What is the impact of food reformulation on individuals' behaviour, nutrient intakes and health status? A systematic review of empirical evidence

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Summary
Food reformulation aimed at improving the nutritional properties of food products has long been viewed as a promising public health strategy to tackle poor nutrition and obesity. This paper presents a review of the empirical evidence (i.e., modelling studies were excluded) on the impact of food reformulation on food choices, nutrient intakes and health status, based on a systematic search of Medline, Embase, Global Health and sources of grey literature. Fifty-nine studies (in 35 papers) were included in the review. Most studies examined food choices (n = 27) and dietary intakes (n = 26). The nutrients most frequently studied were sodium (n = 32) and trans fatty acids (TFA, n = 13). Reformulated products were generally accepted and purchased by consumers, which led to improved nutrient intakes in 73% of studies. We also conducted two meta-analyses showing, respectively, a −0.57 g/day (95%CI, −0.89 to −0.25) reduction in salt intake and an effect size for TFA intake reduction of −1.2 (95% CI, −1.79 to −0.61). Only six studies examined effects on health outcomes, with studies on TFA reformulation showing overall improvement in cardiovascular risk factors. For other nutrients, it remains unclear whether observed improvements in food choices or nutrient intakes may have led to an improvement in health outcomes.

KEYWORDS
consumer behaviour, food environments, food policy, food reformulation

1 | INTRODUCTION

Noncommunicable diseases (NCDs) are leading causes of death worldwide. In Europe, a quarter of NCD deaths are attributed to poor diet through an increased risk of diabetes, obesity, cardiovascular disease and other conditions, so improving diets can reduce the burden of NCDs. Exposure to a healthy food environment has been shown to be a stronger driver of healthy eating than health promotion and education efforts.2,3 Food environment interventions include changes to the availability, price, information or composition of food products. For example, food environments can be changed through reformulation of packaged and processed foods. Reformulation, in the context of the prevention of NCDs, is defined as a change in the nutrient profile of a food with the goal of making it healthier for consumers. If successful, food reformulation strategies will improve...
dietary intakes by changing the composition of foods without changing consumers’ eating habits.

Food reformulation strategies became popular in the mid 2000’s when governments and manufacturers focused on the removal of industrially produced trans fatty acids (TFA) and the decrease in salt content of manufactured products. Given that an average of 46% of daily energy intakes in Europe is from processed foods, reformulation has the potential to improve the dietary intakes of the population, if applied consistently.

1.1 | The role of food reformulation in public health

Food reformulation can take many forms and can be driven by different motivations and incentives. A public health model of food reformulation typically involves the enactment of policies deploying regulation or incentives leading manufacturers to improve the nutritional properties of food products by changing their composition. Reformulated food products would replace, rather than add to, preexisting versions of the same products and would be marketed in ways that would preserve consumers’ acceptance and liking of the products after reformulation, for example, through gradual and ‘silent’ reformulation that would not be perceived by consumers as altering the food product’s sensory characteristics. Reformulation would, in this way, change dietary intakes without significantly altering food choices, potentially leading to health improvements.

In practice, however, food reformulation initiatives often deviate from the model described above, even when they retain a public health goal. A common deviation is that reformulated products add to preexisting versions (which should be more appropriately labelled as diversification of food products, rather than reformulation) compounding food choices and their impacts on dietary intakes. This strategy can be favoured by manufacturers as adding products create product diversity that can be a source of increasing sales. When this happens, marketing strategies may actively encourage consumers to switch to the reformulated versions of their products, which may trigger a wider range of substitutions in consumers’ food choices. In addition, food reformulation may not be prompted by an explicit government policy but rather be driven by voluntary agreements, industry pledges, corporate social responsibility motivations, which often involve less systematic approaches and a reduced scope for food reformulation.

This review is not limited to one or another approach to food reformulation. However, the approach taken may contribute to determining the effectiveness of food reformulation in improving dietary intakes and health outcomes; therefore, this dimension was assessed qualitatively in the review.

1.2 | Existing systematic reviews

Several systematic reviews have studied the effect of reformulation (sometimes amongst other policies) on the consumption of specific nutrients, mainly sodium, TFA, and more recently sugar. Reformulation was effective to reduce populations’ sodium intakes, with a greater reduction observed in countries where reformulation is mandatory compared to countries where it is voluntary. Similarly, the reduction of TFA intakes was greater in countries where TFA reduction is mandatory, than in countries where it is voluntary, or in countries implementing solely labelling policies. Overall, these reviews show that reformulation is most effective in improving dietary intakes when part of multiple-component interventions designed to change the food environment. The systematic review on the effect of sugar reformulation reported that reformulation could lead to reductions in sugar intakes and in body weight. However, these findings derive from studies in controlled environments; the effect of reformulation implemented as a population-wide intervention may be different. Previous reviews on food reformulation do not investigate consumers’ reactions to reformulated foods, such as consumers’ long-term acceptance of reformulated products. Consumer acceptance is a key driver of the effectiveness of reformulation in changing dietary intakes, in the absence of which unwarranted substitutions may take place. Also, no review included at the same time outcomes related to consumer choices, dietary intakes and health outcomes, the three steps through which reformulation may have an impact on public health.

1.3 | Aim of this review

This review aims to assess the empirical evidence of the impact of food reformulation on food choices, nutrient intakes and health status, with no restriction on the type of reformulation strategy employed, nor the nutrient targeted. When possible, we also report the effect of reformulation strategies on children.

2 | METHODS

The systematic review methodology was adapted from the Cochrane methodology for systematic reviews. The protocol is published in the PROSPERO database (CRD42019127624), and the reporting adheres to the Preferred Reporting Items for Systematic Review and Meta-analysis Protocols (PRISMA) statement.

2.1 | Eligibility criteria

Eligibility criteria followed the PICO (Population, Intervention, Comparator, Outcome) framework, shown in Table 1. Studies had to be empirical evaluations of an implemented reformulation intervention, targeting the general population. We only included empirical evidence and excluded studies modelling the expected result of a...
TABLE 1  PICO (population, intervention, comparator, outcome) table for the selection of studies

| PICO Feature | Criteria |
|--------------|----------|
| Population   | General population (subgroup analysis for children if possible). Studies focusing on the effect in specific subgroups with medical conditions were excluded. |
| Intervention | Reformulation interventions include those targeting packaged foods and/or beverages, or food sold in restaurant chains. Reformulation at a population-scale can be driven by mandatory or voluntary targets, labelling, self-regulation or public-private partnerships (PPP). Studies evaluating consumer reaction to reformulated products in lab-experiments will be included though will be analysed separately from policies implemented at population-level. |
| Comparison   | Comparators may include no intervention or a comparison of the same group before the implementation of the intervention. |
| Outcomes     | Studies must focus on food product choices, nutrient intakes or long-term outcomes linked to noncommunicable diseases. Primary outcomes include choice behaviour (purchases and sales), dietary intakes and patterns, risk factors for non-communicable diseases (BMI, blood pressure, biological markers of dietary intakes) or health outcomes (mortality). Excluded outcomes: Changes in awareness, knowledge or beliefs, measures of liking, studies with non-quantitative outcomes, and studies evaluating only the change in food composition but not the change in consumer behaviour. |

We employed keyword searches through EMBASE, MEDLINE and Global Health for peer-reviewed studies published until December 2018 (the search strategy for Medline is available in Appendix A). The search strategy was refined by conducting sensitivity analysis in EMBASE with a test set of 15 key papers. Adjustments to the search strategy concluded once 85% of the key papers were identified. We also included references from four relevant systematic reviews. Grey literature was searched using the NOURISHING database of reformulation initiatives and following advice from experts.

