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# The influence of a front-of-pack nutrition label on product reformulation: A ten-year evaluation of the Dutch Choices programme

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ABSTRACT

Front-of-pack (FoP) labels are regarded as helpful tools to stimulate healthier product reformulation as they are based on nutrient criteria that products should comply with in order to obtain the label. Some FoP labelling programs revise criteria periodically. This is the first study investigating the impact of criteria revisions on product compositions over time. Nutrient contents of 4,343 products, including 27 basic and non-basic product (sub) categories with the Dutch Choices Logo were analysed between 2006 and 2016. The number of labelled products increased over time. Sodium and trans-fat contents reduced significantly in 10 and 11 product categories, respectively. Energy, saturated fat and added sugar decreased significantly whilst fibre increased in 4–6 product categories. Overall, labelled products had healthier compositions and more favourable trends in nutrient content compared with products generally on the Dutch market. The results of this study suggest an important role for FoP labels in product reformulation.

## 1. Introduction

The obesity rates have nearly tripled worldwide since 1975, leading to an increased risk of non-communicable diseases (NCDs) (World Health Organization, 2018). On average, 39% of adults of 18 years and older are overweight of whom 13% are obese (World Health Organization, 2018). A major priority in the WHO Food and Nutrition Action Plan 2015–2020 is to combat obesity by helping consumers identify healthier foods, through front-of-pack (FoP) nutrition labelling (World Health Organization, 2014).

Worldwide, a large range of FoP labels have been developed (van der Bend et al., 2014), although health-conscious consumers may be the main users of information on such labels (Vyth et al., 2010). Besides this, label use is dependent on country, product type, and may be influenced by factors such as age, sex, education levels, and socio-economic status (Grunert et al., 2010; Konttinen, Sarlio-Lähteenkorva, Silventoinen, Männistö, & Haukkala, 2012; Smed, Edenbrandt, Koch-Hansen, & Jansen, 2017; Viola, Bianchi, Croce, & Ceretti, 2016; Vyth et al., 2010). Since these factors are relatively difficult to modify, it is essential that greater emphasis is put on FoP labels' secondary purposes, including product reformulation.

Product reformulation is one of the most effective strategies to address obesity and reduce consumption of saturated fats, sugar and salt, as it does not require significant changes in consumers' eating behaviours (Lehmann et al., 2017). Increasing the availability of healthier products is likely to target the diets of all consumers (Dobbs et al., 2014). Most FoP labelling organisations aim to encourage food companies to reformulate for healthier products by offering them a way to show that their products are 'healthier' than products from competitors (van der Bend & Lissner, 2019). However, FoP labels may play a minor role in companies' final operational innovation process (Blok, Tempels, Pietersma, & Jansen, 2017; Jansen, de Vos, & Blok, 2015). Economic considerations (e.g. product quality and price), consumer demand, stakeholder pressure, competitor behaviour and legislation are weighed against moral considerations (i.e. reformulation for the sake of public health) at companies' strategic level, providing input for the operational innovation process. (Blok et al., 2017).

Yet, previous research suggests beneficial effects of FoP labelling on products nutrient compositions, although effect size differs between products, with often only a limited number of product categories being analysed (Ni Mhurchu, Eyles, & Choi, 2017; Ning, Mainvil, Thomson, & McLean, 2017; Thomson, McLean, Ning, & Mainvil, 2016; Vyth, Steenhuis, Roodenburg, Brug, & Seidell, 2010; Young & Swinburn, 2002). To date, no studies have captured the long-term impact of FoP labelling programs by structurally monitoring nutrient compositions of FoP-labelled products over longer time periods. Yet, this could give

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valuable insight into FoP labelling market developments. Also, periodical criteria revisions, as applied by some FoP labels (Jansen & Roodenburg, 2016), have not been studied in relation to product reformulation so far. Available data from the Dutch Choices Foundation offer a unique opportunity to evaluate reformulation in many different product categories with a positive FoP label over the past ten years, covering three major nutrient criteria revisions.

Our first objective is to investigate in what direction the number and nutrient content of FoP-labelled products have changed over the past ten years, and how these changes relate to changes in the label's nutrient criteria. We generally expect to observe changes 'favourable for health', by which we refer to products with lower levels of energy, saturated fat (SAFA), trans fat (TFA), added sugar and sodium, and higher fibre content, as these are the nutrients targeted specifically in the Dutch Choices Logo (DCL) criteria. However, we expect that many factors besides the presence of FoP labels, including general market developments, may influence the companies' innovation agenda and potentially attenuate the effect of FoP labels. Therefore, to learn about developments in the general food market, our second objective is to compare (trends in) mean nutrient compositions of average products on the Dutch market with DCL-labelled products over the past ten years. We expect that labelled products are relatively lower in energy, SAFA, TFA, added sugar and sodium, and higher in fibre compared to average products, as they need to comply with the DCL's nutrient criteria. Considering that competitor behaviour is partly influencing companies' innovation agenda, we expect that average products follow the same trend as labelled products, or that nutrient compositions of labelled and average market products will slightly converge over time.

## 2. Materials and methods

### 2.1. Materials

To investigate the composition of FoP-labelled products over time, data from the Dutch Choices Foundation was used. The Dutch Choices Foundation was established in 2006, at the request of the Dutch Ministry of Health, by representatives from the food industry, retail, and catering organisations. The Dutch Choices Logo (DCL) or 'Vinkje' is its FoP logo presented on packaged foods sold in supermarkets and sometimes on signs in catering settings.

The DCL is assigned to products that contain less calories, lower levels of SAFA, TFA, added sugar, sodium, and have higher fibre content compared to other products within the same product category. The product criteria are developed by the Choices National Scientific Committee and are based on (inter)national food-based guidelines (Jansen & Roodenburg, 2016; Roodenburg, Popkin, & Seidell, 2011). Products fall either into basic product categories that contribute significantly to the daily intake of essential nutrients (i.e. dairy, vegetables, bread), or into non-basic product categories that do not contribute significantly to daily intake (i.e. soups, sauces, snacks). According to the most recent Dutch Choices criteria from 2015, in total 31 product categories are distinguished (see Supplementary Table S1a and S1b) (Stichting Ik Kies Bewust, 2015).

The DCL criteria are periodically evaluated and adjusted by the Scientific Committee, using available product composition databases in order to set criteria in a way that only best-in-class products will be able to obtain the logo. Revisions of the Dutch Choices product criteria took place one year after the launch of the logo and every four years since (i.e. in 2007, 2011 and 2015), see Supplementary Table S1a and S1b. The criteria were revised regularly to stimulate food producers to improve their products and ensure that the DCL is only granted to best-in-class products.

### 2.2. Data collection procedures

Nutrient compositions of products were collected from Dutch manufacturers and retailers that were member of the Dutch Choices Initiative between 2006 and 2016. The product data of one Dutch retailer joining in 2010 was not available in the database and could therefore not be included in this study.

Between 2006 and 2012, the product composition and identification data of products applying for the DCL were sent to the certifying agents TNO (The Hague, the Netherlands) in 2006, and to SGS (Spijkenisse, the Netherlands) from 2007 by the member companies. Based on the product information in these files, agents made a decision on whether a product qualified for the logo. The certifying agent was allowed to request results of laboratory analyses of products when in doubt whether the provided product composition data were correct. Subsequently, the agents informed the Dutch Choices Foundation and the producer about the outcome of the certification. Only after certification manufacturers could use the DCL on their products.

From 2012, Choices used an online tool to certify products. Once the certifying agent certified a product in the online tool, all product data entered by the companies were automatically added into an online database. All products that were already certified before 2012 were manually loaded into the online database by the Choices Foundation, after which companies were asked to verify whether these products were still being sold with the logo on the package and if their nutritional composition was still correct. If products did no longer carry the logo, they were archived, but their data was still available in the database. If product compositions had changed, companies were asked to archive the product data, submit a new product for certification and add the new product information.

