Impact of price reductions, subsidies, or financial incentives on healthy food purchases and consumption: a systematic review and meta-analysis

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Poor diets are a global concern and are linked with various adverse health outcomes. Healthier foods such as fruit and vegetables are often more expensive than unhealthy options. This study aimed to assess the effect of price reductions for healthy food (including fruit and vegetables) on diet. We performed a systematic review and meta-analysis on studies that looked at the effects of financial incentives on healthy food. Main outcomes were change in purchase and consumption of foods following a targeted price reduction. We searched electronic databases (MEDLINE, EconLit, Embase, Cinahl, Cochrane Library, and Web of Science), citations, and used reference screening to identify relevant studies from Jan 1, 2013, to Dec 20, 2021, without language restrictions. We stratified results by population targeted (low-income populations *vs* general population), the food group that the reduction was applied to (fruit and vegetables, or other healthier foods), and study design. Percentage price reduction was standardised to assess the effect in meta-analyses. Study quality was assessed using the Cochrane Risk of Bias tool and Newcastle-Ottawa Scale. 34 studies were eligible; 15 took place in supermarkets and eight took place in workplace canteens in high-income countries, and 21 were targeted at socioeconomically disadvantaged communities. Pooled analyses of 14 studies showed a price reduction of 20% resulted in increases in fruit and vegetable purchases by 16·62% (95% CI 12·32 to 20·91). Few studies had maintained the price reduction for over 6 months. In conclusion, price reductions can lead to increases in purchases of fruit and vegetables, potentially sufficient to generate health benefits, if sustained.

Lancet Planet Health 2024; 8: e197–212

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Introduction

Poor diet is a major cause of ill health globally.[1] The Global Burden of Disease collaboration estimated that around 8 million deaths worldwide could be attributed to dietary risk factors in 2019.[2] High fasting plasma glucose and high BMI were two of the top three risk factors which had a significant impact on disability-adjusted life-years lost,[2] and were predominantly associated with lifestyle factors such as diet.[3] Higher fruit and vegetable intake is associated with a reduced risk of both non-communicable diseases and premature mortality.[4,5] Improving diet via increased consumption of healthy foods, including fruit and vegetables, could therefore have substantial health benefits.

Many interventions to enhance and sustain dietary improvements at a population level have been evaluated.[6,7] Most dietary interventions that aim to promote behavioural change use methods such as social media campaigns, educational approaches,[8] food labelling,[9] or portion control.[10] These interventions require substantial individual action to change the way people purchase, cook, and eat. While evidence from randomised controlled trials among those at higher risk of chronic disease (such as diabetes) does suggest that lifestyle changes could have some benefits,[11] there are concerns that highly intensive lifestyle interventions are not likely to be generalisable to wider populations,[12] might not be sustainable over time, and might also increase inequity between groups.[13] Therefore, there has been increased interest in fiscal approaches to improve diet (ie, interventions that focus on price or cost of food).[14–19] Price elasticity of food items, a measure of the response of demand when the price of the foodstuff changes, strongly indicates that changing the price of specific food items can alter the purchasing volume.[20] However, most of the literature has focused on the effect of increased taxation on unhealthy beverages, with some studies on unhealthy foods.[21] Whether these single taxes are sufficient to result in measurable health gains in most populations is still unclear; a 2020 Cochrane review found little evidence that taxes on food products with added sugar (eg, sweets, ice cream, confectionery, and bakery products) reduce consumption.[19]

A previous review of price changes,[22] summarising data from 1990 to 2015, that assessed both subsidies (price reductions for the consumer) and taxes suggested that price reductions might have a stronger effect on improving diet than taxes. Thus, a 10% decrease in price (ie, a subsidy) increased purchases of healthy foods by 12%, whereas a 10% increase in price (ie, a tax) decreased purchases of unhealthy foods by only 6%.[22] Healthy foods, such as fruit and vegetables, are relatively more expensive than high energy density foods (eg, chips, biscuits, and fatty meat), and price reductions might increase healthy food consumption to a greater extent among lower-income families, where consumption appears lowest,[23] also improving health equity.

The evidence base for taxation has been reviewed frequently;[14,17,21] however, the effect of price reduction interventions has been evaluated less often.[22] A systematic review from 2022 covered both taxation and subsidies (price rises and reductions) but did not include six studies[24–29] of subsidies or price reductions taking place outside the USA, and of these, three studies[24–26] reported on the consumption, rather than just purchases, of healthier foods.[30] This is important, as the majority of studies on this topic are from the USA and considered only changes in purchases. Four of these six studies were randomised in design,[24,26–28] and thus might be more robust than earlier research.[30]

Intuitively, it is believed that price reductions will alter behaviour, but it is not clear whether changes can be sustained over time, whether savings might be used to purchase and consume other less healthy foods (eg, alcohol), and hence whether reductions might translate into measurable health benefits. In this systematic review, we aimed to appraise the evidence base for price reductions implemented in different settings. First, we quantified the change in percentage of purchasing or consumption resulting from a percentage reduction in price of specific food groups (eg, fruit and vegetables) or healthier foods in general; second, we evaluated the strength of evidence in different settings; and third, we identified evidence gaps meriting future research.

Methods

Selection criteria and search strategy

The protocol for this systematic review and meta-analysis has been previously published[31] and uploaded to PROSPERO (CRD42019125013). Results are reported according to PRISMA guidance. Full methods are also reported in the appendix (pp 1–2).

See Online for appendix

The overall objective of the review was to identify studies evaluating price reductions on healthier foodstuffs targeted directly at consumers, as subsidies aimed at suppliers or wholesalers might not always be wholly passed on to consumers. We used study authors' definitions to determine what was considered a healthier food type. In brief, our search strategy was developed from an earlier review[22] (see appendix pp 2–3). We searched MEDLINE, EconLit, Embase, Cinahl, Cochrane Library, and Web of Science from Jan 1, 2013, to Dec 20, 2021. Searching was supplemented by checking references of other reviews and publications.[22,32] Exact search terms are listed in the appendix (pp 2–3); there were no language restrictions.

We included any studies reporting on how price reduction affects consumers' expenditure and excluded those of limited duration (<4 weeks) or scope (eg, targeting snacking behaviour only, such as vending machines), as studies with longer interventions and follow-up periods have shown attrition in changes in purchases over time.[24,26,33] Study screening, data extraction, and study quality assessment were all carried out independently by two of the five reviewers (PH, FP, JAC, FMA-H, and CW). Disputes were resolved via discussion or input from a third researcher. The primary outcome of interest was the difference in food consumption or purchase—ie, the changes of consumption or purchase between intervention and control groups. Where there was no control group, the difference in food consumption or purchase before and after the intervention was used.

Data analysis

We summarised study results by carrying out a random effects meta-analysis using Stata[34] version 15 when at least three studies reported on the same outcome. If studies produced outcomes at multiple timepoints, the timepoint nearest the end of the price reduction period was used in our analyses. We used a weighted least fit model, assuming a linear relationship between percentage reduction in price and percentage change in the outcome to standardise for variation in the size of the percentage reduction offered by the intervention. Many studies did not report standard errors for the difference in difference outcome, instead performing statistical testing and reporting standard errors only for within-group changes over time (eg, p values for change in purchases or consumption within the intervention and control groups separately). We calculated standard errors for the difference in difference outcome where possible using standard approaches set out by the Cochrane Collaboration[35] (appendix p 31). We conducted sensitivity analyses to explore heterogeneity and subgroup analyses to assess whether there were differences by types of food targeted for the price reduction. For studies that could not be included in a meta-analysis (as percentage change could not be calculated), we described their results narratively. We used validated tools (Newcastle-Ottawa Scale[36] [NOS] and the Cochrane Risk of Bias tool[37] [RoB]) to assess the robustness of observational and randomised studies respectively.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

The initial search identified 7511 articles (7388 articles from database search, and 123 records from the citation search based on other reviews).[22,30,32] After screening for titles and abstracts, 92 full texts were retrieved for further examination, and 34 studies (reported in 38 publications) were included (figure 1). For completeness, we included studies previously identified by Afshin and colleagues[22] using the same search strategy where the papers met our inclusion criteria; this resulted in us including six older studies published before our 2013 initial search date. Two study authors[26,29] were contacted and provided further information. The main characteristics are shown in the appendix (pp 4–9), and table 1 presents the results of all included studies. 14 studies[24–29,44,45,49,53–56,60] were included in quantitative meta-analyses; the remainder were not included as they only reported absolute price change. 17 of 34 studies were randomised control trials (RCTs), 15 were non-randomised intervention studies, and two were cross-sectional studies. Most of the studies were conducted in the USA (23 [68%] of 34), with the rest coming from Australia (3 [9%] of 34), the Netherlands

(2 [6%] of 34), and one (3%) each from South Africa, New Zealand, Spain, Denmark, France, and Ireland.