2.3  |  Screening, data extraction and data synthesis

Studies retrieved from the searches were sequentially screened by title, abstract and full text by one author (MG). A second author (ABS) independently reviewed a sample of 10% of studies based on titles and abstracts. The full text of all studies included by the first author were screened by the second author.

We extracted data about intervention, study design and outcome from the included papers; data on subgroups of the population (defined by age, sex and socio-economic status) were extracted when available.

For studies similar enough to be pooled, we performed a meta-analysis using inverse-variance weighting with random effects. Mean differences were used when outcomes were reported in the same unit. Standardized mean differences (Hedge’s g) were used otherwise as a measure of the effect size. Between-study variance was estimated using restricted maximum likelihood as recommended for continuous outcomes. Heterogeneity was assessed with the I² statistics, and meta-regression was performed to explain heterogeneity. Sensitivity analyses were conducted by restricting the sample to studies with the least risk of bias (see section below). Publication bias was assessed with funnel plots. Otherwise, a narrative review was used to qualitatively analyse extracted data.

2.4  |  Risk of bias assessment

Risk of bias for each study was assessed using an adapted version of the Newcastle-Ottawa Scale (NOS) for assessing the quality of non-randomized studies, given that most studies were designed as natural experiments. Studies were rated on four domains: selection (representativeness of the sample and ascertainment of exposure), comparability of the two groups, outcome (ascertainment of outcome and
duration of follow-up) and adjustment (control for confounders and evaluation of reformulation independent of other mechanisms). An overall score was then calculated (out of seven), reflecting decreasing levels of risk of bias.

3 | RESULTS

The search strategy retrieved 11,315 studies from the three databases. Searching the grey literature and the reference list of included studies led to the addition of 29 papers (PRISMA flow chart13 in Figure 1). After a full-text review of 177 papers against eligibility criteria, 35 papers were included for the review (listed in Appendix B). The 35 papers reported on 32 distinct reformulation initiatives. However, as some of the papers analysed the effect of reformulation on multiple outcomes or nutrients, we included a total of 59 studies in this qualitative analysis.

The majority of studies reported on either the choice and acceptability of reformulated foods (n = 27)15–30 or nutrient intakes (n = 26) in the context of reformulation.5,18,24,25,29,31–42 Only six studies reported on outcomes linked to reduction of NCD burden such as diet-related risk factors or diseases.43–48 The majority of studies were conducted in high-income countries; only three of the 59 studies were conducted in upper-middle-income countries (Costa Rica and Turkey) (Appendix C). Three of the 32 initiatives were mandatory (i.e., bans on the use of TFA), 19 resulted from a rise in consumer awareness (through public health campaigns or nutrition labelling), six were designed as public-private partnerships (with targets to incentivize manufacturers to reformulate their products), two were manufacturer-led and one was a real-condition experiment led by a research group (Appendix C).

The adapted NOS risk of bias tool was effective in differentiating the risk of bias between studies (Appendix D). The domain representing the higher risk of bias was the adjustment domain, with only seven papers (16%) having a point in the two criteria of the domain (adequate control for confounders: 34%, and evaluation of reformulation prevented from other input 27%). Other domains from the risk of bias scale had better compliance, with between 64 and 80% of papers with a low risk of bias.

3.1 | Effect on consumer behaviour and food choices

Overall, reformulated food products were accepted and consumed by the population, that is, when food products were reformulated; those products were purchased, resulting in an improved composition of the population purchases. This means that reformulation did not trigger specific behavioural response. A favourable change in the composition of a food category or of household's basket of purchase was observed in 22 of 27 studies after products were reformulated (Table 2). In those studies, the nutrient content of individual products was weighted by their sales (or purchased quantities) to have a measure representative of households' intakes.

Studies reporting on the acceptability of reformulated products analysed sodium (n = 10), TFA (n = 3), energy reductions (n = 3), fibre (n = 2) or whole grain (n = 2) increases, or an improvement in several nutrients at the same time (n = 5). The extent to which
foods were reformulated changed depending upon the nutrient targeted by reformulation initiatives (i.e., the relative change was different across nutrient targeted). For example, the percentage reduction of TFA in reformulated products (between 80% to almost 100%) was substantially larger than that of reductions in total energy (reductions of around 0.4%–3%27,30) or sugar (reductions of around 2%–3%17,21). The extent to which foods were reformulated also depends on the food category. For example, categories that had the most important salt reduction were cereal products, soups, sauces or cold cuts.17,24,25,30 There was evidence that the larger the improvement of the composition of the food, the larger the effect was on consumers’ purchases: For example, intense reduction in food TFA led to large reduction in TFA purchase (restriction of restaurants TFA to 0.5 g/serving led to a 85% reduction in TFA purchases from restaurants in New York City16); whereas modest reductions in food energy density led to smaller reduction in energy density of total purchases (Clapp et a)23 observed an overall reduction of 1.1% in total purchase, following reductions in foods of around 0.1% to 4.4%).

### 3.2 Effect on nutrient intakes

Twenty-six studies reported the effect on nutrient intakes; 70% of these studies concluded that reformulation led to improved intakes of the relevant nutrient (Table 2). Studies that used biomarkers (from blood or urine) or reported measures (dietary surveys or total purchases taken as a proxy) of nutrient intakes showed similar positive results, with 77% and 69%, respectively (Appendix E). Most of these studies were focused on sodium (n = 20); and of these studies, 13 reported reduced sodium intakes, ranging from a decrease in sodium intake between 4% and 15% per year (Table 3, and meta-analysis below for estimates of mean differences). Five studies evaluated the effect of TFA reduction and again reported positive effects, ranging from a total decrease between 38% and 85%, measured over a range of seven to 19 years (Table 3). No studies investigated the effect of sugar or energy reformulation on dietary intake.