In addition to the certification of products by certifying agents, market controls were performed yearly. For this market control, fifty to hundred DCL-certified products were selected and chemically analysed to check the relevant nutrient contents. Products were particularly selected for market control if the content of one or more nutrients was close to the labelling criteria. Market controls showed that there were hardly any violations of nutrient contents in products that carried the logo, even though many products needed to be innovated after a DCL criteria revision.

### 2.3. Product categories included

All products carrying the DCL between 2006 and 2012 were categorized into product categories, as described in the Dutch Choices product criteria (Stichting Ik Kies Bewust, 2015). The type of product information that was included is described in Supplementary Table S1. Since products were submitted for certification in separate files until 2012, it was not routinely registered if and until when these products still carried the logo. Therefore, per given calendar year it was assumed that all products were still carrying the logo until at least 2012, except when products did not meet the logo criteria one year after new DCL criteria were introduced or when a company was no longer member of the FoP labelling programme.

Next, all products that obtained a logo between the establishment of the online database (2012) and the moment of data collection for this study (March 2016) were retrieved from the online database, categorized into the same product categories and combined with the 2006–2012 file.

Five product categories (i.e. 1, 4, 5, 12 and 14, see Supplementary Table S1a and S1b) concern unprocessed product categories of which the nutritional composition relevant to the criteria is not expected to change significantly over time; therefore they were not included in the initial categorisation process. For categorisation, a total number of 4477 products was present in the database between 2006 and 2016. Product categories that contained fewer than 10 products per year before 2012 were excluded from the analysis (i.e. product categories 3, 7, 8, 10, 11, 19, 20, 21, 22, 23 and 31, see Supplementary Table S1a and S1b). In case of large variation within product categories, the composition of particular subcategories within such product categories

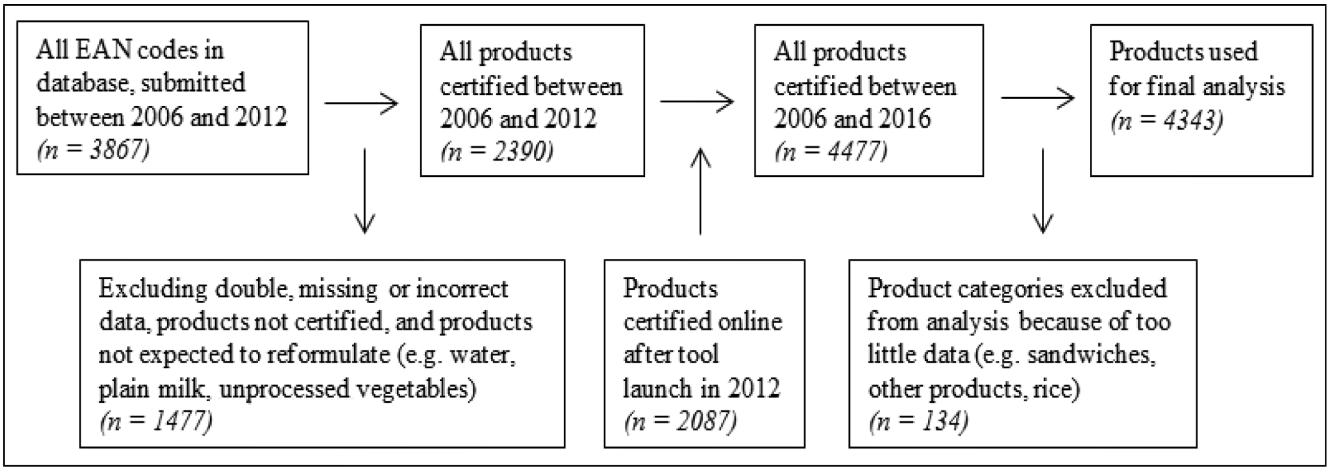



**Fig. 1.** Flow chart of products carrying the Dutch Choices Logo.

was studied as well. A subcategory was defined as a category of products within the product category with a comparable composition or use in the daily diet. For example, within the milk product category the drink yoghurt products were defined as a subcategory. For final analysis, 27 product (sub-) categories were created (basic: n = 15; non-basic: n = 12), including in total 4343 products (Fig. 1).

### 2.4. Comparison with the Dutch Food Composition Database

The Dutch Food Composition Database (NEVO) (RIVM, Bilthoven, the Netherlands) contains nutritional data of food items frequently consumed by a large proportion of the Dutch population. The nutritional composition of these food items can be viewed in the NEVO-online database and is regularly updated by the Dutch Institute for Public Health and the Environment (RIVM). Since 2009, manufacturers are able to enter or change the nutrient composition of their products using an online application from the Dutch Nutrition Centre. These changes are verified by the RIVM and entered in NEVO, after which products are clustered into generic food items, of which the mean nutrient composition is calculated (RIVM, 2016). Thus, the nutrient content of one food item in NEVO reflects the mean of a group of products that have similar characteristics. During revisions of NEVO, it is examined whether products or brands are still available on the market, and if not, they are removed from the database.

To compare mean nutrient compositions of FoP-labelled product categories to mean nutrient compositions of NEVO product categories, the energy or nutrient content of 3 to 9 NEVO food items was averaged into one value, for both 2006 and 2016 (Supplementary Table S3). For each product category, nutrients considered most relevant in the debate on healthy product reformulation were included in the NEVO-FoP label comparisons (Supplementary Table S3).

### 2.5. Statistical analysis

The yearly average nutritional composition of each DCL product category was calculated between 2006 and 2016. Besides energy, the five nutrients that were of main interest for this analysis were added sugar, SAFA, TFA, sodium and fibre. To test the statistical significance of the nutrient composition changes of FoP-labelled products between 2006 and 2016, Mann Whitney U tests were performed. First, an overall analysis was performed to examine whether there was a significant change over time in all products, all basic products and all non-basic products. Next, all 27 product (sub-) categories were analysed individually, using the 2006/07 composition as reference. However, when fewer than 10 products were available for a product category in 2006/07 (i.e. 12 product categories), the reference for the analysis was 2007/08. Similarly, when fewer than 10 products were available in both 2006/07 and 2007/08 (i.e. two product categories), the analysis covered the period between 2008/09 and 2015/16.

To compare changes in mean nutrient composition of FoP-labelled product categories with comparable NEVO product categories, the nutrient content of the NEVO product categories in 2006 were set at 100%. The nutrient composition of NEVO product categories in 2016, and of FoP-labelled product categories in the starting year and in 2015/16 were analysed as a percentage of the NEVO nutrient composition in 2006. As NEVO included only the average composition of a limited number of food items for each category, significance of the difference between NEVO products and FoP-labelled products could not be examined and only descriptive analyses were performed.

## 3. Results

### 3.1. Composition of FoP-labelled products over time

Overall, the number of products with a FoP label increased over time, mainly due to a relatively large increase in the number of non-basic products with the DCL since 2006 (Table 1 and Fig. 2). Within almost all product categories, the total number of products increased since the first year they were included in the analysis, except for processed potatoes and bread toppings (Fig. 2). In 2012/13 a clear reduction in the number of products was observed for all product categories, which can be attributed to the cleaning of the product database when shifting from single product Excel files to the online product database.

In Table 1 and Tables S4a and S4b, 'Old' (i.e. 2006/2007, 2007/2008 or 2008/2009) and 'New' (i.e. 2015/2016) mean nutrient contents for all, basic, non-basic and individual 27 (sub-) product categories are presented. Table 2 describes nutrient content changes between 'Old' and 'New', and compares these to criteria revisions between 2006/2007 and 2011, and 2006/2007 and 2015. When comparing 'Old' to 'New' nutrient contents, for the product categories bread, hard cheeses, soups, ice cream/sorbet and fruit juices a significant change was observed in at least four of the six nutrients analysed. For soft cheese, processed fruit & vegetables, processed fruit, processed fish, processed meat, bread salads, candy (snacks) and soft drinks, a significant change in only one or none of the six nutrients was detected over time (Table 2).