All studies included adults as the main participants (including those defined as the primary shopper for the household); only one study[61] specifically measured food and nutritional intake in children. Most studies included men and women at recruitment, although one Australian study only enrolled female shoppers.[26] Most studies included more women than men, since more women were responsible for the household shopping and being the primary household shopper was an inclusion criterion for these studies. 22 studies focused on low-income or marginalised communities; 10 studies from the USA exclusively examined the Supplemental Nutrition Assistance Program (SNAP) which targets low-income populations, while another two sudies examined the Supplemental Nutrition Program for Women, Infants, and Children. 15 studies were carried out in supermarkets, eight took place in workplace canteens (hospitals, universities, and corporate workplaces), seven were based in farmers' markets or mobile markets, and four were recruited from local communities.

Most studies (25 [74%] of 34) evaluated price reductions applied to fruit and vegetables. Some studies applied the price reductions to other healthier foods (8 [24%] of 34), and one study introduced a price differential between healthy and unhealthy foods.[56] Three main types of financial subsidies were offered: first, a price reduction or discount (n=16); second, coupons, vouchers, or tokens (n=11); and third, rebates, cash back, or gift cards (n=7). Percentage price reductions ranged between 10% and 50%, and were of 1 month[53,43] to 3 years in duration.[3] Besides price reduction intervention alone, ten studies[24,26–29,33,52,54,57,58,60] also assessed the combined effect of price reductions and other interventions, such as nutritional education, text message reminders, multimedia advertisements, and placement interventions (eg, placing healthy food in high-traffic areas).

Most studies reported purchases using data from cash registers, supermarket scanner records, shopping receipts, cafeteria financial histories, or other billing records. Sixteen studies[24–26,33,38,44,52,54,59,60,63–68] also measured consumption as well as purchasing (appendix pp 10–13): ten of them collected consumption data by validated dietary recall or Food Frequency Questionnaires (FFQs),[24,26,38,44,52,54,60,63,65,67] and six others used shortened FFQs or short self-reported surveys.[25,33,59,64,66,68] Three studies included some physical examination (for anthropometry measures; eg, BMI or waist circumference) and biomarkers (eg, blood lipids).[33,34,61]

Ten studies investigated the effects of price reductions on fruit and vegetables in supermarkets (four from the USA, two from Australia, and one each from New Zealand, South Africa, the Netherlands, and Denmark; appendix p 21). The discounts introduced ranged from 20% to 50% from baseline retail price. When standardised to a 20% price reduction, fruit and vegetable purchase or consumption increased by 16·62% (95% CI 12·32 to 20·91). The heterogeneity was high, with I^2 of 66·8% (figure 2, table 1, appendix pp 14–16).

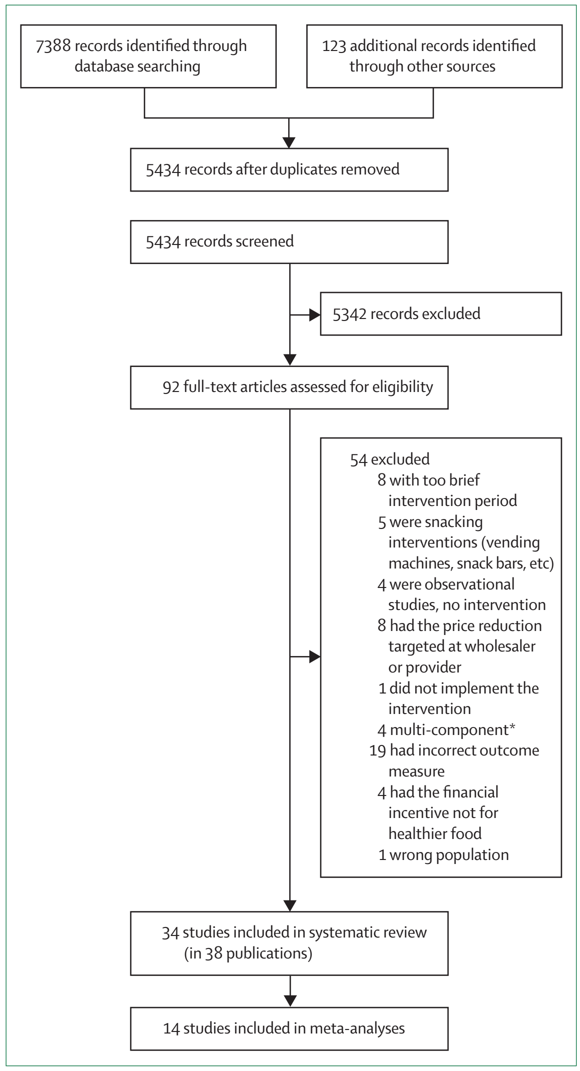

Figure 1: **PRISMA flow chart for study selection**
*Studies were excluded if price reduction was not the main or the only intervention strategy.

Price reductions on fruit and vegetables had a similar effect in low-income populations (15·64% [95% CI 8·10 to 23·19], I^2=80·4%) and the general population (17·26% [13·97 to 20·54], I^2=0·0%). Heterogeneity was very high among the low-income populations, but not among the four studies from general populations. All four general population studies found significant benefits (ranging from 15% to 23% increase in purchases or consumption). Sensitivity analyses including only RCTs showed a similar effect (16·64% [10·79 to 22·49], appendix p 22).

Six studies (four in canteens and two in supermarkets) reported the effect of price reductions on purchases of