Pooled effects were estimated for the effect of reformulation on salt and TFA intakes. Overall, reformulation led to a significant decrease in salt intakes of 0.57 g/day (95% Confidence Interval −0.89 to −0.25)

### Table 2

| Characteristics                        | All Outcomes, n | Acceptability<sup>a</sup> | Intake<sup>b</sup> | Morbidity/Mortality |
|----------------------------------------|----------------|---------------------------|-------------------|---------------------|
|                                        | Studies, n     | Positive Results, %        | Studies, n        | Positive Results, %  |
|                                        | Positive Results, % | Positive Results, % |          |
| Total                                  | 59             | 27                         | 81                | 26                  | 73                | 6                  | 83                |
| Effect of reformulation isolated       |                |                            |                   |                     |                   |                   |
| No                                     | 41             | 16                         | 100               | 22                  | 73                | 3                  | 67                |
| Yes                                    | 18             | 11                         | 55                | 4                   | 75                | 3                  | 100               |
| Nutrient studied                        |                |                            |                   |                     |                   |                   |
| Salt (sodium)                          | 31             | 10                         | 90                | 20                  | 65                | 1                  | 100               |
| TFA                                    | 13             | 3                          | 100               | 5                   | 100               | 5                  | 80                |
| Several nutrients<sup>c</sup>          | 5              | 5                          | 80                |                     |                   |                   |
| Energy                                 | 3              | 3                          | 100               |                     |                   |                   |
| Sugars                                 | 3              | 3                          | 33                |                     |                   |                   |
| Fibres                                 | 2              | 2                          | 50                |                     |                   |                   |
| Whole grains                           | 2              | 1                          | 100               | 1                   | 100               |                   |
| Type of reformulation                  |                |                            |                   |                     |                   |                   |
| Mandatory limit                        | 5              | 1                          | 100               |                     |                   | 4                  | 75                |
| Voluntary reformulation<sup>d</sup>    | 54             | 26                         | 81                | 26                  | 73                | 2                  | 100               |

Note. Positive results were defined as a significant change in average nutrient density of purchased products or a change in nutrient intake going in the direction of an improvement for public health (i.e., reduction for sodium, TFA, energy or sugars, increase in fibres or whole grains and improvement of the nutrient profile of foods), or a reduction in disease risk or mortality.

<sup>a</sup> Acceptability of reformulated products was either measured using sales/purchases of the reformulated product before and after reformulation and the evolution of market-share weighted averages of a nutrient content before and after reformulation.

<sup>b</sup> Intakes were measured by means of traditional methods (dietary survey and biomedical measures) or by evaluating the nutrient content of all purchased items by households representative of the population.

<sup>c</sup> Several nutrients’ is used either for measures of nutrient profile (e.g., score) or when several nutrients where evaluated jointly.

<sup>d</sup> Voluntary reformulation can be triggered via commitment, or the implementation of labelling.
| Nutrient       | Study                          | Country       | Measurement Method | Time Evaluated | Effect of Reformulation Isolated | NOS Score | Effect on Intakes—a  | Effect Size—b |
|---------------|--------------------------------|---------------|-------------------|----------------|----------------------------------|-----------|---------------------|---------------|
| Sodium        | McLaren et al[5]              | Austria       | 24-h dietary recall | 4 y           | No                              | 0         | −1.8% NS            | −1.8% NS      |
|               | McLaren et al[5]              | Switzerland   | 24-h urine sample  | 27 y          | No                              | 2         | +9.5%b              |                |
|               | McLaren et al[5]              | Netherlands   | 24-h urine sample  | 4 y           | No                              | 4         | 0.0% NS             | 0.0% NS       |
|               | Temme et al[35]               | Netherlands   | 24-h urine sample  | 9 y           | No                              | 4         | 0.0% NS             | 0.0% NS       |
|               | McLaren et al[5]              | USA           | Spot urine         | −20 y         | No                              | 4         | −4.0% NS            | −4.0% NS      |
|               | Poti et al[18]                | USA           | Purchases-adjusted 24-h dietary recall | 5 y           | No                              | 5         | −0.0% NS            | −0.0% NS      |
|               | McMahon et al[29]             | Australia     | Sales-adjusted content | 18 weeks     | Yes                             | 5         | −2.5% NS            | −2.5% NS      |
|               | McLaren et al[5]              | Turkey        | 24-h urine sample  | 4 y           | No                              | 0         | −10.0% NA           |                |
|               | McLaren et al[5]              | Ireland       | FFQ                | 5 y           | No                              | 2         | −4.3%b              |                |
|               | Curtis et al[24]              | USA           | Sales-adjusted content | 5 y           | No                              | 3         | −6.8%b              |                |
|               | McLaren et al[5]              | Denmark       | Spot urine         | 4 y           | No                              | 3         | −7.4% NA            |                |
|               | Millett et al[42]             | UK            | Spot urine         | 4 y           | No                              | 4         | −14.0%b             |                |
|               | McLaren et al[5]              | UK (GB)       | 24-h urine sample  | 8 y           | No                              | 5         | −9.3%b              |                |
|               | McLaren et al[5]              | Finland       | 24-h urine sample  | 7 y           | No                              | 5         | −9.8%b              |                |
|               | McLaren et al[5]              | France        | 7-day open-ended survey | 8 y           | No                              | 5         | −5.8%b              |                |
|               | He, 2014 [41]                 | UK            | 24-h urine sample  | y             | No                              | 5         | −15.0%b             |                |
|               | Shankar et al[34]             | UK            | Spot urine         | 4 y           | No                              | 5         | −10.0%b             |                |
|               | Griffith et al[29]            | UK            | Purchases-adjusted content | 6 y           | Yes                             | 6         | −5.1% NA            |                |
|               | Eyles et al[25]               | UK            | Purchases-adjusted content | 5 y           | No                              | 6         | −7.0% NA            |                |
|               | Poti et al[18]                | USA           | Purchase-adjusted content and total sodium purchased | 15 y       | Yes                             | 7         | −12.0%b             |                |
| TFA           | Monge-Rojas et al[31]         | Costa Rica    | 3-day dietary record | 10 y         | No                              | 2         | +                   | −38.0%b       |
|               | Friesen et al[27]             | Canada        | TFA in breastmilk  | 7 y           | No                              | 2         | +                   | −45.0%b       |
|               | Ratnayake et al[23]           | Canada        | TFA in breastmilk  | 19 y          | No                              | 3         | +                   | −85.0%b       |
|               | Vesper et al[26]              | USA           | Blood fatty acids  | 9 y           | No                              | 6         | +                   | −53.0%b       |
|               | Hutchinson et al[41]          | UK            | Food diaries (7 and 4 days) | 10 y         | Yes                             | 6         | +                   | −55.0% NA     |
| Whole grains  | Greve and Neess[38]           | Denmark       | Market shares-adjusted dietary surveys (7-day diary) | 6 y           | No                              | 5         | +                   | +75.0% NA     |

Note. Intakes were measured by means of traditional methods (dietary survey, measures of biomarkers) or by evaluating the nutrient content of all purchased items by households representative of the population.

Abbreviations: FFQ, Food Frequency Questionnaire; GB, Great-Britain; NOS, Newcastle-Ottawa Scale; TFA, trans fatty acids; y, years; NS, nonsignificant; NA, not applicable.

—A positive effect on intake was defined as a significant change in average nutrient density of purchased products or a change in nutrient intake going in the direction of an improvement for public health (i.e., reduction for sodium and TFA and increase in whole grains).