#### 3.1.1. Energy

Overall, the energy density of all 'New' FoP-labelled products was significantly lower than the energy density of all 'Old' labelled products (mean reduction: 29 kcal/100 g (17%)). In non-basic products we also

**Table 1**
Average nutrient contents of all, basic and non-basic products with the DCL (mean (SD)) in different periods (Old[1/2/3] and New[4]).

| | Energy (kcal/100 g/ml) | Saturated fat (g/100 g/ml) | Trans fat (g/100 g/ml) | Added sugar (g/100 g/ml) | Sodium (mg/100 g/ml) | Fibre (g/100 g/ml) |
|---|---|---|---|---|---|---|
| **All (Old[a])** | 169.85 | 2.0 | 0.071 | 2.46 | 333.24 | 1.76 |
| *(N = 582)* | (156.44) | (3.15) | (0.15) | (4.31) | (240.78) | (3.44) |
| **Basic (Old[a])** | 194.55 | 2.57 | 0.078 | 1.06 | 311.59 | 2.06 |
| *(N = 308)* | (181.80) | (4.07) | (0.19) | (1.91) | (263.52) | (2.59) |
| **Non-basic (Old[a])** | 142.09## | 1.36## | 0.064## | 4.03## | 357.57## | 1.42## |
| *(N = 274)* | (116.01) | (1.31) | (0.01) | (5.54) | (210.17) | (4.18) |
| **All (New)** | 140.51** | 1.64** | 0.037** | 2.30 | 305.24** | 1.88* |
| *(N = 1521)* | (142.42) | (3.38) | (0.11) | (4.74) | (244.16) | (4.01) |
| **Basic (New)** | 182.12 | 2.72** | 0.040** | 0.58** | 286.08* | 2.31 |
| *(N = 693)* | (168.50) | (4.69) | (0.14) | (1.26) | (294.90) | (3.45) |
| **Non-Basic (New)** | 105.68**## | 0.74**## | 0.034**## | 3.74## | 321.27**## | 1.53**## |
| *(N = 828)* | (104.19) | (0.92) | (0.067) | (5.95) | (190.35) | (4.40) |

[1] Average composition in 2006/2007; 2 Average composition in 2007/2008; [3] Average composition in 2008/2009; [4] Average composition in 2015/2016.
* Compared to Old: $p < 0.05$ (Mann-Whitney *U* test); ** Compared to Old: $p < 0.01$ (Mann-Whitney *U* test).
# Compared to Basic: $p < 0.05$ (Mann-Whitney *U* test); ## Compared to Basic: $p < 0.01$ (Mann-Whitney *U* test).
Product categories included in 'Basic' and 'Non-basic' are listed in Fig. 2a and b.
*DCL: Dutch Choices Logo*
[a] Includes product categories with different starting years, depending on category (see Tables 2 or 4a–c).

observed a significant reduction in energy density over time (Table 1).

The caloric content changed significantly in 11 product categories, of which 4 showed a significant reduction (Table 2), mostly non-basic categories, i.e. processed vegetables (27 kcal/100 g (40%)), sauces on water basis (26 kcal/100 g (31%)), bread toppings (61 kcal/100 g (23%)) and fruit juices (5 kcal/100 g (12%)) (Table S4). In fruit juices and bread toppings this may be linked to product criteria revisions, as for both groups a criterion for energy content was introduced for the first time in 2011. Fig. 3 shows a clear drop in the energy content for both categories after 2011. For bread toppings, this reduction may be attributed to a SAFA reduction, as added sugar content of this category has increased over time (see section 3.1.4.). However, while the energy criterion for soft drinks were also tightened over the years, no significant energy reduction for this category was observed (Table 2). The significant energy reduction in sauces on water basis may be the result of the introduction of a criterion for added sugar in 2015. The energy reduction observed in processed vegetables cannot be linked to criteria revisions.

For some labelled product categories significant changes in energy density were observed that were less favourable for health. The energy density of bread, cheese, hard cheese, soft cheese, processed meat and meat substitutes, and candy, increased significantly (mean increase respectively: 17 kcal/100 g (7%); 66 kcal/100 g (25%); 38 kcal/100 g (15%); 26 kcal/100 g (20%); 27 kcal/100 g (18%); 1 kcal/100 g (7%)) (Table S4). For cheese, this increase could partly be linked to a less strict criterion for SAFA in 2011 (Table 2 and Fig. 3).

In DCL-labelled sauces on water basis and fruit juices (shown in Figs. 4 and S5c, respectively), the magnitude of the energy reduction appeared to be larger and resulted in a lower mean energy density in 'New' than in comparable NEVO products. Furthermore, the energy density of NEVO bread toppings increased from 'Old' to 'New', which is in contrast with the significant energy reduction observed in DCL-labelled bread toppings (Fig. 4). While the energy density of DCL-labelled candy showed a time trend unfavourable for health, caloric content still appeared to be lower than the comparable NEVO category (Fig. S5c).

### 3.1.2. Saturated fat

Over time, SAFA content of all labelled products has significantly decreased (mean reduction: 0.36 g/100 g (18%)), in basic as well as non-basic labelled products (Table 1). The SAFA content changed significantly in 9 product categories, of which 6 showed a reduction (Table 2); this includes bread, milk-based drinks, milk-based desserts, emulsion sauces, bread toppings and snacks (mean reduction: 0.24 g/100 g (29%); 0.16 g/100 ml (47%); 0.14 g/100 g (73%); 0.21 (10%);

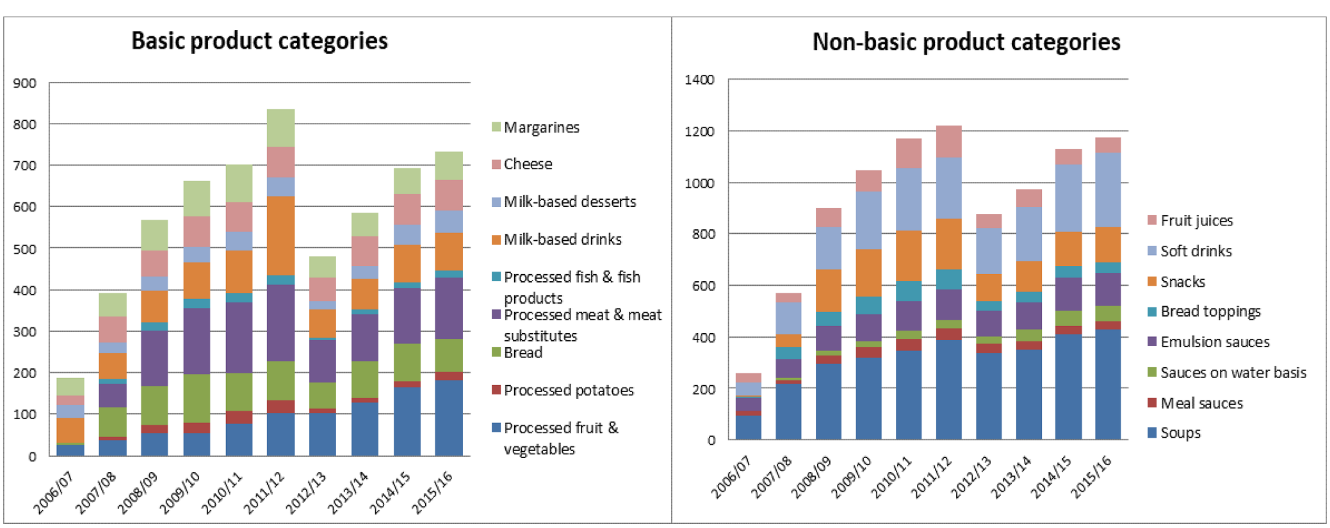



**Fig. 2.** Left: Number of basic DCL products between 2006/07 and 2015/16. Right: Number of non-basic DCL products between 2006/07 and 2015/16. DCL: Dutch Choices Logo.

