability test Conducted at places of employment*	Misc—biscuits	351	176	—	—
Willems, 2014 France	321 (26% male) French adults recruited via external agency; age 18–65 y *Central location test*	Soup—chicken noodle	370	290; 250	—	—
Wyatt, 1983 USA	40 consumers	Bread—white	585	439; 293; 146	—	—
		Bread—whole wheat	585	439; 293; 146	—	—
		Cheese—cottage	390	293; 195; 98	—	—
		Misc—dill	977	795	—	—
		Misc—sweet pickle	388	181	—	—

* Mg Na/100g – converted from reported NaCl concentrations (unless only mg Na was reported); ^ mg Na/100g flour).
Abbreviations: B/L: baseline; LS: low salt; Na: Sodium; KCl: Potassium chloride; IRTA: Institute of Agricultural-Alimentary Research & Technology.

than one reduction within the same "level of salt reduction" group (e.g., 50% and 58% reduction in sausage, meaning both reductions fall in the 40–59% reduction group—Tobin et al. (2013)) the highest level of reduction within that group was used. This was necessary to avoid pooling correlated observations, as the same consumers assessed each product variant, and only mean acceptability scores (as opposed to individual scores) were available. For the same reason, where multiple product types were present within the same reduction group (e.g., both wholemeal and white bread), the product we considered to be more commonly consumed was used for analysis. For three studies where absolute scores were not presented or could not be obtained mean change in acceptability was estimated from published figures (Drake et al., 2011; Methven et al., 2012; Mitchell et al., 2013). For 13 studies which reported consumer acceptability on a scale other than 9-point hedonic, mean change in acceptability scores and standard errors were transformed using the following conversion factors: 150 mm line scale, divided by 16.8; 120 mm line scale, divided by 13.3; 100 mm scale, divided by 11.2; 10 cm scale, divided by 1.2; 10-point scale, divided by 1.1; 1–7 point hedonic scale, multiplied by 1.3.

Separately for each product category and reduction group, summary estimates of mean difference in consumer acceptability before and after salt reduction were derived using a random effect meta-analysis model. Studies were weighted according to an estimate of the sample size as the inverse of the standard error of the mean difference in acceptability before and after salt reduction (Sutton et al., 2000).

The I^2 statistic was derived to quantify the percentage of variability across study estimates due to heterogeneity rather than

Table 2. Salt reduction studies by product type and level of reduction.

		% salt reduction			
Author (Year)	Product description	<40	40–59	60–79	≥80
BREADS					
Adams et al. (1995)	Whole wheat				92
	Oatmeal				88
Bolhuis et al. (2011)	Brown	31	52*	67*	
Ferrante et al. (2011)	French	33*		67*	
Girgis et al. (2003)	White	25^			
Hellemann et al. (1990)	Wheat		41	76*	
	Rye	13,37	52*		83*
La Croix et al. (2014)	50% whole wheat	10,20,30			
Miller et al. (2014)	White pan		55*	63*	
Noort et al. (2012)	White	25	50		
Wyatt (1983)	White	25	50*	75*	
	Whole wheat	25	50	75*	
CHEESES					
Czarnacka-Szymani et al. (2015)	Edam	15,25			
Drake et al. (2011)	Cottage	4,8,13*			
Ganesan et al. (2014)	Cheddar	25, 31*	47	60*	
	Mozzarella	28, 37*	52*	61*	
Karahadian et al. (1984)	Process cheddar		54		
Lindsay et al. (1982)	Cheddar	19*			
Schroeder et al. (1988)	Cheddar	22	49*	74*	95*
Wyatt (1983)	Cottage	25	50*	75*	
PROCESSED MEATS					
Corral et al. (2013)	Fermented sausage	16*			
Galvão et al. (2014)	Turkey ham	19,34			
Lopez et al. (2012)	Marinated broiler	20	40	60	80*
Pietrasik et al. (2014)	Restructured cooked ham		40		
Saha et al. (2009)	Marinated broiler	20	40	60	
Sofos (1983)	Frankfurter	20#	40#		
Tobin et al. (2012)	Frankfurter	17,33	50	67	
Tobin et al. (2013)	Pork breakfast sausage	17,33	42,50, 58,	67	
SOUPS					
Ball et al. (2002)	Pumpkin		43	67†	100*
Carter et al. (2011)	Chicken broth		50†	69	91
Ghawi et al. (2014)	Tomato instant	31	45, 57*		
Methven et al. (2012)	Carrot coriander	27*	51*		100*
Mitchell et al. (2013)	Vegetable		52		
Willems et al. (2014)	Chicken noodle	22*32*			
MISCELLANEOUS					
Adams et al. (1995)	Potato chips				94
	Tortilla chips				98
Kanavouras et al. (2005)	Black table olives	24#			100#
Vázquez et al. (2009)	Biscuit		50		
Wyatt (1983)	Dill	19			
	Sweet pickle		52		

*Indicates statistically significant decline in acceptability between regular and reformulated product as reported by individual studies
^Stepwise reduction i.e. 5% reduction per week over five weeks. NSD in acceptability between weeks.
#Results not available from publication or author
†Significantly higher acceptability score compared to control

chance, with an I^2 greater than 25% indicating substantial heterogeneity (Sutton et al., 2000). For all 36 studies included in the meta-analysis, causes of heterogeneity were explored using random effects meta-regression models to compare pooled estimates obtained for studies grouped according to year of publication (before and after 2004), sample size ($n < 80$ and $n \geq 80$) and baseline sodium content (low/medium $\leq$600 mg/100 g and high >600 mg/100 g (Australian Division of World Action on Salt & Heatlh, n.d.). Mean difference in acceptability was regressed separately on each variable defining the study group.