—Significant at (at least) 5%. Statistic tests were not performed in the study.
The positive effect was greater for studies that measured salt purchased by households (−1.04 g/day 95% CI, −1.11 to −0.97) versus those studies that measured salt intake using 24-h urinary excretion (−0.47 g/day 95% CI, −1.13 to +0.18). There was a high heterogeneity across all salt studies ($I^2 = 98\%$). This was expected given the various nature of the reformulation initiatives implemented: category coverage, targets and baseline intake of populations varied between studies. The method used to estimate salt intake or the duration of the intervention could not explain this heterogeneity: findings were statistically similar both when stratifying by method used and by duration of intervention (see meta-regressions in Appendix F). The effect was stronger when studies with the least risk of bias (NOS score >2) were selected (Appendix G). No publication bias was detected as studies were symmetrically distributed around the pooled estimate (Appendix H), Egger’s test showed no evidence for small study effect. Reformulation of TFA also led to a significant reduction in TFA intakes (estimated effect size using Hedge’s $g$ of −1.20, 95% CI, −0.79 to −0.61) (Figure 3). The effect was stronger when the sample was restricted to women (two studies measured breastmilk TFA), and when only studies with the least risk of bias were selected (Appendix G). There were too few studies to investigate heterogeneity, that was high ($I^2 = 99\%$). There was no small study effect (Egger’s test not significant).

### 3.3 Effect on health status

Six studies investigated the empirical impact of reformulation initiatives on health status (i.e., morbidity and mortality), with five of these studies showing an improvement in health status (Table 3). Of these six studies, five focused on the effect of TFA, whereas only one focused on the effect of sodium reduction. The morbidity or mortality from cardiovascular diseases was reduced in four of the five studies that evaluated the effect of TFA bans in packaged foods or restaurant foods, where mortality was reduced by between 4.3%–6.2% (Table 4). The sodium reduction study concluded that the effect of the UK intervention had a positive impact blood pressure.

| Study                        | Before intervention | After intervention | Mean Diff. with 95% CI |
|------------------------------|---------------------|--------------------|-----------------------|
|                              | N  | Mean | SD | N  | Mean | SD |
| **24h urine sample**         |    |      |   |    |      |   |
| He, 2014 [40]                | 1,147 | 9.5 | 4.7 | 692 | 8.1 | 5.8 | -1.40 [-1.89, -0.91] |
| McLaren, 2016 (Finland)      | 670  | 11.8 | 4.7 | 400 | 10.6 | 4.1 | -1.15 [-1.71, -0.59] |
| McLaren, 2016 (UK)           | 1,724 | 9.5 | 4.5 | 692 | 8.6 | 4.4 | -0.89 [-1.28, -0.50] |
| Temme, 2017                  | 317  | 9.1  | 3.4 | 289 | 9.0  | 3.6 | -0.10 [-0.66, 0.46] |
| McLaren, 2016 (Netherlands)  | 317  | 8.6  | 3.2 | 342 | 8.6  | 3.4 | 0.00 [-0.50, 0.50]  |
| McLaren, 2016 (Switzerland)  | 147  | 8.4  | 3.6 | 1,448 | 9.2  | 3.8 | 0.80 [0.16, 1.44]  |
| **dietary surveys**          |    |      |   |    |      |   |
| McLaren, 2016 (France)       | 1,345 | 8.0 | 2.6 | 1,922 | 7.5 | 2.3 | -0.46 [-0.63, -0.29] |
| McLaren, 2016 (Ireland)      | 5,992 | 8.2 | 5.9 | 9,172 | 7.8 | 3.7 | -0.35 [-0.50, -0.20] |
| McLaren, 2016 (Austria)      | 2,123 | 8.3 | 3.5 | 380  | 8.1  | 3.0 | -0.15 [-0.53, 0.23] |
| **household purchases**      |    |      |   |    |      |   |
| Griffith, 2017               | 16,664 | 6.5 | 4.0 | 28,767 | 5.5 | 3.5 | -1.08 [-1.15, -1.01] |
| Poti, 2017 [18]              | 33,706 | 6.0 | 0.8 | 58,138 | 5.0  | 2.5  | -1.01 [-1.03, -0.98] |
| **spot urine**               |    |      |   |    |      |   |
| Millett, 2012                | 1,668 | 5.3 | 4.2 | 4,269 | 4.6  | 3.3  | -0.74 [-0.94, -0.54] |
| **Overall**                  |    |      |   |    |      |   |
| Heterogeneity: $I^2 = 0.28, I^2 = 98.30\%, H^2 = 58.94$ | | | |
| Test of group differences: $Q_{(3)} = 100.85, p = 0.00$ | | | |

FIGURE 2  Pooled estimate of the effect of initiatives including salt reformulation on populations’ salt intake (in g/day), by measurement method used to measure a change in dietary sodium.
3.4 Isolated effect of reformulation

It was difficult to isolate the effect of reformulation, as many studies were part of larger initiatives including other components such as labelling or public health campaigns. Overall, the effect of reformulation alone could be observed in 18 studies (30% of all studies) (Appendix C). These studies included designs where the only policy implemented was reformulation or, in the case of...
interventions with different components, the effect of reformulation was isolated from the effect of the other components. These studies evaluating only the effect of reformulation were less likely to report positive results on the acceptability of reformulated products, although more likely to report improvement of health outcomes, compared to other studies. Studies not isolating the effect of reformulation reported on an effect that can be the result of reformulation, and other strategies (in the case of multiple-component interventions, or by other uncontrolled inputs such as a change in advertising) (Table 2).

3.5 | Effect on subgroups of the population

Only three studies evaluated the effect of interventions specifically in children or adolescents.31,32,38 Studies showed similar effects across age groups. The majority of studies did not report results by gender.

4 | DISCUSSION

Overall, reformulated products were accepted by consumers, although evidence differs by nutrient. Several studies (10) showed that salt-reduced products were accepted, whereas a limited number of studies found that products reduced in sugar or increased in fibres were less likely to be accepted by consumers. Acceptance in this context means that the reformulated food product led to an improved nutrient composition of total food purchased and hence in intakes. Compensation (overconsumption or a change in dietary patterns such as a switch towards non-reformulated products) did not offset the benefits of reformulation (70% of studies showed a positive overall effect of reformulation). Nonetheless, compensation did occur (e.g., for salt) in some studies in which reformulation did not lead to decreased intakes or led to a smaller decrease than predicted from changes in food composition.18,35 Two studies showed that the effect of reformulation was partly offset by consumers switching to less-healthy options.20,39 Studies using experimental settings found that while abrupt reformulation was noticed by consumers and led to compensation,49,50 silent reformulation did not lead to compensatory behaviours hence reduced intakes of sodium or saturated fatty acids.51,52

Due to the variability in initiatives’ nutrient focus and scope (number of categories and type of foods targeted), it was not possible to quantify compensatory behaviours or to identify the specific context in which compensation occurred. For example, as there was no study on the impact of sugar reduction strategies on intakes, we cannot assess whether consumers would compensate by choosing alternative products with higher sugar content. However, most studies reported an improvement in dietary intakes, confirming that reformulation can lead to a positive change in dietary habits.