**Table 2**
Changes in energy and nutrient contents of 'New' compared to 'Old' DCL products (large symbol), in relation to energy and nutrient criteria changes between 2006 or 2007 and 2011 (1st smaller symbol), and between 2006 or 2007 and 2015 (2nd smaller symbol).

| | Energy | Saturated fat | Trans fat | Added sugar | Sodium | Fibre |
|---|---|---|---|---|---|---|
| Bread[2] | $\uparrow^{a}$ | $\downarrow^{\downarrow\downarrow}$ | $\downarrow^{\downarrow\downarrow}$ | $\downarrow^{0\downarrow}$ | $\downarrow^{0\downarrow}$ | $0^{0\downarrow}$ |
| Cheese[1] | $\uparrow^{a}$ | $\uparrow^{\uparrow\downarrow}$ | $\downarrow^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{0\downarrow}$ | $0^{00}$ |
| Hard cheeses[1] | $\uparrow^{a}$ | $\uparrow^{\uparrow\downarrow}$ | $\downarrow^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $\downarrow^{0\downarrow}$ | $0^{00}$ |
| Soft cheeses[1] | $\uparrow^{a}$ | $0^{\uparrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{0\downarrow}$ | $0^{00}$ |
| Margarines[1] | $0^{a}$ | $0^{\downarrow\uparrow}$ | $0^{\downarrow\downarrow}$ | $\downarrow^{\downarrow\downarrow}$ | $\downarrow^{\downarrow\downarrow}$ | $0^{00}$ |
| Processed fruit & vegetables[1] | $0^{a}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $\uparrow^{\uparrow\uparrow}$ | $0^{\downarrow\downarrow}$ |
| Processed fruit[1] | $0^{a}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{\uparrow\uparrow}$ | $0^{\downarrow\downarrow}$ |
| Processed vegetables[1] | $\downarrow^{a}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $\uparrow^{\uparrow\uparrow}$ | $0^{\downarrow\downarrow}$ |
| Milk-based drinks[1] | $0^{a}$ | $\downarrow^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $\downarrow^{00}$ | $0^{00}$ |
| Milk-based desserts[1] | $0^{a}$ | $\downarrow^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $\downarrow^{\downarrow\downarrow}$ | $0^{00}$ | $\uparrow^{00}$ |
| Processed meat & meat substitutes[2] | $\uparrow^{a}$ | $0^{0\uparrow}$ | $\downarrow^{\downarrow\downarrow}$ | $\uparrow^{\downarrow\downarrow}$ | $0^{0\downarrow}$ | $0^{00}$ |
| Processed meat[2] | $0^{a}$ | $0^{0\uparrow}$ | $\downarrow^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{0\downarrow}$ | $0^{00}$ |
| Meat substitutes[2] | $\uparrow^{a}$ | $0^{0\uparrow}$ | $\downarrow^{\downarrow\downarrow}$ | $\uparrow^{\downarrow\downarrow}$ | $0^{0\downarrow}$ | $0^{00}$ |
| Processed fish[2] | $0^{a}$ | $0^{\uparrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{00}$ | $\uparrow^{0\downarrow}$ | $0^{00}$ |
| Processed potatoes[3] | $0^{a}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{00}$ | $\downarrow^{\downarrow\downarrow}$ | $\downarrow^{0\downarrow}$ |
| Soups[1] | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $\downarrow^{\downarrow\downarrow}$ | $\uparrow^{\downarrow\downarrow}$ | $\downarrow^{\downarrow\downarrow}$ | $\uparrow^{00}$ |
| Emulsion sauces[1] | $0^{\downarrow\downarrow}$ | $\downarrow^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{\uparrow\uparrow}$ | $0^{\downarrow\downarrow}$ | $\uparrow^{00}$ |
| Sauces on water basis[2] | $\downarrow^{0\uparrow}$ | $0^{\downarrow\uparrow}$ | $0^{\downarrow\uparrow}$ | $\downarrow^{0\downarrow}$ | $0^{0\downarrow}$ | $0^{00}$ |
| Meal sauces[1] | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $\downarrow^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $\uparrow^{00}$ |
| Bread toppings[2] | $\downarrow^{\downarrow\downarrow}$ | $\downarrow^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $\uparrow^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{00}$ |
| Bread salads[2] | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $\uparrow^{\downarrow\downarrow}$ | $0^{00}$ |
| Snacks[2] | $0^{\downarrow\downarrow}$ | $\downarrow^{0\downarrow}$ | $\downarrow^{0\downarrow}$ | $0^{00}$ | $\downarrow^{00}$ | $0^{00}$ |
| Cookie/ muesli bar[2] | $0^{\downarrow\downarrow}$ | $0^{0\downarrow}$ | $\downarrow^{0\downarrow}$ | $0^{00}$ | $0^{00}$ | $\uparrow^{00}$ |
| Ice cream/ sorbet[2] | $0^{\downarrow\downarrow}$ | $0^{0\downarrow}$ | $\downarrow^{0\downarrow}$ | $\uparrow^{00}$ | $\downarrow^{00}$ | $\downarrow^{00}$ |
| Candy[3] | $\uparrow^{\downarrow\downarrow}$ | $0^{0\downarrow}$ | $0^{0\downarrow}$ | $0^{00}$ | $0^{00}$ | $0^{00}$ |
| Soft drinks[1] | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $\downarrow^{\downarrow\downarrow}$ | $0^{00}$ |
| Fruit juices[1] | $\downarrow^{\downarrow\downarrow}$ | $\uparrow^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $0^{\downarrow\downarrow}$ | $\downarrow^{00}$ | $\uparrow^{\downarrow\downarrow}$ |

↓ The average nutrient content has significantly reduced between 'Old' and 'New' ($p < 0.05$).
↑ The average nutrient content has significantly increased between 'Old' and 'New' ($p < 0.05$) 0 The average nutrient content did not change significantly between 'Old' and 'New' ($p < 0.05$).
$^{\downarrow}$ Choices nutrient criterion was tightened in 2011 (1st symbol) or 2015 (2nd symbol), compared to criterion valid in 'Old' (i.e. 2006 or 2007 criteria).
$^{\uparrow}$ Choices nutrient criterion was less strict in 2011 (1st symbol) or 2015 (2nd symbol), compared to criterion valid in 'Old' (i.e. 2006 or 2007 criteria).
$^{0}$ No criterion change from 'Old' (i.e. 2006 or 2007 criteria) to 2011 (1st symbol) or 2015 (2nd symbol).
[1] 'Old' (2006/07) is compared to 'New' (2016).
[2] 'Old' (2007/08) is compared to 'New' (2016).
[3] 'Old' (2008/09) is compared to 'New' (2016).
DCL: Dutch Choices Logoa No nutrient criteria were developed for this product category.
[a] No nutrient criteria were developed for this product category.

1.19 g/100 ml (46%); 0.74 g/100 g (55%), respectively) (Table S4). The observed SAFA reductions in bread, milk-based drinks, milk-based desserts, bread toppings and emulsion sauces may be linked to tightening of the criterion for SAFA for these product categories. For example, a clear decrease of SAFA in milk-based drinks was observed after introduction of the 2011 criteria (Table 2), whereas for bread toppings and emulsion sauces SAFA reduction may be related to a stricter criterion in 2015 (Table 2, Fig. 3). The significant SAFA reductions in snacks did not appear to be related to criteria revisions.

Unfavourable changes for health were observed in cheeses; mean SAFA content increased significantly with 3.75 g/100 g, or 52% (Table S4). This increase may be related to a criterion revision for SAFA; in 2011 the criterion for SAFA was raised from 15 to 16 g/100 g, which may have resulted in the significant increase of SAFA in cheese observed between 2011/12 and 2014/15 ($p < 0.05$). The criterion was lowered again in 2015, and although this did not yet result in a significant decrease, the SAFA content appeared to decrease slightly in 2015/16 (Fig. 3).