	Study design	Country	Study population	Targeted foods or measures	Duration of intervention	Price change	Results
A. Supermarket; coupon							
Moran et al (2019)[38]	RCT	USA (Maine)	Low-income households with at least one child	Fruit and vegetables	10 weeks	50% off through coupon or loyalty card, obtained through retail scanner data (double dollar incentive, up to US$10)	Estimated consumption. Primary shopper (n=317) overall difference between intervention and control groups: –0·26 servings (half-cup as one serving), for reference child (n=309) overall difference: –0·22 servings (half-cup as one serving). The differences between intervention and control groups were not significant. Fruit and vegetable purchasing increased by 2·83 servings between the intervention and control groups from baseline to follow-up period (p <0·001). Fruit purchasing: 1·70 (p<0·05); vegetable purchasing: 1·13 (p <0·05).
Andreyeva and Luedicke (2015)[39] and Andreyeva and Tripp (2016)[40]	NRI	USA (New England)	Low-income households participating in WIC	Fruit and vegetables; wholegrain products; fruit and vegetables; milk; cheese; juice	9 months	US$10 for women and US$6 for children per month for eligible households	Fruit spending increased from 4·6% to 6·2% of total expenditure. Vegetable expenditure rose from 5·4% to 6·3%. Fresh vegetables averaged 2·52 kg per month at study end, an increase of 17·5% since 2009; 14·9% increase in fresh vegetable expenditure and 30·9% increase for frozen vegetables.
Phipps et al (2013)[41]	NRI	USA (Philadelphia)	Low-income households	Fruit and vegetables	4 weeks	Prepaid coupons (1 coupon per week)	Fruit purchases increased by 4·7 (95% CI 1·9 to 8·1) servings; vegetable purchases increased by 1·8 servings (–0·8 to 4·0); not statistically significant. During later follow-up period, households purchased 2·1 times more fruit servings (0·03 to 4·5), but no difference in vegetables.
Vadiveloo et al (2021)[42]	RCT	USA (Rhode Island)	Primary household shoppers	Fruit and vegetables	12 weeks	Two US$10 coupons a week	Intervention increased Grocery Purchase Quality Index-2016 scores (between-group difference 1·06 [95% CI 0·27 to 1·86] p=0·01); percentage spending on targeted foods (between-group difference 1·38% [0·08 to 2·69] p=0·04).
B. Supermarket; discount							
Ball et al (2015)[26]	RCT	Australia	Female primary household shoppers	Fruit and vegetables and sugar-sweetened beverages	3 months	20% discount	At 3 months total vegetable consumption increased by 232·7 g per week (3·1 servings or 15% more than at baseline [95% CI 3·8–461·6], p=0·046), and fruit purchases increased by 363·9 g per week (2·4 servings; 35% more than at baseline [95·2–632·5], p=0·008). At 6 months, these changes had attenuated and were not statistically significant (for vegetables a 19·1 g increase [95% CI –224·0 to 262·2]; for fruit a 169·7 g increase [–57·6 to 397·3]).
Brimblecombe et al (2017)[27]	RCT	Australia	Remote Indigenous communities	Fresh and frozen fruit and vegetables; bottled water; artificially sweetened drinks	24 weeks	20% discount	Increase in purchases of sugar-sweetened beverages,(386·2 mL/week [95% CI –52·1 to 824·5], p=0·084). 12·7% increase in grams of purchases of fruit and vegetables (95% CI 4·1 to 22·1) during the discount intervention. This even rose to a 19·8% (6·2 to 35·1) increase after the discount intervention stopped.
Ni Mhurchu et al (2010)[28] and Blakely et al (2011)[43]	RCT	New Zealand	Household shoppers	Predefined and classified healthier food; all eligible healthier food items*	24 weeks	12·5% discount	Saturated fat 6-month outcomes: –0·02% (95% CI –0·4 to 0·36, p=0·91); 12 months –0·12% (–0·51 to 0·27, p=0·54). Also did not differ between intervention groups at 6 or 12 months. Intervention group purchased 0·79 kg per week more healthier products and 0·48 kg per week more fruit and vegetables compared to the control group (p<0·001).
Olsho et al (2016)[44]	RCT	USA (Massachusetts)	SNAP participants (low-income)	Fruit and vegetables (fresh, tinned, frozen, and dried) without added sugars, fats, or oils†	12 months	30% discount	0·24 cup-equivalents per day (95% CI 0·13 to 0·34 cup-equivalents per day) higher among Healthy Incentives Pilot participants; a 23% increase in intake of targeted fruit; and a 30% increase in intake of targeted vegetables.
Polacsek et al (2018)[45]	RCT	USA (Maine)	SNAP participants (low-income)	Fruit and vegetables (fresh, frozen, tinned)	4 months	5% discount on all items and 2 for 1 for fruits and vegetables	Total weekly fruit and vegetable spending increased in the intervention group compared to control group ($1·83 [95% CI 0·29 to 3·88]). The largest increase was for fresh fruit and vegetables ($1·97 [0·49 to 3·44]).
Toft et al (2017)[29]	NRI	Denmark	Population on an island	Fruit and vegetables	3 months	20% discount	Total fruit and vegetable sales: 15·3% increase (p=0·01); 22·2% increase in sales of fresh vegetables (p=0·001) compared with control supermarkets in space and price group. Fresh vegetable sales 18% higher in space and price compared with space only intervention (p=0·02).

(Table 1 continues on next page)

	Study design	Country	Study population	Targeted foods/measures	Duration of intervention	Price change	Results
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Waterlander et al (2013)[24]	RCT	Netherlands	Lower SES in general	Fruit and vegetables	6 months	50% discount	Discount group increased purchases by 3·9 kg (95% CI 1·5 to 6·3); discount plus education intervention increased purchases by 5·6 kg (3·2 to 7·9) at 6 months compared with control. At 6 months, the discount group purchased 5·3 kg more fruit and vegetables (2·8 to 7·7) than the control group (p<0·001); similar pattern found among discount plus education group (5·4 kg [3·0 to 7·8], p<0·001). The difference remained significant in adjusted models: discount group increased purchases by 3·9 kg (1·5 to 6·3); discount plus education group increased by 5·6 kg (3·2 to 7·9). More participants who consumed enough fruit and vegetables at baseline increased from 42·5% to 61·3% at 6 months in the discount groups (p=0·03). In non-discount groups, no significant change was found (from 52·7% to 52·5%, p=0·80). Benefits from the intervention were not maintained after the intervention ended and were reversed by 9 months follow-up.
C. Supermarket; cash back, rebate, or gift card							
Rummo et al (2019)[46]	Quasi-RCT	USA (Michigan)	SNAP participants (low-income)	Fresh produce	14 months	1 point (worth US$1) earnt per $1 spent on qualifying fruit and vegetables up to $20. Points to be spent on future purchases of qualifying fruit and vegetables.	SNAP participants shopping in the intervention supermarket spent 7·4% more on fresh produce compared to those shopping in control stores. In the subsequent year, a 2·2% increase was observed.
An and Sturm (2017)[25] and Sturm et al (2013)[47]	NRI	South Africa	Private health insurance holder	Fruit and vegetables; wholegrain foods; foods high in sugar; foods high in salt; fried foods; processed meats; fast food; non-fat dairy products	Ongoing; measured monthly	10% and 25% rebate	Participants with 25% rebate had 3·87 servings per day of fruit and vegetables, compared to those with no rebate at 3·17 servings per day. 10% and 25% discounts on healthy food purchases were associated with an increase in fruit and vegetable consumption by 0·38 (95% CI 0·37 to 0·39) and 0·64 (0·62 to 0·65) servings per day, respectively. Rebates of 10% and 25% were associated with increases in ratio of expenditure on healthy foods to total food by 6·0% (95% CI 5·3 to 6·8) and 9·3% (8·5 to 10·0); fruit 5·7% (4·5 to 6·9); and vegetables 8·5% (7·3 to 9·7). Decrease in ratio of expenditure on less desirable to total food was 5·6% (4·7 to 6·5) and 7·2% (6·3 to 8·1) for 10% and 25% discounts, respectively.
Phipps et al (2013b)[48] and Phipps et al (2015)[49]	RCT and prospective cohort study	USA (Philadelphia)	Low-income households	Fresh or frozen fruit and vegetables	Intervention of 8 weeks, tapering of 4 weeks	Rebates of 50% during intervention and 25% during tapering period for fruit and vegetables purchases	Phipps et al (2013b): fruit purchases increased by 4·7 servings (95% CI 1·9 to 8·1) and vegetables by 1·8 servings (0·8 to 4·0), not statistically significant. During follow-up, households purchased 2·1 more fruit servings (0·03 to 4·5), but there was no difference in vegetables. Phipps et al (2015): control households had an average of 6·4 servings of fruit and vegetables (combined) per week. The intervention group had 16·7 servings per week; 10·4 more than control (95% CI 4·8 to 17·8; p=0·002) households. After adjustment for weekly price changes difference between the intervention and control groups was 10·2 servings (95% CI 3·6 to 25·7; p=0·001). Intervention households consumed 8·0 more servings of vegetables than control households (1·5 to 16·9, p<0·001).
Steele-Adjognon and Weatherspoon (2017)[50]	NRI	USA (Detroit)	Low-income area; predominantly Hispanic community	Fruit and vegetables	4 months	If US$10 was spent on fresh fruits and vegetables in one transaction, participants got a $10 gift card exclusively for Michigan grown fresh fruits and vegetables	A spending of $0·4 per month (95% CI 0·12 to 0·68) on fruit and vegetables was attributable to the programme; $0·08 per month (–0·08 to 0·24) on fruit; $0·33 per month (0·14 to 0·51) on vegetables.