4.1 | Health outcomes

Five of six studies examining health outcomes show that reformulation can provide health benefits by improving the nutritional properties of foods.53 However, a link between reformulation and health outcomes was only observed for TFA reformulation, and it cannot be generalized to other nutrients. The extent of the reformulation was also a factor driving impact on health outcomes. The combination of a complete removal of TFA from the food supply in some countries, in addition to the strong correlation between TFA intake and health,54 created the conditions for a measurable impact on health. The reformulation of the whole nutrient profile of foods is challenging as most nutrients (sugars, fats, fibres or sodium) play a role in texture, stability and taste of products.55 Also, although products containing artificial TFA are easy to identify, defining what foods should be included in strategies targeting different nutrients is more difficult as nutrients such as sugars or salt are naturally present in foods. Reformulating a food product with the objective of modifying one nutrient has consequences on the whole nutrient profile of the food, as often the quantity of other nutrients needs to be adjusted.56 The fact that the health impact of diets is not mediated solely through one nutrient may explain the difficulty to observe any health impact of the reformulation of single nutrients. Sodium reformulation was done with the use of salt substitutes, and with gradual reductions of the salt intensity. Contrarily to TFA reformulation, sodium reformulation was gradual, possibly the reason why it is more difficult to evaluate the health impact of sodium reformulation.

4.2 | Intervention designs

This review suggests that to have the expected favourable impact on consumers’ intakes and health, reformulation interventions should have large scope across and within food categories that are the major sources of the targeted nutrient. This is because the effect of reformulation can be offset if consumers switch to similar products that have a worse nutrient profile. For all nutrients, it appeared that a reformulation across the maximum of food products, and covering most of food categories (and at a measurable size) was needed to see significant changes.18,21,35 The absence of effect was often explained by a small proportion of products reformulated, or a too slow pace.18,35,57 Strategies are generally designed to promote the reformulation of the foods that represent the leading sources of the targeted nutrient. Foods reformulated to reduce TFA were mostly margarines, fried products, or biscuits although most countries had a limit (either a ban or a 2% of fat limit) applying to all processed foods sold in retail and restaurants. Foods most often targeted in reformulation programmes for the reduction of sodium intakes were cereal products, processed meats and soups. Foods such as biscuits or prepared meals were included in strategies focusing on multiple nutrients, as these foods can be
at the same time sources of salt, sugar and TFA. Reformulating a comprehensive range of food products limits the possibility for consumers to switch to alternative sources of the targeted nutrient (e.g., nonreformulated foods).

4.3 | Different reformulation approaches

Reformulation policies have been mostly implemented at the country level. However, a large part of processed foods is produced by companies operating in different countries. Studies have shown that there are differences in the composition of similar products across different countries: even if they carry the same brand, some products have different formulation to adapt to local preferences, production capabilities or the regulatory environment. Where TFA reformulation was voluntary, studies showed that reformulation of TFA in restaurants was shown to have had a positive impact on health outcomes. Relevant out-of-home settings include canteens (in workplaces or schools), restaurants, fast-food outlets or street vendors. Foods provided in these settings can be industrially produced and can be distributed and advertised similarly to packaged foods for home consumption. These characteristics make foods consumed out-of-home suitable targets for reformulation policies. Foods in out-of-home settings have been targeted specifically (e.g., TFA ban in New York restaurants or food standards in schools) or as part of wider reformulation policies (e.g., the UK sugar reduction initiative targets retailers, manufacturers and foods sold for out of home consumption).

4.5 | Reformulation in the context of wider policies

Reformulation initiatives were often employed in conjunction with other initiatives, most commonly, initiatives to inform and educate consumers. Nation-wide reformulation initiatives for the reduction of sodium and TFA were deployed with public health campaigns that informed consumers about the harmful effects of excessive intake of those nutrients. Further, front of pack labelling, claims or logos incentivized manufacturers to reformulate their products so that they attract consumers.

Systematic reviews on sodium and TFA showed that multicomponent strategies including a reformulation scheme were the most promising to improve diets. In particular, interventions including regulations to change the price or composition of foods (i.e., changing the structure of the food environment) had a greater impact than interventions focusing only on education. This suggests that changes in behaviour (compensation) occurred more often when there was no counterintervention to raise population's awareness to dietary choices, highlighting the need for reformulation to be embedded in wider initiatives comprising education components.

4.6 | Reformulation alone is unlikely to reduce energy intake

Although reformulation is a promising strategy to improve the nutrient profile of foods, it is unlikely to lead to major reduction in the energy density of the food environment (i.e., reformulation is not contributing to obesity prevention). Most often, reformulation strategies included in this review led to products with the same energy density. For example, if a strategy aimed to reduce sodium, TFA or sugar, the energy density of the product would be unchanged following the reduction of the respective nutrient. Reformulating foods to decrease a certain macronutrient is often done by substituting it with a macro-nutrient of the same energy density (e.g., TFA was replaced with other types of fat and sugars by carbohydrates, with the total energy density held constant). One way to decrease energy density of a product is to substitute its sugars with fibres, as fibres provide less energy than sugar for the same weight. Given that reformulation is a strategy designed to gradually improve the food environment, reformulation may be an inadequate strategy to reduce total energy intake of individuals via decreasing the energy density of foods. This is mainly because it is unlikely that major reductions in energy density of products can be achieved in without changing the sensory characteristics of that product, especially texture and taste. An exception could be reformulation of sugar-sweetened drinks, where the replacement of sugar with no-calorie sweeteners decreases the energy content of the drink. This reformulation is easier to implement than reducing sugar in solid foods, as highlighted by the latest report from Public Health England about their sugar reduction programme: the sugar was reduced by 3% in foods, but by 29% in beverages. To
reduce energy intake of populations, other strategies are needed, such as reducing portion sizes of products, and promoting healthier alternatives to energy-dense foods.65

4.7 | Strengths and limitations of the review

This review is the first to evaluate the impact of reformulation interventions, regardless of the nutrient targeted. This approach allows us to make conclusions regarding reformulation as a specific strategy to improve food environments and populations’ health. By looking at three different outcomes (purchases, intakes and health status), this review contributes to the evidence needed to better understand the impact of reformulation on population health. However, our review is subject to limitations. Firstly, there is not equal representation of reformulation on all nutrients, meaning that evidence on reformulation of TFA and sodium are overrepresented. Secondly, some studies relied on labelled nutrient content in foods to measure changes, which can produce a biased measure, as nutrition labels allow for a margin of error between labelled content and actual content.66 This margin of error may not allow the detection of small reformulations that would not require a change in labelling (and hence representing a saving for manufacturers). Thirdly, we could only tease out the effect of reformulation alone on a small proportion of studies (n = 18), of which only seven appropriately controlled for confounders. Finally, we were able to perform a meta-analysis for only two of the included outcomes. Pooled estimates were different by measurement method used, highlighting the systematic bias associated with some methods (e.g., dietary surveys underestimate table salt use).

Further studies are needed to fill the gaps highlighted in this review, as there is missing evidence about the efficacy and impact on dietary intakes (and health) of sugar, fibre reformulation policies. However, population-based monitoring is generally not sensitive enough to link reformulation to health outcomes. Also, studies are needed to understand the impact of reformulation on the whole diet and not only on the nutrient targeted by the reformulation strategy. The impact of reformulated foods on consumer choices is also poorly understood; studies on this topic could help to design effective policies where the reformulation of foods would have an impact on consumers diet.