The SAFA content of NEVO emulsion sauces and snacks increased and the SAFA content of NEVO milk-based drinks and bread toppings decreased over time. Still, the mean SAFA content of comparable FoP-labelled product categories appeared to be lower in 'New', compared to NEVO (Figs. 4, S5c). Furthermore, in NEVO cheeses, SAFA appeared to increase in the same direction as in labelled cheeses, with a similar content. In contrast, the SAFA content of NEVO hard cheeses reduced over time while in labelled hard cheeses SAFA increased significantly. Yet, in 'New' the mean SAFA content of labelled hard cheeses was lower than the mean SAFA content of NEVO hard cheeses (Fig. S5b).

### 3.1.3. Trans fat

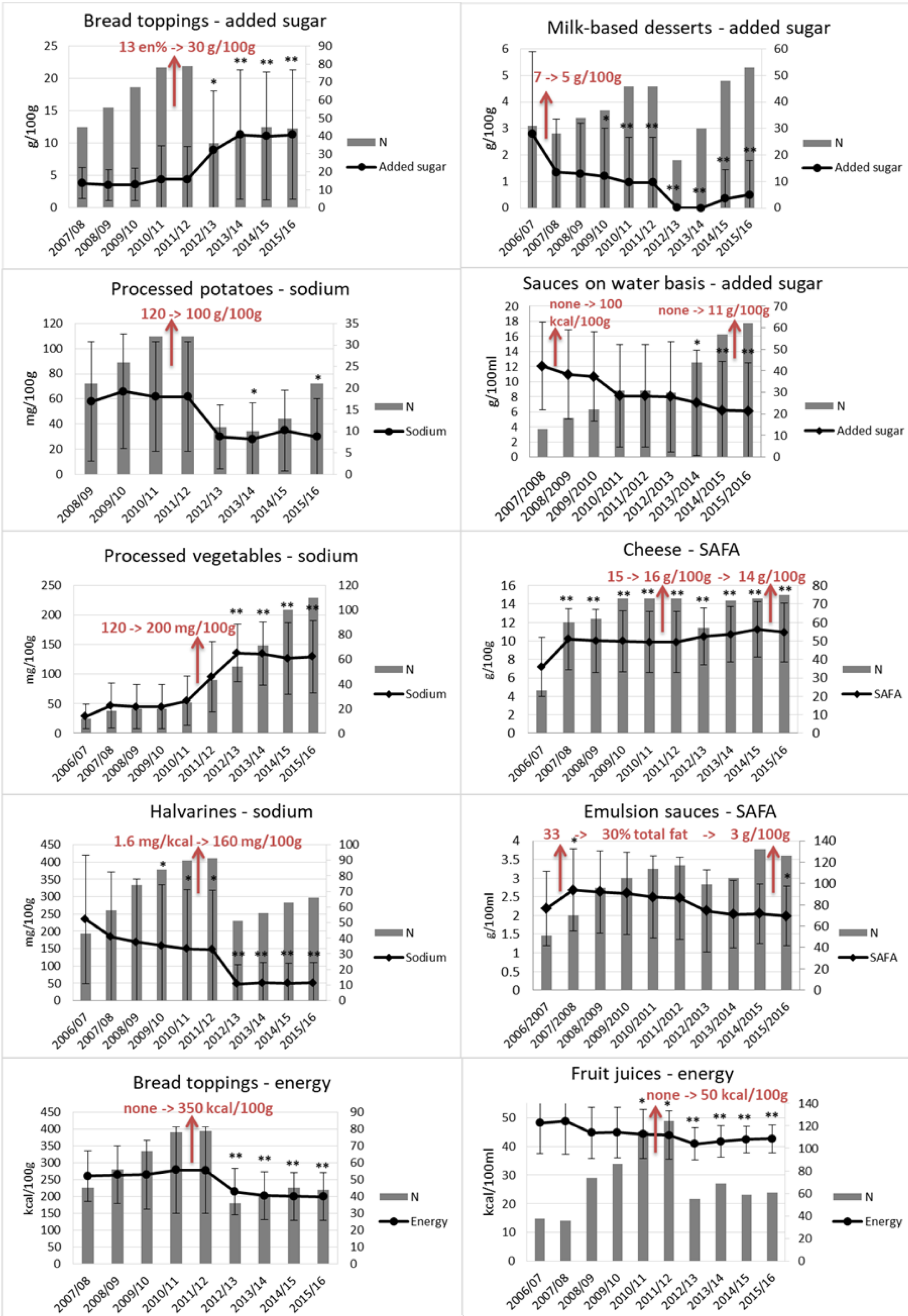
TFA content decreased significantly in all products (mean reduction: 0.034 g/100 g (48%)), and in basic and non-basic products (Table 1).

For all 11 product categories that showed a significant change in TFA, a reduction was observed (Table 2). In cheeses, processed meat and meat substitutes, and ice cream/sorbet this significant reduction led to a mean TFA level of 0 g/100 g (Table S4). Other product categories for which a significant reduction of TFA was observed include bread, soups, meal sauces and snacks. In processed meat and meat substitutes, and snacks, TFA reductions were not accompanied by tightening of the criterion for TFA in 2011 (Table 2).

### 3.1.4. Added sugar

Changes in added sugar content were not consistent over time. In the analysis that included all labelled products, no significant change was observed between 'Old' and 'New'. This may be partly due to a non-significant change in added sugar in non-basic products over time. In basic products the added sugar content decreased significantly (Table 1).

For 9 product categories a significant change in added sugar was observed, of which 4 showed a decrease (Table 2). Added sugar in sauces on water basis significantly decreased to almost half the amount when comparing 'New' to 'Old' (i.e. mean reduction of 5.94 g/100 ml; 49%) (Table S4). This could be related to the introduction of a criterion for added sugar in 2015, but also to revisions of the criterion for energy




*(caption on next page)*

**Fig. 3.** Number of products (right vertical axis) and mean ( ± SD) nutrient content (left vertical axis) from 'Old' to 'New', presented for ten DCL product categories for which a significant nutrient change was observed, accompanied by DCL nutrient criteria revision (red text). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
*Significant change from 'Old' to 'New' (p < 05);
**Significant change from 'Old' to 'New' (p < 0.01).
DCL: Dutch Choices Logo; SAFA: saturated fatty acids.

over time; the sugar content of this product group was regulated by a criterion for energy in the years where no criterion for added sugar was specified (Fig. 3). The added sugar content of bread and milk-based desserts also decreased significantly (mean reduction: 0.45 g/100 g (42%); 2.31 g/100 g (82%), respectively) and in margarines a significant reduction of added sugar led to mean levels of 0 g/100 g in 'New' (Table S4). The added sugar reduction observed in DCL-labelled bread may be linked to a stricter criterion for added sugar in 2015 (Table 2). Fig. 4 shows how added sugar in milk-based desserts is significantly reduced after revising the criterion for added sugar in 2007.

Unfavourable changes for health were also observed, mainly in non-basic product categories. The added sugar content of processed meat and meat substitutes, meat substitutes and soups increased significantly, although with a relatively small magnitude, i.e. 0.23 g/100 g (41%), 0.76 g/100 g (633%) and 0.26 g/100 g (63%), respectively. The added sugar content of bread toppings and ice cream/sorbet also increased significantly, i.e. 7.47 g/100 g (196%) and 4.66 g/100 g (36%), respectively (Table S4). The increase of added sugar in ice cream/sorbets cannot be linked to criteria revisions, as the criterion for added sugar for snacks remained constant from 2007. The change in criterion for added sugar for bread toppings (i.e. from 13 energy% to 30 g/100 g between 2007 and 2011) may explain the increase in added sugar in this category, as relatively more sweet toppings (i.e. jams with reduced sugar content) complied with the criteria for the bread toppings group after 2011 (Fig. 3).