A test for linear trend of change in acceptability across different degrees of salt reduction was performed using a random effects meta-regression model where each mean difference in acceptability was regressed on the ordered variable for reduction into four levels (<40%, 40–59%, 60–79%, >80%). All the random effects meta-regression models included a random effect for the intercept, a random effect for study to allow for autocorrelation between results from the same study, were adjusted for level of salt reduction and weighted each study proportionally to statistical size. Publication bias was assessed using graphical methods (funnel plots) and the Egger test (Sutton et al., 2000).

Results

Search results

A total of 50 studies were eligible for inclusion in the review (Figure 1). Studies failing to meet inclusion criteria, including reasons for exclusion, are detailed in Table S1.

Characteristics of included studies

Characteristics of included studies are summarized in Table 1. Studies included in this review reported the results of consumer acceptability testing of one or more reformulated products from a combined 5101 consumers. Most studies were conducted in the Americas (North: $n = 16$; South: $n = 8$) or European regions ($n = 21$), with a small number in Australia ($n = 2$), Asia ($n = 2$) and the Mediterranean Basin ($n = 1$).

The majority of studies (82%, $n = 41$) were conducted in the previous 10 years (i.e., after 2004), with 33 of these studies being conducted since 2010.

Reformulation strategies investigated included salt reduction alone (31 studies), salt replacement (20 studies) or salt reduction with flavor compensation (9 studies). Across the studies, a total of 63 unique products from a range of categories were reformulated, including processed meats ($n = 18$), breads ($n = 15$), cheeses ($n = 11$), miscellaneous products ($n = 10$) and soups ($n = 9$). Several studies investigated more than one product and/or reformulation strategy. Varieties of products within each category, along with their level of reduction, are summarized in Tables 2, 4 and 5.

Salt reduction

Reformulation via salt reduction alone was conducted in 31 studies of a total of 40 products. Level of salt reduction ranged from 4 to 100%.

Bread

Nine studies investigated the effect of salt reduction in breads, at levels between 10 and 92%. There was strong evidence of a linear trend between change in consumer acceptability and level of salt reduction ($p < 0.001$). Meta-analysis conducted on the eight eligible studies found that in the less-than-40% reduction group (range 25–37%) there was no statistically significant change in consumer acceptability [−0.27 (95% CI, −0.62, 0.08) ($p = 0.13$)]. However acceptability was significantly lower for products in 40–59% [−0.69 (95% CI, −1.19, −0.18) ($p = 0.007$)] and 60–79% [−1.71 (95% CI, −2.56, −0.87) ($p < 0.001$)] reduction groups (ranges 50–55% and 63–76%, respectively). As there were only two studies with greater than 80% reduction, and significant heterogeneity between them [$I^2 = 98\%$ (95% CI, 95%, 99%) ($p < 0.001$)], conclusions were unable to be drawn for this group (Figure 2).

Meta-regression conducted to explore causes of heterogeneity found evidence of a greater decrease in acceptability when reductions were made in breads with lower baseline sodium content ($p < 0.001$). There was no effect of study size ($p = 0.07$) or publication year ($p = 0.59$) on reported acceptability (Table 3). One study (Girgis et al., 2003) was not included in the statistical analyses, as it was a six-week randomized controlled trial in which consumers were provided bread which had the salt content reduced incrementally by 5% each week (resulting in a final reduction of 25%) with breads rated at the end of each week. No difference in liking was found in this study between regular and reduced-salt bread groups over the 6-week period.

Cheese

Seven studies investigated salt reductions ranging from 4 to 95% in various cheeses. There was strong evidence of a linear trend between change in consumer acceptability and level of salt reduction ($p < 0.001$) and meta-analysis of all seven studies found a statistically significant inverse relationship between consumer acceptability and degree of salt reduction at all levels (all p-values < 0.05) (Figure 3). This effect was greatest for cheeses in the 60–79% reduction group (range 60–75%) [−1.99 (95% CI, −2.81, −1.16) ($p < 0.001$)] as well as the one study with >80% reduction (actual reduction 95%) [−3.22 (95% CI, −4.44, −2.0)($p < 0.001$). Significant heterogeneity was present among studies with less than 40% reduction [$I^2 = 82\%$ (95% CI, 61%, 91%) ($p < 0.001$)]. Meta-regression found no association between baseline sodium content ($p = 0.61$), study size ($p = 0.52$) or year of publication ($p = 0.65$) and change in acceptability (Table 3).

Meat

Eight studies investigated salt reduction in meats at rates ranging from 16 to 80%. Meta-analysis of seven eligible studies found no reduction in consumer acceptability for reductions between 16 and 67% (all p-values >0.05), (Figure 4). Meta-regression found no evidence of linear trend in change in acceptability by level of salt reduction ($p = 0.104$). One study (Sofos, 1983) was not included in the meta-analysis as,

Table 3. Effect of independent factors on consumer acceptability as explored by meta-regression.