5 | CONCLUSION

The evidence base examined in this review shows that food reformulation has the potential to improve people’s diet and health. Changes in the nutrient composition of food products translate into changes in the balance of nutrients from food purchased by consumers. Overall, the evidence shows that a reduction in sodium or TFA contents in foods results in a change in the intakes of those nutrients. Further, reductions of TFA in foods tend to be associated with decreased mortality from cardiovascular diseases at a population level. However, many reformulation initiatives lack a robust evaluation of their impacts on food choices, dietary intakes and health. Therefore, our conclusions are based on a subsample of reformulation initiatives and are not necessarily generalizable to all reformulation initiatives. Due to the small number of studies, it was not possible to draw conclusions on the impact of reformulation on children’s diet and health, though the three studies included investigating the effect of reformulation on children suggest that results are similar across age groups.

Although reformulation may be helpful in changing the consumption of some nutrients (including TFA, sodium, sugar or fibres), it is not enough to tackle obesity as a global issue, especially for children. Given the challenges involved in changing behaviours and food choices, reformulation can provide the means to improve dietary intakes and health by changing the environment in which people make their food choices. Nonetheless, the success of reformulation as a public health strategy crucially depends on the breadth of products reformulated and the extent to which they are reformulated.

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APPENDIX A: SEARCH STRATEGY ON MEDLINE FOR PART ONE (SYSTEMATIC REVIEW ON REFORMULATION)

1   sodium, dietary/ or Sodium Chloride/ or sodium chloride, dietary/ or exp ENERGY INTAKE/ or dietary fats/ or Fats, Unsaturated/ or Fatty Acids, Unsaturated/ or Dietary Sugars/ or Dietary fiber/ or exp Nutritive value/ or whole grains/ or dietary carbohydrates/or dietary proteins/

2   (salt or sodium or sugar" or energy or calori" or saturated fat" or "trans fat" or trans?fat or fibre" or fiber" or whole?grain" or wholegrain" or "whole grain" or carbohydrate" or protein" or fatty acid" or nutrient").ab.

3   1 or 2

4   reformulat*.ab.

5   3 and 4

6   ((salt or sodium or sugar" or saturated fat" or "trans fat" or trans?fat or TFA) adj5 (target" or limit" or restrict" or regulat* or reduc*)).ab.

7   ((fibre" or fiber" or whole?grain" or wholegrain" or whole grain") adj5 (improv" or increas" or promot" or favo"r*)).ab.

8   ((energy or calori") adj5 (reduc* or limit" or target")).ab.

9   (((improve" or better or enhance" or health") adj5 (composition" or profile")) and (nutrition or food or nutrient)).ab.

10  5 or 6 or 7 or 8 or 9

11  (sold or sales or intake" or purchase" or consumption or diet" or overweight or diabetes or bmi or cholesterol or "coronary heart disease" or cardiovascular or "dietary habit" or "heart disease risk" or "consumer behaviour" or "consumer behavior" or "blood pressure" or hyperglyc? emia or "glucose tolerance" or "insulin resistance" or hypertension or hyperlipidemia or dyslipidemia).ab.

12  (grocery or groceries or store or stores or supermarket or supermarkets or retailer or retailers or market or markets or food industry or food dispensers or vending or point-of-purchase or point-of-selection or package" or packages or front-of-pack).ab.

13  ((regulat* or polic* or legislation* pledge" or ban or bans or standard or standards or strategy or strategies or intervention" or restriction") and food").ab.

14  12 or 13

15  exp animals/not humans.sh.

16  (restaurant* or fast-food* or "fast food" or fastfood* or takeaway* or take-away* or "take-away"").ab.

17  14 or 16

18  10 and 11 and 17

19  18 not 15

APPENDIX B: LIST OF INCLUDED STUDIES IN PART ONE (SYSTEMATIC REVIEW ON REFORMULATION)

Ahuja JKCC, Pehrsson PR, Haytowitz DB, et al. Sodium monitoring in commercially processed and restaurant foods. Am J Clin Nutr. 2015;101(3):622-631. doi:https://dx.doi.org/10.3945/ajcn.114.084954

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## APPENDIX C: TABLE OF REFORMULATION INITIATIVES INCLUDED IN THE REVIEW, AND SUMMARY OF FINDINGS PER STUDY EVALUATING THEM

| Country     | Description of the Intervention                                                                 | Type of Reformulation (Incentive) | Study Focus | Effect of Reformulation Isolated | Outcome<sup>b</sup> | Morbidity/Mortality | Reference<sup>d</sup> |
|-------------|-------------------------------------------------------------------------------------------------|-----------------------------------|-------------|----------------------------------|---------------------|----------------------|----------------------|
| Australia   | Salt reduction in a bread (large-scale experiment)                                             | Research study                    | Sodium      | Yes                              | +/−                 | −                    | McMahon, 2017         |
| Austria     | Multicomponent initiative on salt since 2011 (public health campaign, reformulation, food procurement policies in some institutions) | Voluntary reformulation (raised awareness) | Sodium      | No                               | −                   | −                    | McLaren, 2016         |
|             | TFA restriction (<2% total fat) for processed foods since 2009                                 | Mandatory limit (standards)       | TFA         | No                               | −                   | −                    | Grabovac, 2018        |
|             | voluntary reformulation of TFA                                                                  | Voluntary reformulation (raised awareness) | TFA         | +                               |                     |                      | Henninger, 1996       |
| Canada      | labelling of TFA and voluntary reformulation                                                    | Voluntary reformulation (raised awareness) | TFA         | No                               | +                   | −                    | Friesen, 2006         |
|             | TFA                                                                                             | Voluntary reformulation (raised awareness) | TFA         | No                               | +                   | −                    | Ratnayake, 2014       |
| Costa Rica  | Public-Private Partnership and Health campaigns to reduce TFA intakes                           | Voluntary reformulation (PPP)      | TFA         | No                               | +                   | −                    | Colón-Ramos, 2006     |
|             |                                                                                                 |                                   | TFA         | No                               | +                   | −                    | Monge-Rojas, 2013     |
| Denmark     | Ban on TFA from 2003                                                                            | Mandatory limit (standards)       | TFA         | Yes                              | +                   | −                    | Restrepo, 2016 [47]   |
|             | Danish Whole Grain Partnership: public-private partnership                                       | Voluntary reformulation (PPP)      | Whole grains | No                               | +                   | −                    | Greve, 2014           |
|             | Energy reduction in 8 products (retailer brand)                                                 | Voluntary reformulation (manufacturer led) | Energy      | Yes                              | +                   | −                    | Jensen, 2017          |
|             | Multicomponent initiative on salt since 2008 (Public health campaign, nutrition labelling, reformulation, food procurement policy in some institutions) | Voluntary reformulation (raised awareness) | Sodium      | No                               | +                   | −                    | McLaren, 2016         |
| Finland     | Multicomponent initiative on since 1979 (public health campaign, nutrition labelling, reformulation, food procurement policy in some institutions) | Voluntary reformulation (raised awareness) | Sodium      | No                               | +                   | −                    | McLaren, 2016         |
| France      | Multicomponent initiative on salt since 2001 (public health campaign, reformulation, food procurement policies in some institutions) | Voluntary reformulation (raised awareness) | Sodium      | No                               | +                   | −                    | McLaren, 2016         |
|             | Voluntary reformulation (PPP)                                                                    | Sodium                            | Yes         | +/−                              |                     |                      | Oqali, 2016           |
|             | Sugars                                                                                          | Yes                               | +/−         |                                  |                     |                      |                      |
| Country     | Description of the Intervention                                                                 | Type of Reformulation (Incentive)                                                                 | Study Focus | Effect of Reformulation Isolated a | Outcome b | Reference |
|-------------|------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|-------------|-----------------------------------|-----------|-----------|
| Ireland     | Multicomponent initiative on salt since 2003 (public health campaign, reformulation, nutrition labelling) | Voluntary reformulation (raised awareness)                                                                 | Sodium      | No                                | +         | McLaren, 2016 |
| New Zealand | Health Star Rating (Front-of-pack labelling using a nutrient profile model) since 2015            | Voluntary reformulation (raised awareness)                                                                 | Sodium      | No                                | +         | Ni Mhurchu, 2017 |
| Slovenia    | Public health campaign in 2015–2016                                                               | Voluntary reformulation (raised awareness)                                                                 | TFA         | No                                | +         | Zupanić, 2018 |
| Spain       | Salt reduction in breads (voluntary reformulation by a manufacturer)                              | Voluntary reformulation (raised awareness)                                                                 | Sodium      | No                                | +         | Quilez, 2016 |
| Switzerland | Multicomponent initiative on salt since 2008 (public health campaign, reformulation, food procurement policies in some institutions) | Voluntary reformulation (raised awareness)                                                                 | Sodium      | No                                | –         | McLaren, 2016 |
| The Netherlands | Mandatory limits for salt in bread (gradual reduction from 2009, latest amendment in 2013), several industry engagement to reduce salt in their foods | Voluntary reformulation (standards + voluntary)                                                                 | Sodium      | No                                | –         | Temme, 2017 |
| Turkey      | Multicomponent initiative on salt since 2011 (public health campaign, reformulation, food procurement policies in some institutions) | Voluntary reformulation (raised awareness)                                                                 | Sodium      | No                                | +         | McLaren, 2016 |
| UK          | FSA salt reduction programme from 2003 to 2011 (agreements with the food industry to reformulate, public health campaigns and nutrition labelling) | Voluntary reformulation (PPP)                                                                 | Sodium      | No                                | +         | Eyles, 2013 |