The added sugar content of NEVO sauces on water basis and ice cream/sorbets decreased over time. For DCL-labelled sauces on water basis the same trend was observed, while for DCL-labelled ice cream/sorbets the added sugar content increased significantly. Yet, for both DCL-labelled categories, in 'New' the added sugar content was lower than comparable NEVO categories (Fig. 4). The added sugar content of DCL-labelled and NEVO soft drinks and bread toppings increased over time. Yet, in both 'Old' and 'New' the added sugar content of DCL-labelled categories was lower than that of comparable NEVO categories (Fig. 4 and Fig. S5c).

### *3.1.5. Sodium*

Sodium content decreased significantly from 'Old' to 'New' in all products (mean reduction: 26 mg/100 g (8%)), and in basic as well as non-basic products (Table 1).

Sodium content changed significantly in 14 product categories, of which 10 showed a decrease (Table 2). A significant decrease of sodium was observed for the following basic product categories: processed potatoes (27.9 mg/100 g (48%)), bread (64.34 mg/100 g (14%)), hard cheeses (65.38 mg/100 g (8%), margarines (182.92 mg/100 g (78%)) and milk-based drinks (7.85 mg/100 ml (15%)) (Table S4). With respect to non-basic product categories, a significant decrease of sodium was found in soups, soft drinks, snacks, ice cream and fruit juices (mean reduction: 8.09 mg/100 g (3%); 6.87 mg/100 ml (59%); 113.76 mg/100 g (69%); 15.06 mg/100 g (77%); 0.73 mg/100 ml (26%), respectively). Fig. 4 shows that the sodium reduction in margarines and processed potatoes may be related to a criterion revision for sodium in

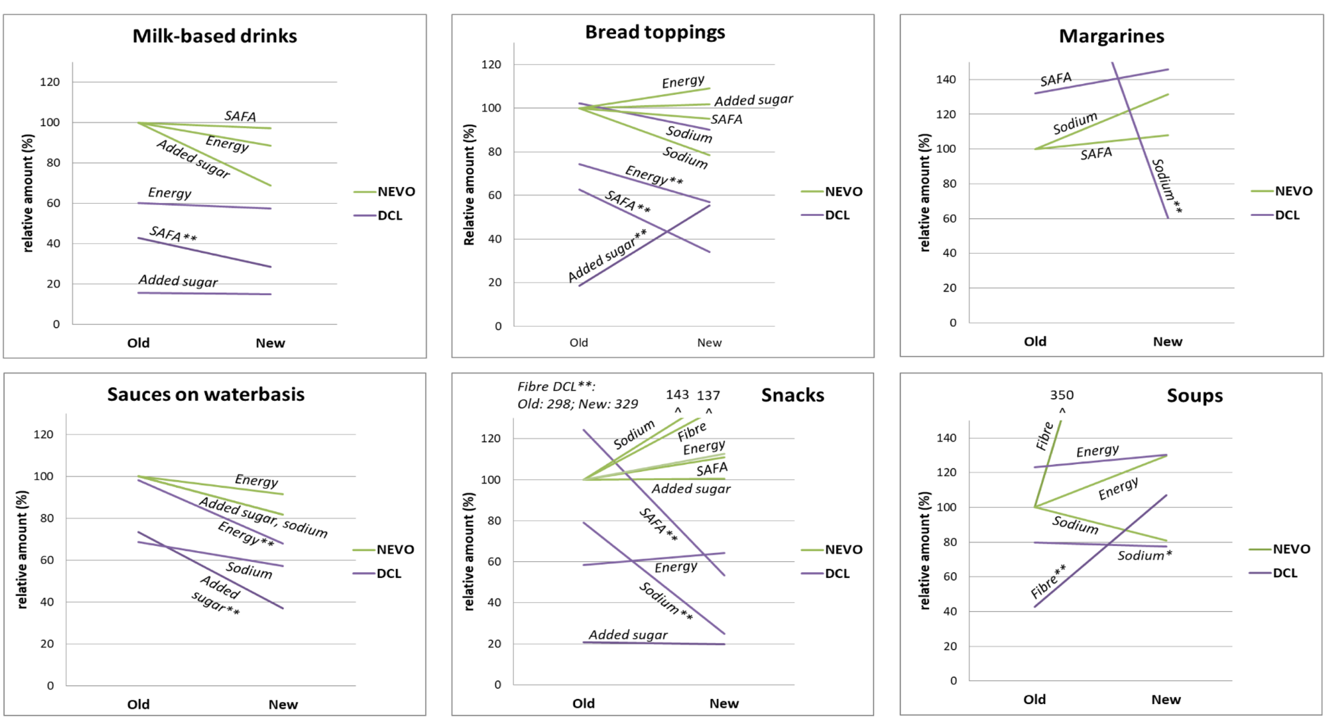



**Fig. 4.** Changes in energy and nutrient composition of DCL basic and non-basic product categories over time, compared to similar NEVO products of 2006 and 2016/2017. NEVO 'New' and DCL 'Old' and DCL 'New' are shown as percentages of NEVO 'Old', which is set at 100%.
*Compared to 'Old' DCL, p < 0.05 (Mann-Whitney U test);
**Compared to 'Old' DCL, p < 0.01 (Mann-Whitney U test).
'Old' includes product categories with different starting years, depending on category (see Table 2 or Tables 4a, b and c).
DCL: Dutch Choices Logo; NEVO: Dutch Food Composition Database; SAFA: saturated fatty acids.

2011. For bread, the sodium reduction may be related to the tightening of the criterion for sodium in 2015 (i.e. from 500 to 450 mg/100 g). In the revised criteria of 2011, a restriction of the sodium content of several product categories, including soups, cheeses and bread, was already mentioned before the next revision in 2015. This could explain the early sodium reduction in these categories. The significant reduction of sodium in snacks cannot be linked to criteria revisions.

Unfavourable changes for health were observed as well; the sodium content of processed fish increased significantly with 106.91 mg/100 g or 51% (Table S4). This increase cannot be linked to criteria revisions, as the criterion for sodium for processed fish remained 450 mg/100 g from 2007 to 2011 and was even reduced to 400 mg/100 g in 2015 (Table S1a). Sodium content of bread salads and processed vegetables also increased significantly over time. For bread salads this trend cannot be linked to criterion revisions. The sodium increase in processed vegetables may be linked to criteria revisions, as the sodium criterion for processed vegetables and fruits changed from 120 to 200 mg/100 g between 2007 and 2011 (Fig. 3).

Sodium content of NEVO bread, hard cheeses and soups decreased over time. This trend was also observed in the comparable DCL-labelled categories, although in 'New' the labelled categories were still lower in sodium (Figs. 4, S5b). Sodium in NEVO processed potatoes, margarines and snacks increased over time, leading to higher sodium content in 'New' compared to similar DCL-labelled products. (Figs. 4, S5b). The sodium content of both NEVO and DCL-labelled processed fish increased. Yet, in 'New' NEVO processed fish was higher in sodium compared to labelled processed fish (Fig. S5a). Sodium content of NEVO processed vegetables and bread toppings decreased. Yet, over time the sodium content of both NEVO categories were higher than the sodium content of comparable DCL-labelled categories (Figs. 4, S5b).

### 3.1.6. Fibre

Fibre content increased significantly in all DCL-labelled products (mean increase: 0.12 g/100 g (7%)). Fibre content of non-basic products increased significantly, while for basic products no significant changes were detected over time (Table 1).

Fibre content changed significantly in 8 product categories, of which 6 showed an increase in fibre (Table 2). Increases mostly occurred in non-basic product categories, i.e. soups (0.33 g/100 g (194%), emulsion sauces (0.32 g/100 g (229%)), meal sauces (0.33 g/100 g (485%)), cookies/muesli bars (2.43 g/100 g (30%)) and fruit juices (0.14 g/100 g (40%)). With respect to basic categories, a significant fibre increase was observed in milk-based desserts (0.11 g/100 g (28%)) (Table S4). None of the observed increases can be linked to criteria revisions in 2011 or 2015, except for fruit juices; the fibre criterion for this category has been tightened over time.

