LWT - Food Science and Technology 223 (2025) 117787

Contents lists available at ScienceDirect

LWT

journal homepage: www.elsevier.com/locate/lwt

Transforming plant-based milk alternatives for better health

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ARTICLE INFO

Keywords:
Nutrition
Reformulation
Milk alternatives
Nutri-score
Sustainability

ABSTRACT

Plant-based milk alternatives do not always meet nutritional standards, and the reported reformulation efforts are weak. Therefore, there is a need for insight into the potential of making these products healthier. The first aim of this study was to analyse the nutritional and compositional quality of these products. Here, we conducted an online market inventory of 66 plant-based milk alternatives, calculated their Nutri-Scores based on updated Rayner's score, and analysed their additives (number & types) and proportions of processed/unprocessed plant sources. Our second aim was to identify the factors influencing the nutritional and compositional quality of the products. Therefore, we examined the correlations between the nutritional, compositional, and price characteristics of the products. The third aim was to explore the potential for reformulation to make products healthier. We considered realistic cut-off levels for nutritional and compositional values. We found that almost half of the 66 products analysed were of poor nutritional quality (Nutri-Score of D) and contained one to three additives. As solutions, we identified approaches that could reduce the Rayner's score (−12 points), total sugar content (−8 g/100 ml), calorie content (−36 kcal/100 ml), percentage of processed plant sources (−17 %), and number of additives (−3) of these products.

1. Introduction

Plant-based milk alternatives (hereafter, milk alternatives) have become increasingly popular in recent decades (Munekata et al., 2020; Silva et al., 2020; Vaikma et al., 2021). This trend is driven by a shift in consumption patterns from animal-based to more plant-based diets, increased health consciousness, and the growing demand for more sustainable food products (Ammann et al., 2023; Munekata et al., 2020; Runte et al., 2024). Milk alternatives are thus an interesting product category to help transform the food system towards more sustainability and health, given their lower environmental impact compared to animal-based products (Springmann, 2024; Mehner et al., 2024; Poore & Nemecek, 2018).

Recent literature has pointed out that milk alternatives are not comparable to cow milk in terms of their nutritional profile (Drewnowski, 2022; Mehner et al., 2024; Walther et al., 2022). Therefore, milk alternatives should be considered as separate product category that can serve as a supplement to the daily diet (Mehner et al., 2024). According to the NOVA classification, which categorizes foods into four groups (NOVA 1–4) based on their level of processing, milk alternatives fall under ultra-processed foods (NOVA 4) (Drewnowski, 2021, 2022; Jeske et al., 2017). Ultra-processed foods consist of food substances that are never or rarely used in kitchens (e.g. hydrolysed proteins and additives such as sweeteners, and thickeners) (Monteiro et al., 2019). The consumption of ultra-processed foods has been associated with nutritional deficiencies, excessive calorie intake, obesity, and adverse health outcomes (Monda et al., 2024; Monteiro et al., 2018). Therefore, researchers have called for stipulating stricter and harmonised regulatory guidelines for milk alternatives and establishing feasible ranges for ultra-processed foods to limit or improve their nutrient content (Drewnowski, 2022).

Food and beverage reformulation (reducing harmful over consumed nutrients such as sugar, fat, and salt or increasing potentially beneficial nutrients such as fibre, protein, and micronutrients) is an interesting strategy for improving the nutritional quality of processed foods and beverages without largely changing consumer behaviour (Fanzo et al., 2023; Gressier et al., 2021; Scott et al., 2017). Research on product reformulation has mainly focused on soft drinks, such as in Belgium, Italy, the Netherlands, Spain, and Sweden (Chen et al., 2022; Food Drink Europe, 2022). However, there is a lack of research on the reformulation of milk alternatives to make them healthier for several reasons. First, research on milk alternatives has gained importance only in the last

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https://doi.org/10.1016/j.lwt.2025.117787
Received 23 December 2024; Received in revised form 31 March 2025; Accepted 13 April 2025
Available online 15 April 2025

decade (Van der Maarel, 2020; Sethi et al., 2016). Second, potential barriers to reformulation—such as negative impacts on technological aspects, sensory qualities, consumer preference, and cost (Fanzo et al., 2023)—may have further hindered reformulation efforts.

Furthermore, in recent years, milk alternatives have been classified as food in the Nutri-Score calculation. As a result, these products receive less stringent limits for their sugar content, resulting in Nutri-Score A or B, which indicates good nutritional quality. However, in March 2023, the Nutri-Score transnational governance framework decided to change the Nutri-Score algorithm for milk alternatives from foods to beverages (Public Health France, 2024). The updated beverage algorithm applies a stricter maximum level for total sugar content and considers food additives, such as non-nutritive sweeteners. A recent study analysed 221 milk alternatives and assessed the impact of transitioning from the old to the new Nutri-Score for these products. The findings revealed that 55 % of the products applying the new Nutri-Score had a lower nutritional quality compared to the products applying the old Nutri-Score (Huybers & Roodenburg, 2024). This poses unavoidable challenges for countries and food industries where the Nutri-Score is already applied as a profiling method. Thus, more knowledge is needed on the nutritional and compositional aspects that influence the Nutri-Score of the products to identify approaches for improving these values.