Product category	Baseline Na content(Low/mod vs. high)*	Statistical size($n < 80$ vs. $n \geq 80$)	Year of publication(<2004 vs. ≥ 2004)
Bread	$p < 0.001$ at lower baseline Na	$p = 0.07$	$p = 0.59$
Cheese	$p = 0.61$	$p = 0.52$	$p = 0.65$
Soup	$p = 0.008$ at lower baseline Na	$p = 0.83$	n/a†

*≤600 mg/100 g vs. >600 mg/100 g (AWASH)
†Soup: Only one study pre-2004, year of publication not assessed
Omitted product categories: Meat – no significant heterogeneity among studies; Miscellaneous – meta-regression not conducted due to dissimilar products

although overall acceptability was investigated, data was not presented and could not be obtained. The authors reduced salt in frankfurters by 20% and 40%, and found that those with 40% reduction scored lower than regular and 20%-reduced salt variants (Sofos, 1983).

Soup

Six studies investigated salt reduction in soups with salt reductions from 22 to 100%. There was no evidence of linearity ($p = 0.064$) in the association between level of salt reduction and change in acceptability (Figure 5). In considering causes of heterogeneity, meta-regression found evidence of a significant effect of baseline sodium content, in that products with lower baseline sodium experienced a greater decrease in acceptability ($p = 0.008$). There was no effect of study size ($p = 0.83$) (Table 3).

Miscellaneous products

Four studies investigated salt reductions ranging from 19 to 98% in six miscellaneous products, with acceptability scores for most being similar to their regular-salt varieties: Adams et al. (1995) compared commercial regular and reduced-salt potato and tortilla chips, with reductions of 94% and 98%, respectively, finding both variants scored similarly to the regular salt chips. A biscuit with 50% less added salt was produced by Vázquez et al. (2009), and resulted in acceptability scores equal to those of the conventionally prepared biscuit. Wyatt (1983) found that dill and sweet pickle with 19% and 52% less salt respectively did not differ in liking compared to regular salt equivalents. Kanavouras et al. (2005) reduced or removed NaCl in brines to produce lower-salt olives, finding that the variant with no salt scored significantly lower to the point of being unacceptable, while brines with 24% less salt achieved a similar mean score to the control product.

Table 4. Salt replacement studies by product type and level of reduction.

			% salt reduction		
Author	Product description	Replacement method	<40	40–59	60–79
BREADS					
Braschi et al. (2009)	White	K-salts	25*, 30,30	50*	60*
Kremer et al. (2013a)	Whole meal	Soy sauce	39^		
Kremer et al. (2013b)	Whole meal	Soy sauce	17,28*, 39*	56*	
CHEESES					
Gomes et al. (2011)	Minas fresh	KCl	25	50*	75*
Grummer et al. (2013)	Cheddar	KCl			66
Kamleh et al. (2012)	Halloumi	KCl	30	50	
Karahadian et al. (1984)	Process cheddar	KCl			73*
Lindsay et al. (1982)	Cheddar	KCl		55*	
PROCESSED MEATS					
Almli et al. (2013)	Smoked salmon	KCl	33		
Campagnol et al. (2012)	Fermented sausage	KCl		50*	
Canto et al. (2014)	Restructured caiman steak	KCl; MgCl; both		50†,50 50	
Carvalho et al. (2013)	Marinated beef	KCl	25	50	
	Marinated chicken	KCl	25	50	
Corral et al. (2013)	Fermented sausage	KCl	16		
Corral et al. (2014)	Fermented sausage	KCl	25		
McGough et al. (2012)	Frankfurter	Soy sauce	10†20† 30		
		Soy sauce + KCl	20† 35	50	
Monteiro et al. (2014)	Restructured tilapia steak	KCl; MgCl; both		50,50*50	
Pietrasik et al. (2014)	Restructured cooked ham	Low-Na sea salt	30	48	
SOUPS					
Goh et al. (2011)	Cream of tomato	Soy sauce	8, 17, 24, 33		
Kremer et al. (2009)	Cream of tomato	Soy sauce	3,9,12,17		
Kremer et al. (2013b)	Cream of tomato	Soy Sauce	8,17, 24,33*		
MISCELLANEOUS PRODUCTS					
Goh et al. (2011)	Salad dressing	Soy sauce	13,25, 38,	50	
Kremer et al. (2009)	Salad dressing	Soy sauce	13,25, 38,	50	
Mitchell et al. (2009)	Frozen lasagne ready meal	KCl		48	

*Indicates statistically significant decline in acceptability between regular and reformulated product as reported by individual studies
^Results from 15-day in-home consumption test. Significant reduction in acceptability for first five days, NSD from day six onwards.
†Significantly higher acceptability score compared to control
Abbreviations: KCl = potassium chloride; MgCl = magnesium chloride

Table 5. Flavour compensation studies by product type and level of reduction.

Author	Product description	Compensation method	% salt reduction			
			<40	40–59	60–79	≥80
BREAD						
Bolhuis et al. (2011)	Brown	KCl + IMP/GMP	31	52*	67*	
CHEESE						
Grummer et al. (2013)	Cheddar	HY; PB; I; G			66,66,′ 66* 66	
PROCESSED MEAT						
Campagnol et al. (2012)	Fermented sausage	Lys; GMP/IMP; both		50*50*50		
Corral et al. (2014)	Fermented sausage	Yeast	25			
Guàrdia et al. (2006)	Fermented sausage	K-lactate + KCl		50*50*50,50,50,50		
Guàrdia et al. (2008)	Fermented sausage	K-lactate + KCl		50*50*50*50*50,*50		
Pietrasik et al. (2014)	Restructured cooked ham	Savoury powder	40			
SOUP						
Ball et al. (2002)	Pumpkin	Glutamate		43†	67†	100*
MISCELLANEOUS PRODUCTS						
Mitchell et al. (2011)	Chili con carne ready meal	Yeast extract		60		

*Indicates statistically significant decline in acceptability between regular and reformulated product as reported by individual studies
†Significantly higher acceptability score compared to control
Abbreviations: KCl = potassium chloride; IMP/GMP = disodium inosinate/disodium guanylate; HY = hydrolysed vegetable protein/yeast extract blend; PB = potassium blocker type powder; I = disodium 5′ inosinate; G = disodium 5′ guanylate; Lys = lysine

Salt replacement

Reformulation via salt replacement was conducted in 20 studies of 24 products. Level of salt reduction ranged from 3 to 75% (Table 4).