(Table 1 continues on next page)

	Study design	Country	Study population	Targeted foods/measures	Duration of intervention	Price change	Results
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D. Canteen; discount							
Fernández Torres et al (2014)[51]	NRI	Spain	University students and staff	Calories; lipids; cholesterol; sodium (compared to RDA)	NR	Not stated	Percentage of RDA consumed pre-intervention: calories 96·9%; lipids 92·8%; cholesterol 214·3%; sodium 374·6%. During intervention, percentages of RDA consumed were: calories 86·6%; lipids 79·5%; cholesterol 185·3%; sodium 289·9%.
Geaney et al (2016)[52]	NRI	Ireland	Employees in manufacturing companies	Salt intake; fat intake; sugar and fibre intake; nutrition knowledge; BMI; weight; midway waist circumference; resting blood pressure	9 months	Not stated	Environmental modification group (mainly price change) versus control group: BMI 0·3 (95% CI –1·1 to 1·6), no health benefit was observed. The combined intervention (environmental and education) showed small benefits in BMI –1·2 (–2·4 to –0·1); salt intake –1·3 (–2·3 to –0·3); nutrition knowledge 4·2 (0·3 to 8·2).
Kottke et al (2013)[53]	NRI	USA (Minneapolis)	Workers at the Health Partners headquarters	Salad	1 month	50% discount	Total sales at salad bar (in US$) February $3344; March (intervention month) $6747; April $3629; May $3899; and June $3874. Sales in March were 83% higher than the averages of other months (p=0·008).
Lowe et al (2010)[54]	RCT	USA (Philadelphia)	Worksite cafeterias in two hospitals	Lower energy density food	3 months	15% discount for low energy density foods and 25% discount for very low energy density foods (as defined in study)	Both the environmental intervention and environmental plus discount intervention groups had the energy content of lunch purchases decrease from 656·09 kcal (SD±183·83) at baseline to 585·47 kcal (±170·09) at 1 month. All time points showed statistically significant differences (p<0·01). The percentage of energy from fat also fell (p=0·001). 24-h dietary recall showed no statistically significant changes over time in reported intake of total energy, vegetables, bread products, or dairy products. The environmental plus discount group (includes subsidies) increased fruit intake (from 0·77 servings to 0·98 servings) while the environmental group (no subsidies) decreased fruit intake (from 1·41 servings to 0·96 servings; p<0·05). Participants in both groups decreased their meat intake during the cafeteria monitoring period (p=0·06). No significant changes in body fat or waist circumference over time. For purchased kcal outcome: baseline month 1: 665·1 (SD 185·1); baseline month 2: 572·2 (163·4); intervention month 1: 580·4 (159·2); intervention month 2: 548·5 (158·7); intervention month 3: 570·0 (179·9).
Michels et al (2008)[55]	NRI	USA (Boston)	University staff and students	Healthy foods (salad bar, stir-fried dishes, Saluté [a nutritionally optimised entrée], wholegrain pizza, yogurt, and fruit) and less healthy foods (regular entrée, regular pizza, hamburger, hot dogs, fries, cookies, cakes, desserts)	5 weeks	20% discount on healthy options	6% increase in consumption of healthy options during the 5-week intervention compared to baseline (95% CI 5 to 8). Healthy food consumption then rose to 17% at 5-week follow-up (13 to 20). Not statistically significant 2% decline in consumption of less healthy food options during the 5-week intervention compared to baseline (–4 to 1), which remained the same at the 5-week follow-up (–5 to 1).
Patsch et al (2016)[56]	NRI	USA (Colorado Springs)	Hospital employees	Paired swaps: burgers (traditional hamburger swapped for healthier turkey burger) and salads (traditional salad *vs* healthier salad).	9 months	35% discount	Results presented for two sites. Penrose Hospital: traditional burger sales fell 47·9% (p<0·001) and healthy burger sales increased 600% (p<0·001). Changes in salad sales were not significant; traditional salad sales fell 5·7% and healthy salad sales increased 2·6% (p=0·238). St Francis Medical Centre: traditional burger sales fell 20·4% and healthy burger sales increased 371·2% (p<0·001) Traditional salad sales fell 25·4% and healthy salad sales rose 71·1% (p<0·001).

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	Study design	Country	Study population	Targeted foods/measures	Duration of intervention	Price change	Results
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Velema et al (2018)[57]	RCT	Netherlands	Cafeteria consumers	Snacks; fruits; salad; cheese; meat; sandwiches	12 weeks	25% discount	Number of healthy sandwiches sold per 100 customers increased by mean of 3·3 (SD ±3·1) in the intervention group compared with 0·9 (±2·2) in the control group; regular sandwiches decreased from 14·2 (±0 7·8) to 11·3 (±7·1). This stayed constant in control group. Significant increase in the purchase of low-fat cheese products in the intervention group (from 1·3 [± 1·7] to 4·8 [±3·5]) and the control group (2·3 [±4·3] to 3·3 [±7·1]) and fruit (additional 0·7 pieces of fruit per 100 consumers). No significant differences were noted for snacks, pre-packaged snacks, healthier salads, healthier meat products for bread toppings.
E. Canteen; cash back							
Thorndike et al (2016)[58]	RCT	USA (Massachusetts)	Hospital employees	Green items (all items labelled as green, yellow, or red based on positive criteria [fruit and vegetables, wholegrains, and lean protein or low-fat dairy as main ingredient] and negative criteria [saturated fat and calories])	3 months	$10 if reaching the proportion target of green labels each month‡	Percentage change in green categorised (classified as healthy) purchases was larger in feedback incentive group (2·2%, p=0·03) and borderline in feedback only group (1·8%, p=0·07) compared to control (0·1%); the two intervention groups were not significantly different. After wash-out period there were no significant differences between any of the groups. The least healthy quartile (as measured by green purchases) showed no changes. The healthiest quartile showed the largest differences.
F. Community based; coupon							
Bihan et al (2012)[33]	RCT	France	Low-income adult individuals	Received vouchers for fresh fruit and vegetables (not processed, tinned, or frozen)	Up to 12 months	Absolute € value vouchers dependent on household size and composition (between €10 and €40)	Between baseline and 3 months, mean fruit and vegetable consumption increased significantly in both the advice group (0·62 [SD ±1·29] times per day, p<0·0004) and the fruit and vegetable vouchers groups (0·74 [±1·90], p<0·002), with no difference between groups. At 3 months mean consumption per day was 2·51 (±1·44) in the advice group and 2·93 (±1·40, p<0·09) in the vouchers group. The fruit and vegetable vouchers group had significantly decreased risk of low fruit and vegetable consumption (<1 time per day) compared to the advice group (p<0·008). 25·8% of participants in the advice only group consumed fruit and vegetables less than one time per day versus 5·5% in voucher group (p<0·001).
Segura-Perez et al (2017)[59]	RCT	USA (Hartford)	Local residents (low-income families as within SNAP programme)	Fruit and vegetables	4 weeks	4 US$5 coupons	The intervention group spent significantly more on fruit than controls ($42 *vs* $30, p=0·027).
G. Community based; discount							
Harnack et al (2016)[60]	RCT	USA (Minneapolis)	Low-income adults not enrolled in SNAP	Fresh fruit and vegetables subsidised; sugar-sweetened beverages, sweets, and baked goods restricted	12 weeks	30% reduction	Incentive group: fruit intake increased by 0·4 servings per day (SE 0·2) versus control group (0 servings per day [0·1]). No statistically significant differences in BMI were observed. The incentive group increased 0·1 kg/m² (SE 0·2); the restriction group increased 0·1 kg/m² (0·2); the incentives plus restriction group increased 0·2 kg/m² (0·2); and the control group increased 0·1 kg/m² (0·5).
Black et al (2013)[61]	NRI	Australia	Low-income Aboriginal families with ≥1 child	Fresh fruit and vegetables	12 months	Each family paid US$5 for a box containing $40 worth of fruit and vegetables (or $60 if five or more children in the household)	There were no significant changes in fruit and vegetables intake reported using 24-h dietary recall, –0·3 (95% CI –0·76 to 0·15) servings per day. There was a small but significant decrease in vegetable consumption using the short questions (–0·49 [– 0·82 to –0·16]). There was significant increases in plasma b cryptoxanthin (28·9 nmol/L [95% CI 4·2 to 53·6]), lutein–zeaxanthin (39·3 nmol/L [96·2 to 72·5]), and vitamin C (10·1 μmol/L [2·0 to 18·1]) in the adjusted model.