Unfavourable changes for health were detected in processed potatoes and ice cream/sorbet; the fibre content of these categories decreased significantly with 0.63 g/100 g (20%) and 0.32 g/100 g (32%), respectively (Table S4). These reductions cannot be linked to criteria revisions (Table 2).

Fibre content of NEVO soups appeared to increase over time, resulting in a higher fibre content than DCL-labelled soups (Fig. 4). Fibre content of NEVO cookies/muesli bars also appeared to increase over time, but fibre content was still lower than DCL-labelled cookies/muesli bars. The fibre content of NEVO fruit juices and processed potatoes appeared to decrease over time, resulting in lower fibre content compared to similar DCL-labelled categories in 'New' (Fig. S5b, c).

## 4. Discussion

To our knowledge, this is the first study to investigate long-term reformulation trends of products with a front-of-pack (FoP) nutrition label over more than a decade. Our results show that, over the past ten years, many product categories with the Dutch Choices Logo (DCL) have been reformulated to achieve a healthier nutrient composition (i.e. lower energy densities, lower contents of SAFA, TFA, sodium, added sugar, and higher fibre content). Also, FoP-labelled products appeared to have more favourable nutrient composition than the average of all Dutch products.

Regarding trends in product reformulation, we found that the degree of reformulation differs per product category and per nutrient. Overall, as expected, reformulation of products towards a healthier nutrient composition was observed in both basic and non-basic DCL product categories. TFA and sodium contents were significantly reduced in most products, i.e. 11 and 10 categories, respectively, while energy, SAFA, added sugar significantly decreased in 4–6 of the product categories analysed. Fibre content increased significantly in 6 product categories.

The analyses showed that energy reductions were generally more significant in non-basic categories than in basic categories, i.e. we observed substantial reductions in sauces on water basis, bread toppings and fruit juices. Changes in added sugar content were less consistent, and significant reductions were mostly observed for basic product categories, i.e. bread, margarines, and milk-based desserts. SAFA and sodium contents decreased more consistently, in both basic and non-basic products. For example, SAFA was significantly reduced in bread, milk-based products, emulsion sauces, bread toppings and snacks, and sodium significantly decreased in bread, hard cheeses, margarines, milk-based drinks, processed potatoes, soups, snacks, soft drinks and fruit juices. Fibre generally increased over time, although slightly more consistent in non-basic product categories, i.e. soups, emulsion sauces, meal sauces, cookies/muesli bars and fruit juices. TFA decreased most consistently in the labelled product categories, and in many categories, decreases in TFA led to an absolute mean level of 0 g/100 g. However, this paper focuses less on TFA, as most TFA levels were almost negligible in many labelled product categories analysed, which is considered a positive trend. TFA content in most products in the Netherlands has dropped in the past years; currently the intake of TFA by the Dutch population (i.e. 1 to 1.5 g of trans-fat per day) is below the maximum recommendation of the Dutch Health Council (Dutch Nutrition Center, 2018).

Regarding the literature about FoP labels, energy and sodium were previously also found to be target nutrients for the Health Star Rating (HSR), the Tick and the DCL. A few studies examining short-term effects of FoP labels on nutrient composition showed that labelled products had lower energy density and sodium contents (Ni Mhurchu et al., 2017; Ning et al., 2017; Thomson et al., 2016; Vyth et al., 2010). Fibre was also a target nutrient for the HSR and DCL in previous studies, resulting in higher content (Ni Mhurchu et al., 2017; Vyth et al., 2010). Similar to our findings, in a previous short-term reformulation study on the DCL a fibre increase in DCL fruit juices, an energy reduction in bread toppings, and a reduction in SAFA and added sugar in milk-based products was observed (Vyth et al., 2010). Vyth et al also observed that sodium was the nutrient reformulated in most product categories and that added sugar reductions were generally less consistent, which is in line with our findings. In a recent reformulation study on the HSR label, added sugar was mentioned as a highly important target nutrient for future reformulation efforts (Ni Mhurchu et al., 2017).

Regarding the relation between nutrient changes in FoP-labelled products and nutrient criteria revisions over time, we clearly observed three different phenomena:

### 4.1. No significant change in energy/nutrient content, while product criteria changed

This phenomenon was mostly observed for SAFA, TFA and added sugar. An explanation for this may be that a large proportion of these products already contained low absolute levels, which made further reformulation unnecessary. An example of this is SAFA in processed potatoes; mean SAFA content was already 0.4 g/100 g in 2008/09 while the criterion for SAFA was 1.4 g/100 g at that time. The Choices

Scientific Committee defined special criteria for several nutrients in low-energy-dense products. These 'insignificant levels' are defined as ' < 5% of the daily nutrient recommendation in g or mg per 100 g of a food product' (Roodenburg et al., 2011). Product categories for which the insignificant level was restricted, are not expected to influence the average composition of the products, and therefore were not mentioned explicitly in the results section.

### 4.2. Significant changes in energy/nutrient content, while product criteria were not changed;

This phenomenon may confirm our hypothesis that some of the nutrient changes observed may have been the result of other factors influencing product reformulation. As mentioned earlier, underlying motives of food manufacturers are often complex: moral motives (i.e. responsibility) as well as instrumental motives (i.e. profit) and technical aspects may play an important role in product innovation decisions by the food industry (Blok et al., 2017; Garst, Blok, Jansen, & Omta, 2017).

Several food companies that are members of the Dutch Choices initiative do not (always) use the product criteria as a guideline for product innovation. Although the criteria serve as a good guideline, the demand of consumers and the nutrient contents of products of competing food firms are more important in the firm's decision to reformulate (Garst et al., 2017). For example, previously reported factors impacting sodium reductions include increased consumer and industry interest in healthier nutrition profiles of their products (Ning et al., 2017). Part of this may also depend on the type of food sector. For example, the Dutch meat sector reported to rather focus on obtaining an 'animal welfare-label' than on a healthy food-label (van Gunst, Roodenburg, & Steenhuis, 2018). FoP-label nutrient criteria are always challenged by other societal actors (e.g. NGOs), making it difficult for food companies to decide which societal actor to follow. Furthermore, national reformulation programmes may influence product reformulation by industry, as reported in a study on sodium reduction in the Tick programme (Ning et al., 2017). Another example of this phenomenon concerns sodium in bread in the Netherlands; the Dutch bakery sector has been an active player in the field of salt reduction via regulations laid down in the Commodities Act, which resulted in a gradual decrease of salt in bread, partially explaining the sodium reductions in bread in our study (Temme et al., 2017). These regulations are developed in line with the recommendations of the Choices Scientific Committee.

On the other hand, FoP labels may be drivers to differentiate in the market, and can be viewed as showing a company's innovative attitude. Also, the label's nutrient criteria are seen as a useful tool to define products with a healthy composition and as a guideline on which many relevant stakeholders have agreed (Garst et al., 2017). In fact, many food producers in The Netherlands confirmed to use the product criteria as guideline for their product innovations, even if they did not join the initiative officially (Roodenburg, 2017).

Other unexpected significant changes, e.g. increased fibre content in milk-based desserts, could be due to technological aspects, also mentioned in an earlier study (Vyth et al., 2010). Addition of vegetables might explain the fibre increase in soups or meal sauces over time. Additionally, food producers may be eager to use nutrition or health claims to promote their products, e.g. for cookies/muesli bars. The addition of fibre may enable them to claim a certain amount of fibre in their products and relate to national recommendations for higher fibre intake.