Bread

In three bread studies, partial NaCl substitution with either naturally brewed soy sauce (Kremer et al., 2013a, b) or various potassium salts (Braschi et al., 2009) was investigated. There was no clear relationship between level of replacement and overall acceptability. For instance, Kremer et al. (2013b) found that repeated exposure of a "soy sauce" bread yielded similar acceptability scores at 17% less salt, but was liked significantly less with 28–56% salt reduction. In comparison a similar product with 39% less salt was tested over 15 days of in-home consumption, and while there was a significant difference between control and reduced-salt variants overall, when daily liking scores were considered there was no significant difference in acceptability from the sixth day onwards (Kremer et al., 2013a). Braschi et al. (2009) substituted between 25 and 60% of NaCl with five different potassium (K) salt combinations: 25% bicarbonate (K-bic); 30% citrate (K-cit); 50% chloride (KCl); 60% gluconate (K-gluc); and 30% of a mixture of KCl + K-bic, finding that all except the two variants with 30% substitution (K-cit and KCl + K-bic) scored significantly lower than the standard bread for overall acceptability.

Cheese

Meta-analysis was conducted on all five cheese studies investigating salt replacement with KCl. In the two studies with up to 40% replacement (range 25–30%), no significant decrease in acceptability was seen ($p = 0.22$), in contrast to a significant decrease in the 40–59% ($p = 0.003$) and 60–79% ($p < 0.001$) reduction groups (range 50–55% and 66–75%, respectively). Heterogeneity was significant in the higher reduction groupings (both $p < 0.05$) (Figure S1).

Meat

Nine studies investigated salt replacement in meat products at 10–50%. KCl was the most commonly used replacer, with others including magnesium chloride (MgCl), soy sauce, a KCl/MgCl mixture or low-sodium sea salt. Meta-analysis was possible for the seven studies using KCl, with no change in acceptability found for both <40% (range 16–33%) and 40–59% (all reductions 50%) reduction groups (both $p > 0.05$) (Figure S2). Significant heterogeneity was present in the 40–59% reduction group ($p < 0.001$). For the studies investigating other salt replacers, all variants scored similar to or greater than controls.

Soup

Three studies investigated replacement of conventional salt with naturally brewed soy sauce in cream of tomato soup to reduce overall salt content by 8–33% (Goh et al., 2011; Kremer et al., 2013b) or 3–17% (Kremer et al., 2009). Goh et al. (2011) found that all levels of reduction did not differ from the control in terms of pleasantness rating. Kremer et al. (2009) also reported no significant effect on pleasantness rating, however, the accompanying figure indicates there was a significant effect. This discrepancy could not be clarified by the authors. Kremer et al. (2013b) demonstrated no effect of up to a 24% salt reduction on liking.

Miscellaneous products

Three studies examined the effect of NaCl reductions between 13 and 60% in ready meals or salad dressings. In a frozen lasagne ready meal, Mitchell et al. (2009) replaced 48% NaCl with KCl and found no impact on acceptability. Kremer et al. (2009) and Goh et al. (2011) investigated up to 50% NaCl