(Table 1 continues on next page)

	Study design	Country	Study population	Targeted foods/measures	Duration of intervention	Price change	Results
(Continued from previous page)							
H. Farmers' markets or mobile markets; token or coupon							
Anderson et al (2001)[62]	RCT	USA (Michigan)	WIC and CSFP participants	Fruit and vegetables	2 months	US$20 coupons	The analyses were only reported within the treatment group. χ^2 results showed that higher coupon redemption was associated with greater decreases in total daily grams of fat per person (p=0·002), and greater increases in daily servings of fruits and vegetables per person (p=0·018), but not with greater increases total daily grams of fibre per person (p=0·10).
Durward et al (2019)[63]	NRI	USA (Utah)	SNAP participants (low-income adults)	Fruit and vegetables	Average 7 weeks follow-up	Up to US$10 worth of vouchers valid for the farmers' market depending on questionnaire completion ($2 dollars when baseline questionnaire completed, $3 posted to participants at follow-up, with an additional $5 if both questionnaires were completed)	Only 138 (40%) of 339 participants completed follow-up questionnaires, thus only 40% of participants received the full $10 worth of vouchers. Significant increase in median fruit and vegetable consumption, from a median of 2·82 times per day to 3·29 times per day (IQR 1·48–3·99 and 3·28–5·02, respectively; p=0·002).
Lindsay et al (2013)[64]	NRI	USA (California)	SNAP participants (low-income adults)	Fruit and vegetables	18 months	Not stated	The percentage of respondents reporting eating five or more daily servings of fruit and vegetables increased from 23·7% to 29·6% at months 3 and 6, and from 19·4% to 24·2% at month 12.
Olsho et al (2015)[65]	Cross–sectional	USA (New York)	Low-income neighbourhood	Fruit and vegetables	Programme started from 2005	Scheme offers one US$2 voucher for fresh fruit and vegetables at farmers' markets per $5 spent from EBT cards.	Scheme users were more likely to report increased consumption (p<0·05). Difference in difference model did not find evidence that the programme increased the fruit and vegetable consumption in the neighbourhood (β=0·013, SE 0·013).
Ratigan et al (2017)[66]	NRI	USA (San Diego)	Low-income individuals receiving governmental benefit	Fruit and vegetables	7 months	Money matching scheme for food tokens to be used at farmers' market where US$1 could be exchanged for $2 worth of tokens. Up to $20 could be exchanged per month.	Food token use was associated with 2% per month increase in fruit and vegetables servings. OR=1·02 (95% CI 1·01 to 1·03, p=0·003).
Savoie-Roskos et al (2016)[67]	NRI	USA (Utah)	SNAP participants (low-income households)	Fruit and vegetables	4 weeks	Money matching scheme of up to US$10 per week to be used at farmers' market.	Fruit and vegetable intake was 3·3 (SD 0·8) times per week at baseline, and after intervention consumption was 4·0 (0·8) times per week.
Young et al (2013)[68]	Cross-sectional	USA (Philadelphia)	SNAP participants (low-income households)	Fruit and vegetables	1 year programme, but this is only a survey; there is no follow-up	Evaluation of Philly Food Bucks scheme where participants received a US$2 coupon for every $5 they spent	Users were significantly more likely than non-users to report eating more fruit and vegetables since becoming a market customer (OR=2·4 [95% CI 1·6 to 3·7]), and to report trying new or unfamiliar fruit and vegetables since becoming a market customer (1·8 [1·2 to 2·7]).

RCT=randomised control trial. NRI=non-randomised intervention. WIC=Special Supplemental Nutrition Assistance Program for Women, Infants and Children (a US programme offering additional benefits to low-resource women with children younger than 5 years). SNAP=Supplemental Nutrition Assistance Programme (a US programme providing food benefits to low-income families). EBT=electronic benefit transfer. SES=socioeconomic status. RDA=recommended daily allowance. NR=not recorded. CSFP=Community Action Agency Commodity Supplemental Food Programme. OR=odds ratio. *Eligible food included cereals and cereal products, fats and oils, fruit and vegetables, meat and meat alternatives, and milk and milk products. These were predefined using the Heart Foundation's Tick programme nutrient profiling criteria. In total, 1032 database products (35%) met the Tick criteria and were classified as healthier. †Excluding white potatoes, mature legumes (dried beans and peas), and 100% juice. ‡Employees who started above the top threshold of 80% green purchases could earn US$5 a month for maintaining at or above this level.

Table 1: **Results of included studies**

	Study	Country	Price reduction (%)	Difference (%)	% change of fruit and vegetable purchase and consumption per 20% price reduction (95% CI)	Weight* (%)
Low-income population						
Brimblecombe et al (2017)	RCT	Australia	20·0	12·7	12·70 (3·70 to 21·70)	9·81
Harnack et al (2016)	RCT	USA	30·0	15·8	10·53 (–8·93 to 29·99)	3·80
Olsho et al (2016)	RCT	USA	30·0	26·0	17·34 (9·34 to 25·35)	10·79
Phipps et al (2015)	RCT	USA	50·0	61·9	24·76 (20·34 to 29·18)	14·58
Polacsek et al (2018)	RCT	USA	50·0	15·4	6·16 (0·10 to 12·22)	12·84
Waterlander et al (2013)	RCT	Netherlands	50·0	49·9	19·97 (7·70 to 32·24)	7·16
Subtotal (I^2=80·4%, p=0·000)					**15·64 (8·10 to 23·19)**	**58·98**
General population						
An and Sturm (2017)	NRI	South Africa	25·0	21·0	16·80 (12·84 to 20·76)	15·04
Ball et al (2015)	RCT	Australia	20·0	23·2	23·18 (13·05 to 33·31)	8·80
Ni Mhurchu et al (2010)	RCT	New Zealand	12·5	10·0	16·03 (6·87 to 25·20)	9·66
Toft et al (2017)	NRI	Denmark	20·0	15·3	15·32 (3·56 to 27·08)	7·52
Subtotal (I^2=0·0%, p=0·674)					**17·26 (13·97 to 20·54)**	**41·02**
Overall (I^2=66·8%, p=0·001)					**16·62 (12·32 to 20·91)**	**100·00**

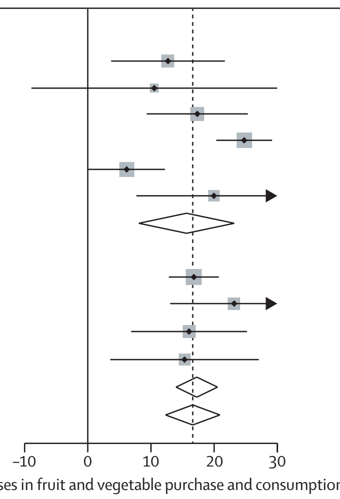

Figure 2: **Price reduction and fruit and vegetable consumption by income level of the study population**
NRI=non-randomised intervention. RCT=randomised control trial. *Weights are from random effects analysis.

items classified as healthier foods, other than fruit and vegetables (table 1). The healthier foods targeted were varied, and included salad bars, lower energy density food, stir-fried dishes, specifically developed or reformulated main dishes in canteens (eg, burgers), wholegrain pizza, and yoghurt. A standardised 20% price reduction increased healthy food purchase or consumption by 11·95% (95% CI 4·72 to 19·19; I^2=84·50%; figure 3, appendix pp 14–16). The study with the largest reduction in price[53] was a cohort at a Health Improvement Organisation, reporting changes in salad bar purchases over 3 months before and after a price change. This study did not adjust for potential seasonal effects on purchases. The other three studies reported more modest, but still significant, increases in these healthier food purchases.

Five studies examined the effect of reducing prices of healthy foods (or creating a price difference between healthy and unhealthy food) on the subsequent purchase or consumption of unhealthy foods (three reported changes in purchases, two in consumption; appendix p 23). Food was defined as unhealthy in different ways by the studies, but mainly as food that was high in sugar, fat, and salt (table 1; appendix pp 4–10). Pooled results showed that for each 20% price reduction there was no statistically significant change in unhealthy food purchases or consumption: unhealthy food purchase or consumption fell by 2·40% (95% CI –7·70 to 2·91; figure 4, table 1, appendix pp 4–9, 14–16). Harnack and colleagues[60] reported the largest reduction of 23·5%; this study took place in a low-income population and also introduced restrictions on purchases using SNAP payments (ie, SNAP could not be used to purchase less healthy foods). Ball and colleagues[26] reported an increase in purchases of sugar-sweetened beverages, although this was not statistically significant in the adjusted model (386·2 mL/week [95% CI –52·1 to 824·5]). The appendix (p 22) summarises the results from RCTs in supermarkets which assessed these income effects (ie, the effects of the fruit and vegetable price reduction on purchases or consumption of other foodstuffs within the same supermarket). Overall, there was no compelling evidence of any negative effects on other purchases or consumption from reductions in price of fruit and vegetables or other healthy foods.