(Continues)
| Country                          | Description of the Intervention                                                                 | Type of Reformulation (Incentive)                  | Study Focus | Effect of Reformulation Isolated | Outcome<sup>b</sup> | Reference<sup>d</sup> |
|--------------------------------|------------------------------------------------------------------------------------------------|--------------------------------------------------|-------------|---------------------------------|---------------------|------------------------|
|                                | PHE sugar reduction programme from 2017 (voluntary reformulation targets and soft-drink industry levy) | Voluntary reformulation (raised awareness)       | Sodium      | No                              | +                   | McLaren, 2016           |
|                                | voluntary reformulation of TFA                                                                    | Voluntary reformulation (raised awareness)       | Sugars      | No                              | +                   | Tedstone, 2018          |
|                                |                                                                                                  |                                                   | Total       | Yes                             | +                   | Hutchinson, 2018        |
| USA, New York States           | TFA restriction in fast food restaurants                                                           | Mandatory limit (standards)                      | TFA         | Yes                             | +                   | Angell, 2012            |
|                                |                                                                                                  |                                                   | TFA         | Yes                             | +                   | Brandt, 2012            |
|                                | Multicomponent initiative on salt since the late 1980s (public health campaign, reformulation, nutrition labelling) | Voluntary reformulation (raised awareness)       | Sodium      | No                              | –                   | McLaren, 2016           |
|                                | National Salt Reduction Initiative: voluntary targets                                              | Voluntary reformulation (PPP)                    | Sodium      | No                              | +                   | Ahuja, 2015              |
|                                |                                                                                                  |                                                   | Sodium      | No                              | +                   | Clapp, 2018             |
|                                |                                                                                                  |                                                   | Sodium      | No                              | +                   | Curtis, 2016            |
|                                |                                                                                                  |                                                   | Sodium      | Yes                             | +                   | Poti, 2017 [19,33]      |
|                                |                                                                                                  |                                                   | Sodium      | No                              | –                   | Mancino, 2008           |
|                                | New dietary guidelines on whole grain intakes in 2005 restriction in fast food restaurants, labelling for packaged foods | Voluntary reformulation (raised awareness)       | Whole grains | No                              | +                   | Vesper, 2017            |

<sup>a</sup> Abbreviations: PPP, public-private partnership; TFA, trans fatty acids; PHE, Public Health England; FSA, Food Standard Agency.

<sup>b</sup> The effect of reformulation was estimated to be estimated on its own when the effect of the reformulation initiative was isolated from potential confounders (such as educational campaigns aiming at changing behaviours).

<sup>c</sup> Positive results were defined as a significant change in the outcome measured, going in the direction of an improvement in public health (i.e., reduction of intakes for sodium, TFA, energy or sugars, increase for fibres or whole grains), or a reduction in disease risk or mortality.

<sup>d</sup> The number of the reference is specified when the short citation is ambiguous.
## APPENDIX D: RISK OF BIAS OF INCLUDED STUDIES (ACCORDING TO THE NEWCASTLE-OTTAWA SCALE)