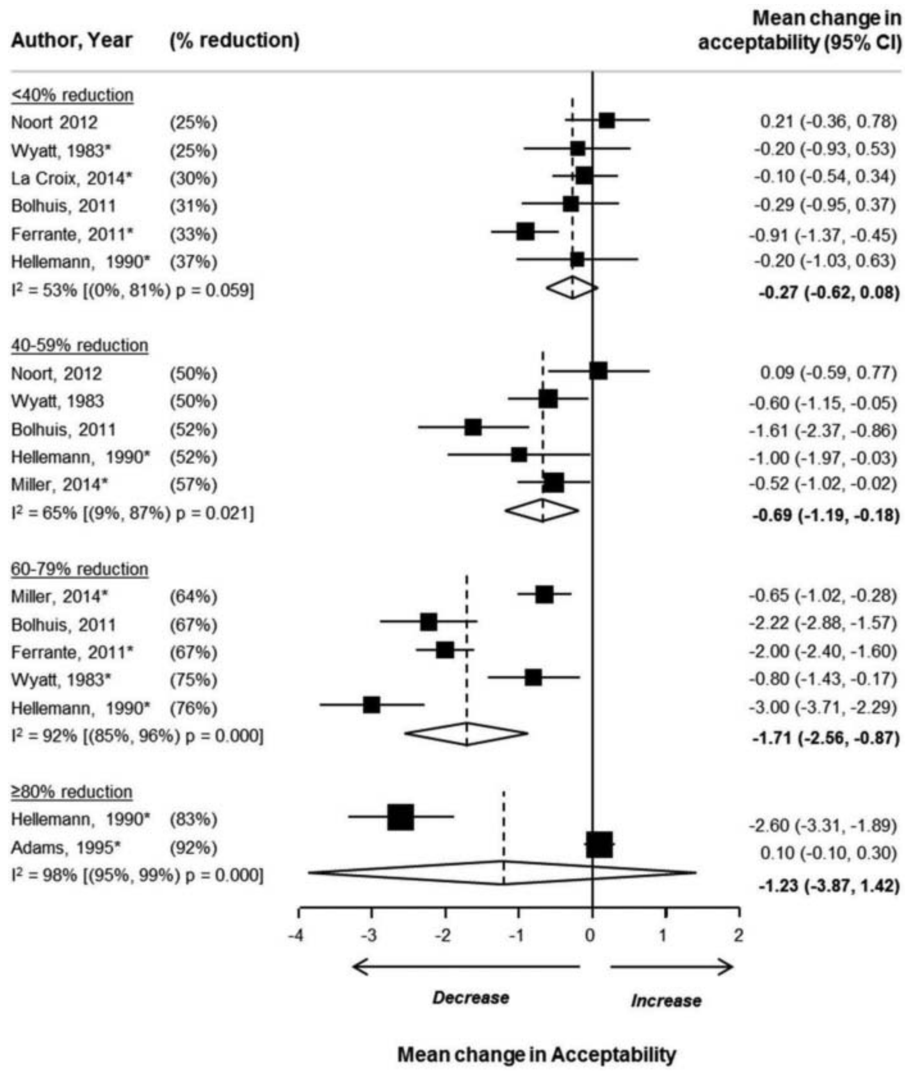

Figure 2. Forest plot for consumer acceptability of salt reduced breads. *Imputed standard error for mean change in acceptability.

reduction in salad dressings via naturally brewed soy sauce and found that consumer acceptability was not changed.

Flavour compensation

Reformulation via flavor compensation was conducted in nine studies of nine products. Level of salt reduction ranged from 3 to 75% (Table 5).

Bread

Flavor compensation was investigated in only one study: Bolhuis et al. (2011) replaced NaCl with a mixture of KCl and a flavor enhancer, finding a 31% reduction rated equally as pleasant as the control while 52% and 67% lower salt variants were considered significantly less pleasant.

Cheese

Grummer et al. (2013) used flavor enhancers (hydrolyzed vegetable protein, Potassium Blocker, disodium 5′ inosinate or disodium 5′ guanylate) in 66% reduced-salt cheddar cheese, with all variants achieving similar acceptability to the full-salt variety.

Processed meat

Five studies investigated the use of flavor compensation in meat products with 25–50% less salt. Several flavor enhancers were used with varying effects. At 25% reduction, a yeast-enhanced fermented sausage was liked significantly less than the control (Corral et al., 2014). In 50% reduced-salt fermented sausages, different combinations produced varying results; the addition of lysine or disodium inosinate and disodium guanylate (IMP/GMP) scored less favorably than the control, while a combination of lysine and IMP/GMP was liked equally (Campagnol et al., 2012). Guàrdia and colleagues used K-lactate with KCl in varying ratios in 50% salt-reduced small calibre fermented sausages, finding that variants with higher concentrations of K-lactate were liked significantly less, while those with higher concentrations of KCl were as acceptable as controls (Guàrdia et al., 2006, 2008). Pietrasik and Gaudette (2014) added savory powder to fermented cooked ham with 40% less salt, and found