Studies that used absolute subsidies (ie, vouchers for a specific cash amount or cash back [n=17], or those that did not clearly report the specific value of subsidies [n=3]) could not be included in the pooled analyses (table 1). These studies were critically assessed and reported narratively (tables 1–3). Aside from four studies done in Europe (France, Ireland, Spain, and the Netherlands) and one study in Australia, all other studies were based in the USA (n=15). Of the 20 studies, seven were conducted in supermarkets, four in canteens, seven in farmers' markets or mobile markets, and two in the local community.

In general, a positive association between the price reduction and increased purchase or consumption of fruit and vegetables was found in 13 studies.[38,39,41,46,50,57,59,63–68] An RCT conducted by Bihan and colleagues[33] found that participants in the group that received vouchers reported consuming fruit and vegetables more times per day compared with the group who were given advice; however, the self-reported outcome is not validated and might be biased. A few studies considered whether the price reduction appeared to alter purchases or consumption of

Study	Study design	Country	Food group	Price reduction (%)	Difference (%)	% change in healthy food purchase and consumption per 20% price reduction (95% CI)	Weight* (%)
Brimblecombe et al (2017)	RCT	Australia	Healthy food	20·0	5·8	5·80 (–1·15 to 12·75)	16·62
Kottke et al (2013)	NRI	USA	Salad	50·0	83·0	33·21 (19·90 to 46·52)	11·79
Lowe et al (2010)	RCT (LA)	USA	VLED food	20·0	9·2	9·24 (0·73 to 17·76)	15·43
Michels et al (2008)	NRI	USA	Healthy food	20·0	6·0	6·00 (4·50 to 7·50)	19·47
Ni Mhurchu et al (2010)	RCT	New Zealand	Healthier products	12·5	11·2	17·91 (9·47 to 26·35)	15·49
Patsch et al (2016)	NRI	USA (PH site)	Healthy salad	35·0	–11·7	–6·66 (–16·35 to 3·02)	14·52
Patsch et al (2016)	NRI	USA (SFMC site)	Healthy salad	35·0	70·1	40·04 (17·28 to 62·80)	6·67
Overall (I^2=84·5%, p=0·000)						**11·95 (4·72 to 19·19)**	**100·00**

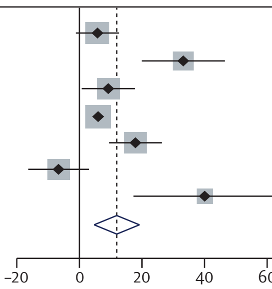

***Figure 3:* Price reduction and healthy food purchase or consumption**
RCT=randomised control trial. NRI=non-randomised intervention. LA=longitudinal analysis. VLED=very low energy density. PH=Penrose Hospital. SFMC=St Francis Medical Centre. *Weights are from random effects analysis. Patsch et al (2016) reported results in two sites. PH had an existing healthy food promotion programme on top of the current intervention, while SFMC did not have another intervention in place. We therefore reported the study results separately by site. Salad bar purchases (Kottke et al, 2013) were not included in the fruit and vegetable analyses as it was not clear whether salad included other types of foods distinct from fruit and vegetables. The healthy burger (Patsch et al, 2016) was not included in this analysis, as the increase in purchases for this item was so substantial that the effect might be because of an increased number of people using the canteen for cost reasons (outcompeting alternative shops during the price reduction period) rather than being a true change in purchasing behaviour by regular customers.

Study	Study design	Country	Food group	Price reduction (%)	Difference (%)	% change of unhealthy food purchase and consumption per 20% price reduction (95% CI)	Weight* (%)
Ball et al (2015)	RCT	Australia	SSB	20·0	59·0	59·02 (–5·25 to 123·29)	0·67
Brimblecombe et al (2017)	RCT	Australia	Less healthy food	30·0	5·3	5·30 (–2·20 to 12·80)	18·68
Harnack et al (2016)	RCT	USA	Restricted food	30·0	–23·5	–15·69 (–37·44 to 6·06)	4·96
Ni Mhurchu et al (2010)	RCT	New Zealand	Less healthy food	12·5	1·7	2·74 (–5·87 to 11·36)	16·69
Patsch et al (2016)	NRI	USA (PH site)	Unhealthy burger and salad	35·0	–4·4	–2·52 (–3·65 to –1·38)	29·39
Patsch et al (2016)	NRI	USA (SFMC site)	Unhealthy burger and salad	35·0	–16·1	–9·18 (–9·93 to –8·43)	29·61
Overall (I^2=95·5%, p=0·000)						**–2·40 (–7·70 to 2·91)**	**100·00**

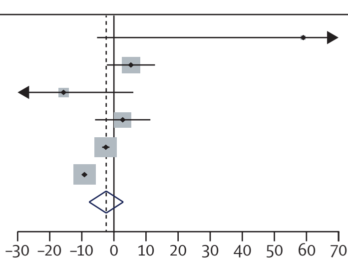

***Figure 4:* Price change and unhealthy food purchases or consumption**
RCT=randomised control trial. SSB=sugar-sweetened beverages. NRI=non-randomised intervention. PH=Penrose Hospital. SFMC=St Francis Medical Centre. *Weights are from random effects analysis. Patsch et al (2016) reported results in two sites. PH had an existing healthy food promotion programme on top of the current intervention, while SFMC did not have another intervention in place. We therefore reported the study results separately by site.

other types of foodstuffs, healthy or unhealthy. A study among participants on SNAP in the USA[40] suggested that those also enrolled in the women, infants, and children programme increased purchases of healthy food by 3·9% ($p<0·05$), while this decreased among the non-participating group by 3·5% ($p<0·05$). However, the trial did not directly compare changes between these two groups. In addition to the increase of healthy food purchases, there was also a decrease in what the authors defined as less healthy beverage purchases (eg, full-fat milk) of approximately 25%.

One multi-component study of workplace canteens found that a price incentive intervention had a larger effect on increased healthy food consumption compared with receiving feedback as an intervention (the feedback group received information about their purchases to encourage healthy food consumption, and the price incentive group received both feedback and a financial incentive).[58] However, the greatest change in healthy food purchases was observed in the healthiest quartile (as determine by baseline data of canteen purchases), with little change seen in the least healthy quartile.

We also performed sensitivity and subgroup analyses on the included studies. Only a minority (ten [29%] of 34) of studies reported consumption outcomes rather than purchases. The ten studies that report consumption data have their results highlighted in the appendix (pp 10–13). These studies were not conclusive, but the RCTs among low-income groups identified similar, and potentially important, effects of price reductions for consumption of healthier food products (eg, a 0·4 increase in servings of fruit per day).[44,60]

Our pooled analyses reported studies of both purchases and consumption. In sensitivity analyses we therefore

	Selection bias*: randomisation	Selection bias: concealment	Outcome assessment masking	Incomplete outcome data	Selective reporting	Other sources of bias	Final score
Anderson et al (2001)[62]	Unclear	Unclear	Low	High	Low	Unclear	High
Ball et al (2015)[26]	Low	Low	Low	Low	Low	Unclear	Low
Bihan et al (2012)[33]	Unclear	Unclear	Unclear	High	Low	High	High
Brimblecombe et al (2017)[27]	Low	Low	Unclear	Unclear	Low	Low	High
Harnack et al (2016)[60]	Low	Low	Low	Low	Low	Low	Low
Lowe et al (2010)[54]	Unclear	Unclear	Unclear	High	Unclear	Low	High
Ni Mhurchu et al (2010)[28] and Blakely et al (2011)[43]	Low	Unclear	Low	Low	Unclear	Low	Low
Olsho et al (2016)[44]	Low	Low	Unclear	High	Low	High	High
Phipps et al (2013b)[48] and Phipps et al (2015)[49]	Low	Low	Low	Low	Low	Unclear	Low
Polacsek et al (2018)[45]	Low	Low	Low	Low	Low	Unclear	Low
Segura-Perez et al (2017)[59]	Unclear	Unclear	Unclear	Low	Low	High	High
Thorndike et al (2016)[58]	Low	Unclear	Low	Low	Low	Low	Low
Velema et al (2018)[57]	Low	Low	Low	Unclear	Low	Unclear	Low
Waterlander et al (2013)[24]	Low	Low	Unclear	High	Low	Low	High
Moran et al (2019)[38]	Unclear	Unclear	Low	High	Unclear	Low	High
Vadiveloo et al (2021)[42]	Low	Low	Unclear	Low	Low	Low	Low

High=high risk of bias. Unclear=unclear information provided, therefore possibly some concerns of risk of bias. Low=low risk of bias. See the appendix (pp 12–14) for further details of the basis of these ratings. *Based on Cochrane Risk of Bias for randomised control trials.