### 4.3. Significant energy/nutrient content changes after product criteria were changed

#### 4.3.1. Energy/nutrient content and product criteria change in the same direction

Of all trends observed, this trend most likely indicates an association between criteria revisions and nutrient changes in labelled products, as hypothesized initially. Nutrient content could change in two directions: making the criteria less strict may lead to nutrient changes less favourable for health, whereas tightening the criteria may lead to nutrient changes more favourable for health. The first phenomenon was clearly observed in bread toppings, cheeses and processed vegetables (Fig. 3). For example, the criterion for sodium for processed vegetables were made less strict in 2011 to stimulate manufacturers to join the initiative. The 120 mg/100 g sodium criterion in 2007 was too strict for producers as the average sodium content of these products on the Dutch market was almost twice as high. After increasing the criterion to 200 mg/100 g, producers were able to reduce sodium content below 200 mg/100 g. Consequently, the sodium content in and the number of labelled processed vegetables increased, while on average a sodium reduction was stimulated. The second phenomenon (tightening of criteria followed by favourable nutrient changes) was clearly observed in milk-based desserts, processed potatoes, sauces on water basis, margarines, emulsion sauces, bread toppings and fruit juices (Fig. 3). For example, after introducing a stricter sodium criterion for margarines in 2011, mean sodium content dropped significantly, which resulted in a lower mean sodium content in 2016.

### 4.4. Energy/nutrient content and product criteria change in opposite directions

This may be the result of external or company-related factors mentioned in 4.2. Additionally, the observed mean changes in energy or nutrient content is often the result of a changing range of products within a product category (i.e. products losing the logo certificate, or new products registered with the logo), which may lead to unexpected changes in mean nutrient contents across products in such a category over time. Consequently, average nutrient contents observed in this study may partly reflect a change in number and diversity of DCL products within a category. An example of this is the observed significant increase of sodium in processed fish; as over time relatively more fish products with higher sodium content qualified for the logo, the mean sodium content of this product category did not change in the same direction as the criteria. Therefore, looking at individual products in addition to product categories is considered very valuable.

With regard to our second objective, i.e. comparing nutrient changes in FoP-labelled products with average products on the Dutch market, we conclude that over the ten-year study period most labelled product categories indeed had a healthier product composition than comparable products generally available on the Dutch market. While in many product categories the directions of the observed nutrient changes were rather similar in both groups, there was no clear indication that the difference diminished over time. We observed that either 1) the nutrient content of labelled products was more favourable for health than in similar NEVO products over time (e.g., while there was an increase in the SAFA content in labelled hard cheeses, the SAFA content was still lower than in NEVO products); or that 2) the direction of significant nutrient changes in labelled products was more favourable than NEVO (e.g. sodium in hard cheese decreased in both labelled and NEVO products, but the effect size in labelled products appeared to be larger). However, there were a few exceptions; some labelled products had a less favourable nutrient content than similar NEVO products, as well as a less favourable direction of change, i.e. processed meat and meat substitutes (SAFA), bread toppings (sodium), soups (fibre) and meat substitutes (sodium). In some cases, the nutrient content of labelled products was less favourable in 2006 compared to NEVO but changed significantly towards more favourable nutrient content compared to NEVO in 2016, e.g. sodium in processed potatoes and margarines, SAFA in snacks, and energy in fruit juices.

Regarding the literature, recent analyses investigating the impact of the Dutch National Reformulation Initiative, started in 2014, confirm that average products available on the Dutch market still contain too much salt and sugar (RIVM, 2018). Also, larger reformulation effects in labelled products compared with non-labelled products have been observed previously, which is in line with our study results (Ni Mhurchu et al., 2017).

Our study has some limitations. First, when changes in mean nutrient content in labelled products occurred in a similar direction as in NEVO products, this may suggest that these changes have directly occurred as a result of Choices criteria revisions. However, the results of this study alone do not prove that these product composition changes are directly caused by criteria revisions, and therefore additional research on other relevant factors influencing product reformulation is required.

Second, nutrient contents within several product categories have a large standard deviation, which is attributable to a large variety of products within these product categories. Third, the statistical significance of the nutrient changes observed should be critically viewed; a non-significant change does not rule out a nutritionally relevant change. Most preferably, future studies should also focus on tracking compositions of individual products over longer time periods, to get better insight in product reformulation on the product level instead of product category level.

Fourth, this study may have measured only part of the potential reformulation effect of the criteria revision in 2015, as data collection was conducted shortly after publishing the 2015 criteria. Manufacturers had one year to reformulate their products in line with these criteria. Covering this full period in the analyses might have led to an even larger reformulation effect.

Finally, regarding the mean nutrient contents of NEVO product categories and DCL-labelled product categories, it must be noted that NEVO product categories may be compiled in a slightly different way than DCL product categories. However, we expect that the differences are expected to be relatively small, as we used NEVO food items that were similar to the type of products included in DCL categories. Also, NEVO and DCL nutrient contents are derived from the same sources, i.e. data from food manufacturers or nutrition declarations on product labels. Additionally, when comparing product composition changes of DCL and NEVO product categories, statistical significance could not be determined as the individual product data are not available in NEVO and only mean levels of compiled food items are presented online. Yet, we believe that the descriptive measures used to compare NEVO and labelled product categories are relevant to obtain an overall picture of the differences in trends. However, providing publicly available lists of individual products reflected in each food item in NEVO, including their nutrient composition, is recommended: it would create possibilities to more thoroughly evaluate observed differences between NEVO and DCL product categories, including statistical significance. This would contribute to opportunities for FoP labelling initiatives to develop product nutrient criteria on a valid and transparent basis.

Despite the above limitations, this study is the first to date to investigate product reformulation over a prolonged period, relating nutrient content changes of FoP-labelled products to nutrient criteria revisions, and comparing nutrient compositions of labelled products with that of products generally available on the market. The large amount of available product composition data made it possible to evaluate nutrient contents of many different labelled product categories over time, including data from almost all food manufacturers and retailers that were member of the Dutch Choices Initiative between 2006 and 2016. These were 100 food producers, including the biggest caterers, and 90% of the retailers, based on their sales data. Thus, our product data may be considered a representative sample of the Choices products available on the Dutch market.

This study focused exclusively on product nutrient composition changes, and we did not collect data on sales or consumption. Therefore, we cannot draw any conclusions about the effects of the observed nutrient changes of labelled products on consumption patterns, dietary behaviour and intake or health outcomes. However, a previous modelling study reported that consuming a Choices-compliant diet may lead to substantial improvements of energy and nutrient intake (Roodenburg et al., 2009). Since then the criteria have become stricter and the possible effect might even be larger.

## 5. Conclusions

To conclude, the results of this study offer long-term insights into changes in nutrient compositions of product categories with a positive FoP label, outlined against trends in the general market, providing an indication of the potential impact of FoP labelling on product reformulation. Not only are most products with a FoP label front runners when it comes to healthier nutrient composition, but also, reformulation of such products towards healthier nutrient compositions may have stimulated manufacturers to reformulate comparable non-labelled product categories. The reformulation effect of FoP labels can be used to combat non-communicable diseases such as diabetes and obesity at the source, since food composition is altered before products enter the supermarket, which is of great importance for consumers that are less health-conscious.

While we show that FoP labels appear to be effective tools in stimulating producers to make healthier products, additional research is required to obtain a more comprehensive view on the extent to which FoP labels are influencing factors when it comes to reformulation, and at which company level FoP labels and other factors are considered. To obtain more complete insight into the impact of FoP labels on product reformulation, it is recommended that the nutrient contents of products with and without FoP labels is monitored longitudinally, including the related motives of food manufacturers to reformulate products. Additionally, to obtain more insight into the impact of product reformulation on dietary behaviours, sales data could be linked to reformulation data of FoP-labelled products, e.g. by using online tools or databases. Finally, dietary intake estimates based on the composition of FoP-labelled and other products might provide data on the ultimate health impact of FoP labelling initiatives.

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## CRediT authorship contribution statement

**Daphne L.M. van der Bend:** Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization. **Léon Jansen:** Conceptualization, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition. **Gerben van der Velde:** Validation, Formal analysis. **Vincent Blok:** Writing - review & editing.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2020.100086.

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