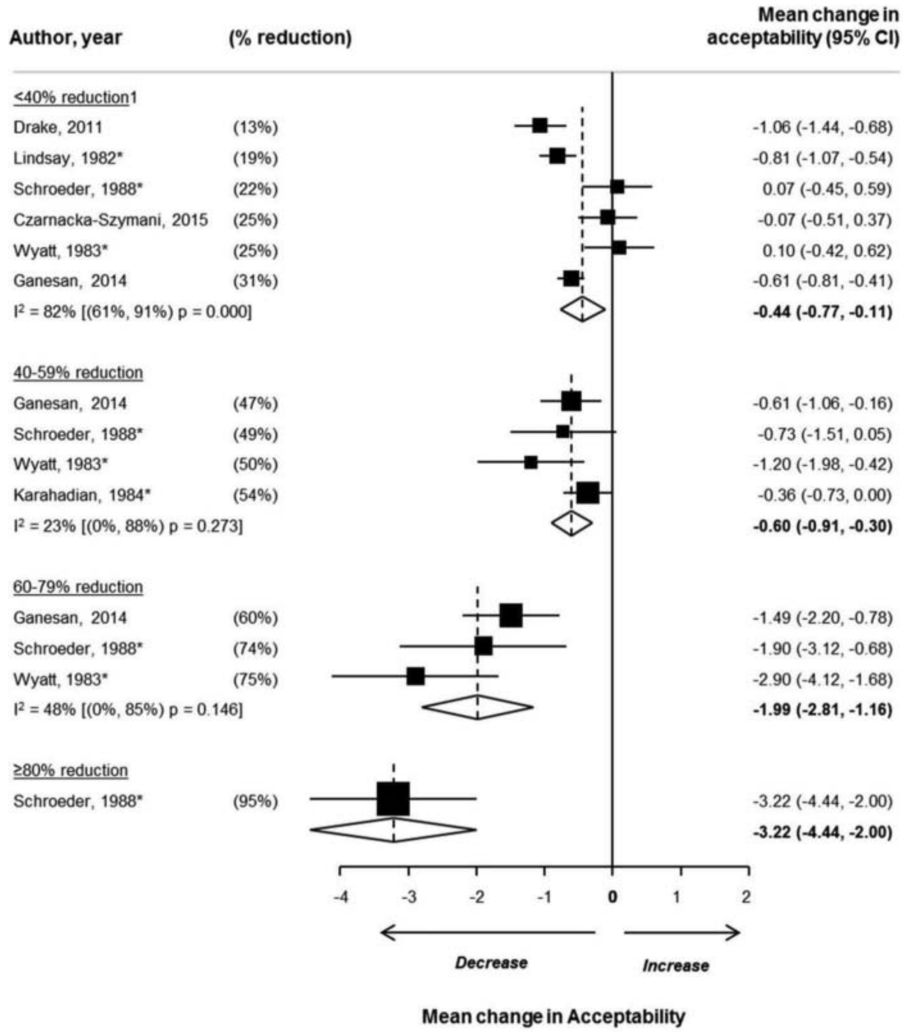

Figure 3. Forest plot for consumer acceptability of salt reduced cheeses. *Imputed standard error for mean change in acceptability.

no difference in acceptability between the flavor-enhanced variant and control.

Soup

One study added glutamate at different concentrations to 43%, 67% and 100% salt-reduced pumpkin soup and found that addition of glutamate, regardless of the concentration, to 43% and 67% reduced salt soup resulted in significantly higher liking scores while reduced acceptability was found with the 100% reduced salt variant (Ball et al., 2002).

Miscellaneous products

Mitchell et al. (2011) found that flavor compensation with yeast extract in a 60% salt-reduced chili con carne ready-meal produced no significant difference in product acceptability compared to the non-salt-reduced control meal.

Assessment of bias

Risk of bias across all studies was generally unclear (66%, $n = 33$), as insufficient detail was provided to assess against risk of bias criteria. One study had high risk of bias as panellists were not blinded to the product modification (Table S2). The remainder (32%, $n = 16$) had a low risk of bias. Funnel plots and the Egger test performed on each meta-analysis did not show any evidence of publication bias (all $p > 0.05$).

Discussion

This review investigated the extent to which salt could be reduced in various food products without jeopardizing consumer acceptability.

The number and recency of studies that were identified (82% conducted in the last 10 years, and 66% in the last five) highlights the increasing attention being given to salt reduction as a global public health priority. Further, nearly all of the countries represented in this review have in place voluntary or mandatory sodium targets for food products (Webster, 2014). The studies in this review examined salt reductions of 3–100% in five different categories of processed foods, all of which are important contributors to salt in the diet. Whilst the majority of the studies ($n = 31$) were on salt reduction alone, 20 studies examined the impact of reducing salt using salt replacement and nine using flavor compensation.

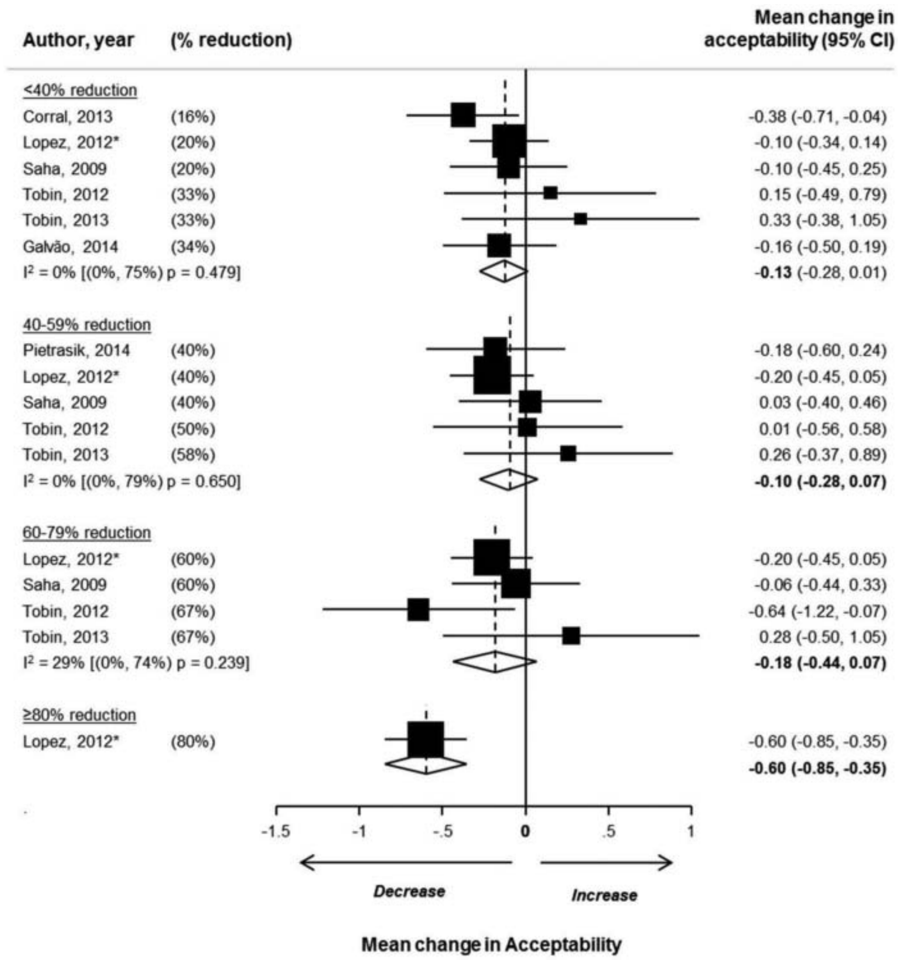

Figure 4. Forest plot for consumer acceptability of salt reduced processed meats. *Imputed standard error for mean change in acceptability.