Table 2: **Risk of bias assessment for studies with randomised controlled design**

excluded five studies which reported consumption data only (one study in common for fruit and vegetables and unhealthy food analysis). However, this did not change the results compared to our main analyses (fruit and vegetables 15·81% [95% CI 8·52 to 23·10]; healthy food 14·45% [3·65 to 25·25]; and unhealthy food: –1·69% [–7·15 to 3·77]; appendix pp 24–25). We also performed a sensitivity analysis of the three studies with a multi-component intervention (price reductions combined with other interventions, such as nutrition education or spatial interventions). Although the pooled analysis indicated a positive effect of price reduction on fruit and vegetables (17·24% [5·00 to 29·47], I^2=63·7%; appendix p 25), the inclusion of only three studies limits the conclusions that can be drawn.[24,26,60] However, Harnack and colleagues' study[60] suggested that price reduction had a greater effect on overall diet for the group where unhealthy foods were restricted alongside a price reduction compared with the group that had price reductions alone.

Among studies reporting price reduction and healthy foods, one study, Patsch and colleagues,[56] had two options, healthier salads and healthier burgers, as the main food types targeted. The healthier burger had a lower salt and fat content compared to a standard burger in the canteen. However, as the health benefits of these products might be less clear-cut than those targeted in other studies (such as very low energy density food or fruit and vegetables) we performed a sensitivity analysis after excluding this study. Results of this sensitivity analysis were similar (12·65% [95% CI 5·52 to 19·78], appendix p 26).

We did further sensitivity analyses for studies of longer duration; four studies where the intervention lasted 6 months or more showed a similar effect on fruit and vegetable purchase or consumption compared to the main results (16·15% [95% CI 11·51 to 20·79], appendix p 27).

We also conducted subgroup analysis based on the level of the intervention agency involved. We defined interventions that relied on participants' personal resources as high agency (eg, participants needed to present a paper voucher or coupon to redeem), whereas interventions that required less individual recall were classed as low agency (eg, price reductions automatically applied to all the participants, or all employees qualified for the price reduction). Studies with higher levels of intervention agency might be expected to show a slightly weaker effect on fruit and vegetable purchase or consumption compared with those requiring low levels of intervention agency, but our analysis was underpowered and not conclusive (14·94% [95% CI 3·93 to 25·95] and 17·06% [14·12 to 20·01], respectively; appendix p 28).

Tables 2 and 3 show the quality assessment of included studies using RoB and NOS quality assessment tools. Due to the nature of food price interventions it is difficult to implement masking among participants during the intervention phase. We therefore modified the Cochrane RoB tool slightly, by omitting the criterion for blinding for participants or researchers in this review (see appendix pp 18–20 for more details). Eight out of 16 RCTs were considered to have a high risk of bias. Among all domains, bias due to incomplete

	Selection*				Comparability* of cohorts on the basis of the design or analysis	Outcome*			Final score*
	Representativeness of the exposed cohort	Selection of the non-exposed cohort	Ascertainment of exposure	Demonstration that outcome of interest was not present at start of study		Assessment of outcome	Was follow-up long enough for outcomes to occur?	Adequacy of follow-up of cohorts	
Andreyeva and Luedicke (2015)[39] and Andreyeva and Tripp (2016)[40]	0	1	1	1	2	1	1	0	7
An and Sturm (2017)[25] and Sturm et al (2013)[47]	1	1	1	1	2	1	1	0	8
Black et al (2013)[61]	0	1	1	1	1	1	1	0	6
Durward et al (2019)[63]	1	1	1	1	0	0	0	0	4
Fernández Torres et al (2014)[51]	1	1	1	1	1	1	1	0	7
Geaney et al (2016)[52]	1	1	0	1	1	0	1	0	5
Kottke et al (2013)[53]	1	1	1	1	0	1	0	0	5
Lindsay et al (2013)[64]	1	1	0	0	1	0	1	0	4
Michels et al (2008)[55]	1	1	1	1	0	1	0	1	6
Olsho et al (2016)[44]	1	1	1	1	0	0	0	0	4
Patsch et al (2016)[56]	0	1	1	1	2	1	1	0	7
Phipps et al (2013)[41]	0	1	1	1	1	1	0	1	6
Ratigan et al (2017)[66]	1	1	1	1	2	0	1	0	7
Rummo et al (2019)[46]	0	1	1	1	0	1	1	1	6
Savoie-Roskos et al (2016)[67]	1	1	1	1	1	0	0	0	5
Steele-Adjognon and Weatherspoon (2017)[50]	1	1	1	1	2	1	1	0	8
Toft et al (2017)[29]	1	1	1	1	1	1	1	0	8
Young et al (2013)[68]	1	1	1	1	0	0	0	0	4

NOS=Newcastle Ottawa Scale. *Based on the NOS. The maximum score of NOS is 9. The selection domain has a maximum score of 4, and each subdomain ranges from 0 to 1; the comparability domain has a maximum score of 2 (range 0–2); the outcome domain has maximum score of 3, and each subdomain ranges from 0 to 1. A higher score indicates better quality of the study.

Table 3: **Risk of bias assessment for studies with non-randomised design**

outcome was rated as high in six studies (usually due to losses to follow-up). Most studies were at low risk in selective reporting, as they reported the outcomes originally intended. Other sources of bias concerned were reporting bias (ie, self-reported outcomes), representativeness of the intervention group, and selection bias (eg, willingness of the store owners and shoppers to participate in the study). Most studies in supermarkets relied on volunteers to sign up to a loyalty card or similar scheme to implement the price reduction and keep track of their purchases. This may affect generalisability, if shoppers who did not sign up are those less influenced by the price reduction. 29 (30%) of 96 risk assessments were rated as unclear by researchers among the six domains of the risk of bias tool.

Using the NOS tool (scoring ranges 0–9, higher score indicates better quality) to assess the study quality among studies with non-randomised designs, three out of 18 scored 8, four scored 7, three scored 5, four scored 6, and four scored 4. The most concerning area of the quality assessment results was adequacy of follow-up of cohorts, with only three studies rated as adequate; the rest all had a minimum of 20% loss to follow-up. Outcome assessment was another common issue: seven studies rated a 0, mostly due to use of self-reported outcomes (eg, self-reported changes in consumption of fruit and vegetables). Seven studies had short follow-up periods (ie, less than 3 months).

Fewer studies (n=16) reported consumption as an outcome, and many of these were quite small. Only half of these were randomised in design, and only four used optimal approaches to assess consumption (eg, dietary recall) and reported differences in changes in food consumption clearly across study groups (appendix pp 10–13).

A further concern was that many studies had not performed optimal statistical analyses. For example, some studies reported fruit and vegetable purchases in the intervention and control groups separately, with a p value for the within-group change but no assessment of change or statistical significance of this change between the groups.

Discussion

The strongest evidence of benefits from price reductions came from RCTs taking place in supermarkets, where we found that a modest 20% price reduction resulted in a 17% increase in the purchase of fruit and vegetables. Positive changes were similar for other types of healthier foods, and across different study designs and settings. We included several well designed interventions in low-income or marginalised groups, and these showed a similar effect overall. Few adverse income effects were identified (such as increased purchases of unhealthy foods), although this was not assessed in many studies. Greater health gains from improving diet might be expected in more marginalised groups, since their baseline consumption of healthier foods, particularly fruit and vegetables, is typically lower.