| Reference   | Selection | Comparability | Outcome | Adjustment |
|-------------|-----------|---------------|---------|------------|
|             | Representativeness | Ascertainment of Exposure | Comparability | Ascertainment of Outcome | Follow-up Long Enough | OUTCOME | Control for Confounders | Reformulation Isolated | Sum of Points |
| Brandt, 2017 | 1         | 1             | 2       | 1          | 1           | 2       | 1           | 1          | 2           | 7          |
| Restrepo, 2016 [47] | 1         | 1             | 2       | 1          | 1           | 2       | 1           | 1          | 2           | 7          |
| Restrepo, 2016 [48] | 1         | 1             | 2       | 1          | 1           | 2       | 1           | 1          | 2           | 7          |
| Poti, 2017 [19] | 1         | 1             | 2       | 1          | 1           | 2       | 1           | 1          | 2           | 7          |
| Grabovac, 2018 | 1         | 1             | 2       | 1          | 1           | 2       | 1           | 0          | 1           | 6          |
| Angell, 2012 | 1         | 1             | 2       | 1          | 0           | 1       | 1           | 1          | 2           | 6          |
| Colón-Ramos, 2006 | 1         | 1             | 2       | 1          | 1           | 2       | 1           | 0          | 1           | 6          |
| Hutchinson, 2018 | 1         | 1             | 2       | 1          | 0           | 1       | 1           | 1          | 2           | 6          |
| Vesper, 2017 | 1         | 1             | 2       | 1          | 1           | 2       | 1           | 0          | 1           | 6          |
| Eyles, 2013 | 1         | 1             | 2       | 1          | 0           | 1       | 1           | 1          | 2           | 6          |
| Griffith, 2017 | 1         | 1             | 2       | 1          | 1           | 2       | 0           | 1          | 1           | 6          |
| Spiteri, 2018 | 1         | 1             | 2       | 1          | 1           | 2       | 0           | 1          | 1           | 6          |
| He, 2014 [46] | 1         | 1             | 2       | 1          | 1           | 2       | 0           | 0          | 0           | 5          |
| He, 2014 [41] | 0         | 1             | 1       | 1          | 1           | 2       | 1           | 0          | 1           | 5          |
| McLaren, 2016 (Finland) | 1 | 0 | 1 | 1 | 1 | 2 | 1 | 0 | 1 | 5 |
| McLaren, 2016 (UK) | 1 | 1 | 2 | 1 | 1 | 2 | 0 | 0 | 0 | 5 |
| McMahon, 2017 | 1         | 1             | 2       | 1          | 1           | 2       | 0           | 1          | 1           | 5          |
| Poti, 2017 [33] | 1         | 1             | 2       | 1          | 1           | 2       | 0           | 0          | 0           | 5          |
| Shankar, 2013 | 0         | 1             | 1       | 1          | 1           | 2       | 1           | 0          | 1           | 5          |
| McLaren, 2016 (France) | 1 | 1 | 2 | 1 | 1 | 2 | 0 | 0 | 0 | 5 |
| Greve, 2014 | 1         | 1             | 2       | 1          | 1           | 2       | 0           | 0          | 0           | 5          |
| Jensen, 2017 | 1         | 1             | 2       | 0          | 1           | 1       | 0           | 1          | 1           | 4          |
| Millett, 2012 | 0         | 1             | 1       | 0          | 1           | 2       | 1           | 0          | 1           | 4          |
| McLaren, 2016 (Netherlands) | 1 | 1 | 2 | 0 | 1 | 2 | 0 | 0 | 0 | 4 |
| McLaren, 2016 (USA) | 0 | 1 | 1 | 1 | 1 | 2 | 0 | 0 | 0 | 4 |
| Ni Mhurchu, 2017 | 1         | 1             | 2       | 1          | 1           | 0       | 1           | 0          | 0           | 4          |

(Continues)
| Reference          | Selection | Compressibility | Outcome | Adjustment | Sum of Points |
|--------------------|-----------|-----------------|---------|------------|---------------|
| Temme, 2017        | 0         | 1               | 1       | 2          | 4             |
| Clapp, 2018        | 0         | 1               | 1       | 2          | 4             |
| Mancino, 2008      | 1         | 1               | 1       | 1          | 4             |
| Curtis, 2016       | 0         | 1               | 1       | 1          | 3             |
| Quilez, 2016       | 1         | 1               | 1       | 1          | 3             |
| Ratnayake, 2014    | 0         | 1               | 1       | 2          | 3             |
| Ahuja, 2015        | 0         | 0               | 1       | 2          | 3             |
| McLaren, 2016      | 1         | 0               | 1       | 1          | 3             |
| Tedstone, 2018     | 1         | 1               | 1       | 0          | 3             |
| Friesen, 2006      | 0         | 1               | 1       | 1          | 2             |
| McLaren, 2016      | 1         | 0               | 1       | 1          | 2             |
| (Ireland)          |           |                 |         |            |               |
| McLaren, 2016      | 0         | 0               | 0       | 2          | 2             |
| (Switzerland)      |           |                 |         |            |               |
| Monge-Rojas, 2013  | 0         | 1               | 1       | 0          | 2             |
| Zupanić, 2018      | 0         | 1               | 1       | 0          | 2             |
| Ogali, 2016        | 1         | 0               | 1       | 0          | 2             |
| Henninger, 1996    | 0         | 1               | 1       | 1          | 2             |
| McLaren, 2016      | 0         | 0               | 0       | 0          | 0             |
| (Austria)          |           |                 |         |            |               |
| McLaren, 2016      | 0         | 0               | 0       | 0          | 0             |
| (Turkey)           |           |                 |         |            |               |
APPENDIX E: SUMMARY OF RESULTS FOR STUDIES REPORTING THE EFFECT OF REFORMULATION ON INTAKES

Table 1 Summary of results for studies reporting the effect of reformulation on intakes. Biomarker measures include spot or 24h urine for sodium measures, or TFA concentration in blood or breastmilk. Reported measures include data from dietary surveys (food frequency questionnaires, 24-h dietary recalls) and from total purchases or sales.

| Nutrient studied | Total N Studies | % Positive Results | Studies Reporting a Measure of Intakes | Reported Measures |
|------------------|----------------|-------------------|----------------------------------------|-------------------|
|                  | Total          |                   | Total N Studies | % Positive Results | N Studies | % Positive Results | N Studies | % Positive Results |
|                  | 26             | 70%               | 13             | 77%               | 13        | 69%               |
| sodium           | 20             | 65%               | 10             | 70%               | 10        | 60%               |
| TFA              | 5              | 100%              | 3              | 100%              | 2         | 100%              |
| whole grains     | 1              | 100%              |                |                   | 1         | 100%              |

APPENDIX F: Meta-regressions to explain heterogeneity in the pooled estimate of changes in salt intakes

TABLE F1 Meta-regression using method of salt intake estimation to explain heterogeneity

|  | Estimate | 95% CI     | P Value |
|---|----------|------------|---------|
| Intercept | −0.46 | −0.94 to 0.01 | 0.06 |

Difference with 24-h urinary samples

|  | Estimate | 95% CI     | P Value |
|---|----------|------------|---------|
| Dietary surveys | 0.14 | −0.67 to 0.94 | 0.7 |
| Household purchases | −0.58 | −1.49 to 0.33 | 0.2 |
| Spot urine | −0.28 | −1.49 to 0.93 | 0.6 |

TABLE F2 Meta-regression using timeframe between baseline and follow-up to explain heterogeneity

|  | Estimate | 95% CI     | P Value |
|---|----------|------------|---------|
| Intercept | −0.31 | −1.01 to 0.38 | 0.4 |

Difference with studies measuring a change <5y

|  | Estimate | 95% CI     | P Value |
|---|----------|------------|---------|
| 5–10 y | −0.29 | −1.28 to 0.69 | 0.6 |
| >10 y  | −0.36 | −1.20 to 0.49 | 0.4 |

APPENDIX G: SENSITIVITY ANALYSES FOR META-REGRESSIONS

FIGURE G1 Sensitivity analysis of the pooled estimate of the effect of initiatives including salt reformulation on populations’ salt intake (in g/day). Only studies with a NOS Score >2 were selected [Correction added on November 28, 2020 after first online publication: Figure G1 has been updated.]
APPENDIX H: FUNNEL PLOT OF THE TWO META-ANALYSES

FIGURE G2 Sensitivity analysis of the pooled estimate of the effect of initiatives including TFA reformulation on populations’ TFA intake (the effect size is the standardized mean difference given by the Hedge's g statistic). Only studies with a NOS Score >2 were selected.
Funnel plot of changes in TFA intake