Meta-analyses of 27 studies investigating salt reduction alone indicated that salt can be reduced in breads and processed meats by up to 37% and 67%, respectively, without a decrease in consumer acceptability. With breads and processed meats being some of the highest contributors to population salt intake (Australian Bureau of Statistics, 2014; Bates et al., 2014; Elliott & Brown, 2007; Health Canada, 2010; Webster et al., 2014), our findings that such large reductions are possible should be encouraging for governments looking to implement national salt reduction strategies as part of programs to reduce the burden of chronic diseases. The results provide robust evidence for manufacturers looking to make salt reductions across the range of product categories which in turn will substantially contribute to a healthier food supply and reduction of population sodium intakes.

Our results show that the effect of salt reduction on consumer acceptability varies according to product type. There are several characteristics which contribute to the overall acceptability of a product, with taste being one of the most important factors in food choice (Liem et al., 2011). Salty taste perception is influenced by factors such as the nature of the food matrix (e.g., perceived saltiness will be greater in an aqueous solution than in a solid at the same sodium concentration), as well as interactions with other taste compounds (for instance sodium suppresses bitterness and thus a reduction in salt will result in increased bitter taste) (Liem et al., 2011). Salt is a major contributor to cheese flavor (Buttriss & Benelam, 2010) and plays a key role in determining the overall liking of cheese (Gomes et al., 2011), meaning slighter reductions are more likely to be easily detected. This may explain the significant decline in acceptability in this category, even at reductions below 20%. On the other hand, processed meats contain several other flavor components, such as seasonings, spices, sugar, other sodium-containing compounds and fat, allowing for greater reductions before acceptability is impacted. Similarly, soup composition varied in complexity however with the limited number of studies there did not appear to be a clear relationship between this and change in acceptability.

It is important to note that consumer acceptability is only one consideration when reformulating food products. Salt has numerous functions that impact upon a food's sensory, quality and technical properties, and this varies by product category. In bread, salt controls yeast growth and fermentation rate, contributes to texture and flavor, and assists in preservation and spoilage reduction (Belz et al., 2012). Whilst salt reduction is unlikely to greatly affect baking performance or microbiological safety and quality outcomes in bread (Braschi et al., 2009; Taormina, 2010), it is suggested that future work consider effects of substantial salt reduction on such factors as staling and shelf-life (Braschi et al., 2009). In cheeses and processed meats, salt plays an integral role in controlling microbial growth, as well as

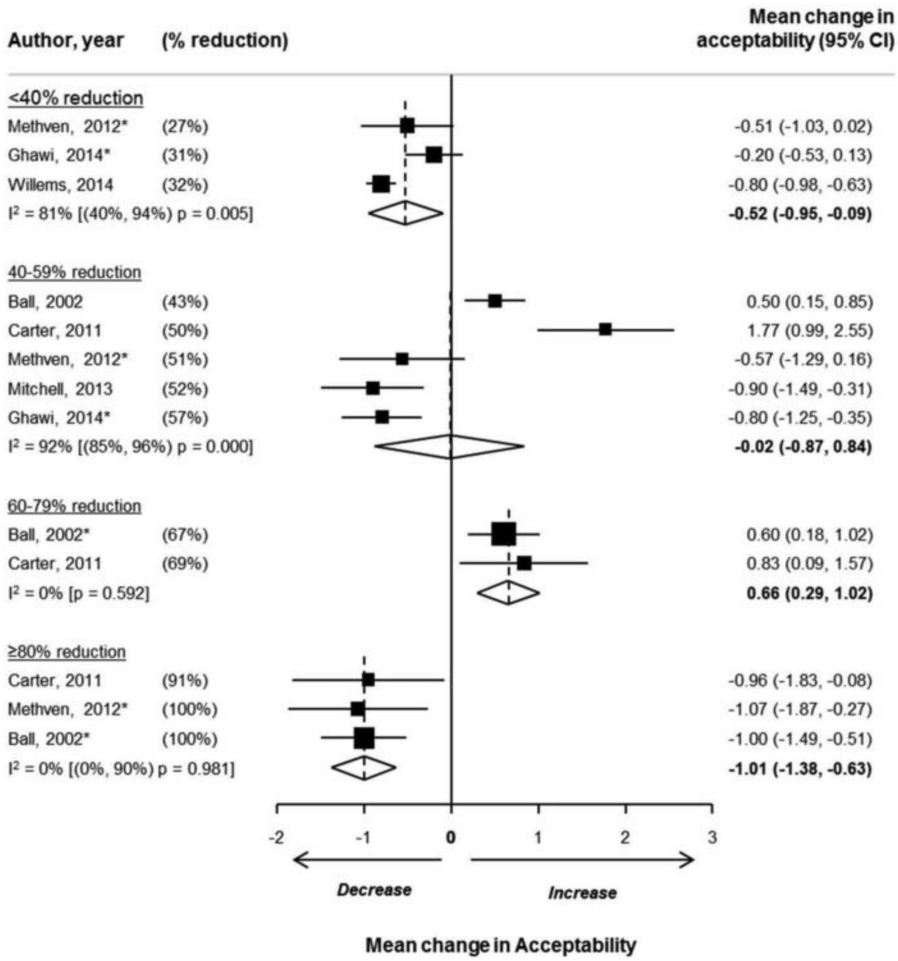

Figure 5. Forest plot for consumer acceptability of salt reduced soups. *Imputed standard error for mean change in acceptability.

influencing texture and consistency (Buttriss & Benelam, 2010; Cruz et al., 2011; Desmond, 2006; Doyle & Glass, 2010), any of which may be compromised with a reduction in salt. It is therefore necessary to investigate these factors to ensure acceptable parameters are maintained (Desmond, 2006; Dötsch et al., 2009).