In the UK, average consumption of fruit and vegetables is currently 3·8 portions a day, therefore an increase of approximately 17% would result in an additional 0·6 servings per day. An increase in daily servings of approximately 0·6 could have significant public health implications, as meta-analyses suggest that a single unit increase in fruit and vegetable intake can reduce risk of death by about 13% for stroke,[4] 4% for myocardial infarction,[4] 6% for diabetes,[69] and about 2–8% for different cancers.[4,70] Taken individually these risk reductions might seem modest, as many thousands of people die every year from these causes, but the absolute population benefit effect could be substantial and the effect on health-related quality of life and non-fatal events would probably be even greater. Larger reductions in price could have even larger effects.[24,53]

This effect size from our review compares favourably with other dietary interventions. A social marketing campaign in the UK was estimated to have resulted in an increase of only 0·25 servings of fruit and vegetables per day (about 7%),[71,72] although it was deemed cost-effective.[72] Cost-neutral ways of implementing price reductions policies have been identified,[56] and policy evaluation elsewhere has shown changes in just one meal a day can be sufficient to result in small but significant dietary benefits, suggesting that price changes in workplace canteens might also be beneficial.[72]

Previous narrative and systematic reviews and studies on pricing interventions have reached mixed conclusions. A previous review[22] found slightly larger effects of price reductions on purchases of healthy foods, but did not include the more recent randomised evidence. Another review of both taxation and subsidies[30] found similar benefits for purchases, but suggested that there was no evidence of benefits of price reduction on consumption. This remains an evidence gap, but our review assessed three RCTs[26,44,60] that showed a similar pattern of benefits of price reduction for consumption outcomes (increased fruit and vegetable consumption and reduced unhealthy food consumption), which were not included in this previous review.[30] While this was not an original aim of our protocol, three studies explored whether other intervention strategies combined with price reduction (eg, nutrition education, or restricting the use of food subsidies for unhealthy foods)[24,26,60] had a greater effect than price reduction alone. Conversely, nutrition education interventions alone had no effect on fruit and vegetable purchases, in agreement with other studies.[72] We also explored whether simplifying the application of the price reduction (eg, discounts automatically applied on loyalty card) could increase purchases of healthier foods, but this was not conclusive.

Our analysis has several strengths. We conducted a comprehensive search process that identified more studies than earlier reviews. We identified nine studies that were not included in previous reviews;[22] with our sensitive search strategy, we also included six more studies compared with the 2022 review:[30] all of these additions were studies not from the USA, and four were RCTs. We included several recent RCTs in low-income and marginalised communities, which found overall similar though more heterogeneous estimates of effect. We also appraised studies using recommended tools and summarised the robustness of the evidence base. Most studies targeted price reductions in fruit and vegetables; this is appropriate as these are relatively expensive commodities, and there is good evidence that on a population level, very few consume sufficient portions.

Many studies had not reported standard errors for the differences between study groups, reporting only changes in purchases or intakes resulting from the price reduction intervention for both intervention and control groups separately, each accompanied by its own p value. We contacted several study authors or performed further analyses to estimate the information required (standard errors of the change between groups) and were thus able to perform a meta-analysis of the direct comparison between the intervention and control groups, even though this was not reported in some of the original studies. We standardised the level of discount (20%) to compare studies with different price reductions and to generate an overall effect. Whilst heterogeneity was observed in several of our meta-analyses, we further explored this through subgroup analyses (eg, for different food groups, and low-income populations) and sensitivity analyses.

Our systematic review has limitations, mainly reflecting weaknesses within specific studies that we included. Our database search was comprehensive, but price reductions are complex interventions that are difficult to search for, and some may be published only in grey literature or are harder to identify with typical search methods. Although we contacted two study authors to clarify key study outcomes, other authors may have been able to add detail (eg, to risk of bias assessments where these were not clear).

Most studies focused mainly on purchases rather than consumption as the key outcome measure influenced by the price reduction. However, although consumption is a more immediate outcome, purchases can be measured very accurately (based on electronic sales or purchase data collected for billing purposes by canteens and supermarkets), while nutrient consumption is notoriously difficult to measure well. It could also be assumed that in canteen-based studies, participants are more likely to consume the meal they have just purchased, and our overall estimate of the effect of subsidies in canteen-based studies was very similar to that from supermarkets and other settings. 16 studies also attempted to measure consumption, some using measures (eg, 24-h dietary recall), and found results broadly in agreement with those based on purchases alone (appendix pp 4–9). However, the evidence for consumption data is limited, as most studies were small, not all had a randomised trial design, and they did not necessarily use optimal methods of assessing dietary intakes. Many studies only analysed results within each group before and after intervention, rather than changes between groups, or used FFQ, which might be more biased. Most studies applied the price reduction to fruit and vegetables, but some applied it to other food types that they defined as healthier. The healthier foods targeted in these studies varied considerably and results were also heterogeneous. Whether price reductions can alter purchase or consumption of other food groups (eg, wholegrain foods) had less data to explore and draw conclusions from. Even the studies focusing on fruit and vegetables had somewhat variable definitions—for example, some subsidising only fresh fruit and vegetables while others included tinned or frozen produce, or in a few cases fruit juice, despite reasonable concerns about the high sugar content of juice.

We only included studies reporting price reduction as the main intervention strategy, or studies which reported results separately for different strategies. However, some studies[3,47,51] integrated other intervention components in design, and we cannot entirely rule out cumulative subtle effects from other intervention components that supported the effect of price reduction (eg, signage posting, or favourable positioning of healthier food).

Many studies included in our review had high rates of losses to follow-up, which might introduce bias. Most were also relatively short term, lasting only a few months. It is therefore not clear whether the observed improvements might be sustained over time. The few studies[46,60,64] with longer intervention periods and follow-up times reported variable sustainability over time. Repeated reminders or other forms of engagement might be required to maintain benefits. However, our sensitivity analysis among studies with intervention duration longer than 6 months showed similar changes in fruit and vegetable purchase or consumption to the overall analysis that included those studies with a shorter intervention duration.

Finally, some studies reported on potential income effects (appendix p 17). While few negative effects were identified, none could completely rule out the possibility that purchasers responded to price reductions by purchasing other less healthy foodstuffs elsewhere. However, some studies did perform sensitivity analyses (eg, among shoppers who reported at baseline that they never or rarely shopped elsewhere), and most found no strong evidence of substantial or potentially adverse effects.[28]

Further research is needed to assess changes in consumption over the long term using validated tools. Studies could assess the effect of price reductions on overall dietary quality or calorie intake, rather than just the foods targeted. Studies of lunchtime meal changes, particularly in workplace canteens, should explicitly assess the effect of price reductions on dietary quality. Food purchased for immediate consumption (eg, in workplace canteens) is more likely to be consumed rather than wasted; additional studies in such settings might enhance understanding of the relationship between food prices and diet and sustainability over time. Studies could explore whether the method of implementation of the price reduction influences its uptake and use.

In conclusion, if sustained, price reductions targeted at fruit and vegetables (and potentially other healthier foods) could lead to significant changes in purchases and consumption that are substantial enough to yield health benefits. Available evidence generally suggested that in more disadvantaged communities, where fruit and vegetable intake is usually lower, increases in supermarket purchases of fruit and vegetables were comparable to the general population, suggesting a greater potential for overall health benefits in these communities.

Contributors
JAC, FP, LJA-R, and PH: conceptualisation, study design. FP: search strategy. FP, JAC, and CW: study screening. PH, JAC, FP, FMA-H, and CW: data extraction and study assessment. PH and JAC: data analysis. JAC, PH, FP, CW, and KW: manuscript drafting. FMA-H, SFA, and LJA-R: critical revisions of manuscript. JAC and PH are the guarantors of this work and, as such, had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Declaration of interests
We declare no competing interests.

Acknowledgments
We thank Simon Capewell for critical comments on an earlier draft. This publication was made possible by National Priorities Research Program grant number 10-1208-160017 from the Qatar National Research Fund (a member of Qatar Foundation). The statements made herein are solely the responsibility of the authors.

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