Among the most common strategies to counteract the effect of reduced salt content on flavor is the use of salt replacers and flavor enhancers. Our results indicate that the use of KCl, one of the most common salt replacers (Desmond, 2006), had no significant impact on acceptability of meat products with up to 50% replacement. There were no studies which investigated replacement above this level, likely since it would result in a significant increase in bitterness and loss of saltiness (Desmond, 2006). It is similarly suggested that a residual sour flavor can occur in cheeses with greater than 50% KCl substitution (Cruz et al., 2011); in our review, four of the six cheeses with 50% or more of NaCl replaced with KCl demonstrated significantly reduced acceptability while there was no difference in those with 25–30% replacement. Flavor enhancers are suggested for use when salt reduction is greater than 25% (Christopher & Wallace, 2014), however in our review this was found to successfully maintain or improve acceptability in only half of the instances they were used. Whilst these strategies have potential to retain the acceptability of some salt-reduced products, there are associated barriers. They may increase production costs and bring about consumer concern regarding the use of ingredients perceived as "unnatural" (Dötsch et al., 2009). Further, salt replacers retain salty taste and thus do not shift taste preferences away from salty foods (Cobcroft et al., 2008; Ruusunen & Puolanne, 2005).

This review indicates that substantial salt reductions can be achieved for bread and processed meat products without jeopardising consumer acceptability while other product categories had less conclusive results and may require a different approach such as making changes gradually and over time (Buttriss & Benelam, 2010; Liem et al., 2011; Ruusunen & Puolanne, 2005). It is reported that repeated exposure to low sodium foods or diets results in increased sensitivity to salty taste, which may in turn lower the threshold for saltiness detection without change to acceptability (Dötsch et al., 2009). In this review, four studies explored extended exposure to bread or soup, finding that product acceptability was maintained or improved from baseline following three to eight weeks' exposure (Bolhuis et al., 2011; Girgis et al., 2003; Kremer et al., 2013a; Methven et al., 2012). Most importantly, to ensure that consumers adapt to diets substantially lower in salt, a whole-of-industry approach needs to be adopted (Cruz et al., 2011; Dötsch et al., 2009), which is likely to require strong strategic focus and direction from governments and other leaders, and may be achieved more effectively through regulation (Trieu et al., 2015; Webster et al., 2014). In addition, educational campaigns and product labelling should be implemented in parallel in order to raise awareness and shift consumer perceptions regarding the health benefits and create increased demand for low salt products (Cruz et al., 2011).

Limitations

There were some limitations which impacted the ability to draw firm conclusions with regard to the impact of salt reduced products on consumer acceptability for some product categories. Meta-analysis was performed on 36 eligible studies that investigated salt reduction across similar products and provided an estimate of mean difference in acceptability before and after the salt reduction, leaving approximately 25% of studies ineligible for inclusion due to the variation in product type as well as strategies and agents used. As the different food categories could not be directly compared, four separate meta-analyses were required, with between four and seven studies in each. Further, several studies investigated multiple products and/or levels of salt reduction within the same food category and/or level of reduction. For meta-analyses, only one set of observations per product category and level of reduction could be included to avoid pooling correlated observations given that the same consumers assessed each variant. Thus, we were limited to between two and six studies per level of reduction across all food categories, with some displaying a high level of heterogeneity. We were however able to perform random-effects meta-regression which allowed for all products and levels of reduction, except those in the miscellaneous category, to be considered.

Another limitation was missing data; given that some studies were conducted more than ten years previously, we were unable to make contact with these authors or they were not able to provide the required data. Where data could not be obtained, we were required to impute standard errors to enable meta-analyses. This method is accepted by the Cochrane Collaboration in the event that required data is missing (Higgins & Green, 2011). In addition, for studies where data was imputed, we were able to demonstrate that the direction and significance of change in acceptability was consistent between meta-analysis and individual study results, thus confirming validity of this method.

Lastly, it is possible that findings of this review are not generalizable to the entire population or representative of all food product categories across regions or countries. The majority of identified studies were conducted in European or Americas regions, likely because our search was limited to English-language databases, potentially excluding studies conducted in other countries and not published in English. Further, many other unpublished consumer acceptability studies may have been conducted by food product manufacturers which were not covered by this review. We did however conduct assessment of publication bias on each meta-analysis and found no evidence of this.

Conclusions

This review has provided a synthesis and analysis of existing studies, giving evidence that salt can be substantially reduced in bread and processed meats—two of the highest contributors to population salt intake—without jeopardising consumer acceptability. This is important, as an increasing number of national governments are now implementing strategies to reduce population salt intake, including encouraging the food industry to reduce salt in foods. Where the evidence supporting the consumer acceptability of salt reduction in other products is less conclusive, it is suggested that research into novel strategies to reduce salt while maintaining consumer acceptability of products continue. Further studies are warranted to build on our results and investigate the extent of consumer acceptability for salt reduction in other product categories where few studies to date have been conducted.

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