To achieve a successful reformulation by avoiding potential barriers (e.g. technological, sensory, and liking) (Fanzo et al., 2023), feasible and realistic minimum and maximum thresholds for target nutrients must be considered. Detailed information on the nutritional profile (calorie and sugar content, Nutri-Score) and the composition (additive, processed ingredients) of commercial milk alternatives is needed to identify the potential for reformulation of milk alternatives with realistic cut-off values. Although milk alternatives currently have poor nutritional profiles (with large variability among those with same or different plant sources) and have been identified as ultra-processed food, studies on reported reformulation work are scant. Furthermore, it appears increasingly important to outline future pathways for the reformulation of milk alternatives, as changes to the algorithm used to calculate the Nutri-Score negatively affect the nutritional quality of these products.

To this end, the first aim of this study was to analyse the nutritional and compositional quality (Nutri-Score, number, and types of additives, the percentage of processed and unprocessed plant sources) of milk alternatives available in the Swiss market. The second aim was to identify factors influencing the nutritional and compositional quality of the products. Therefore, we examined the correlations between nutritional and compositional characteristics and the price of milk alternatives. We considered price to be another relevant information due to the cost differences between healthy and unhealthy foods (Pachali et al., 2023; Rao et al., 2013; Szakál et al., 2023). Third, we aimed to identify a feasible frame for the reformulation of milk alternatives produced from different plant sources. Therefore, we explored the potential for reformulating healthier milk alternatives based on realistic nutritional and compositional cut-off (minimum and maximum) levels of commercial products. Nutritional, compositional, and price information was retrieved from product packaging and websites.

Our study is novel for three main reasons. First, this is the first study to investigate the overall reformulation potential to develop healthier milk alternatives. In addition to nutritional and compositional characteristics, we provide leeway to reducing the level of processed ingredients. Second, we apply the newly updated Nutri-Score algorithm for milk alternatives and suggest reformulation strategies that could enhance the nutritional profiles of these products. Third, we propose feasible cut-off levels to enhance the overall nutritional profile of milk alternatives. Our manuscript is highly relevant for its contributions to the development of stricter and more harmonised regulatory guidelines for the reformulation of commercial milk alternatives. Furthermore, the results we present could serve as an incentive for the food industry to undertake voluntary reformulation, particularly in countries where the Nutri-Score is used as a profiling method.

2. Materials and methods

We conducted a comprehensive online market inventory of milk alternatives in Switzerland and collected data on the nutritional and compositional values and prices of the products. We then analysed the data in three steps, as illustrated in Fig. 1, which presents the overall approach.

2.1. Market inventory and database

Market inventories are useful for collecting detailed commercial product information (Liechti et al., 2022a,b). Therefore, products available on the Swiss online market in 2023 (May–July) were considered for this study. The information was retrieved from three supermarkets in Switzerland, which were among those with the largest online food offerings (Appendix A). The nutritional and compositional characteristics, as well as the price of the products, were retrieved from the product packaging. For this study, we considered the total number of products included in the database (n = 66). Due to 3 missing values, our analysis of the percentage of processed/unprocessed plant sources covered 63 products (Fig. 2, composition variables).

2.2. Data analysis

To calculate the Nutri-Score for the milk alternatives, we used the Rayner's score algorithm for beverages, which was adapted in 2023 (Public Health France, 2024; Rayner, 2017). Based on the Rayner's score, the Nutri-Scores range from A (good nutritional quality, dark green coloured) to E (poorest nutritional quality, dark red coloured). Concerning the additives, we gathered the name (with the corresponding E-number) and the role of the food additives from the list of ingredients on the packaging. Finally, we calculated the total number of additives per product. We also gathered information from the product ingredient list on whether the principal plant source was processed (added as a semi-finished product, such as dried flour, powder or pastes, extracts, and protein isolates) or unprocessed (raw material).

To identify the factors that influence the nutritional profile of the products, we performed multi-criteria mapping with a total of 18 quantitative variables (Fig. 2). We then investigated correlations between products' calories, sugar content, Rayner's score, number of additives, percentage of unprocessed and processed plant sources, price, nutritional variables (fat, saturated fat, carbohydrates, fibre, protein, and salt), and composition (number of minerals and trace elements, number of vitamins, number of ingredients, number of total ingredients). The composition variable 'number of total ingredients' reflects the complete ingredient list with the retrieved ingredients (e.g. water, sugar, and oil), additives, aroma, minerals, trace elements, vitamins, and enzymes retrieved. The composition variable 'number of ingredients' reflects only ingredients.

We considered the products' nutritional and compositional variability for milk alternatives with the same plant sources to define the potential for reformulation (Liechti et al., 2022a,b). Previous research indicates that a larger variability with an increased delta between the minimum and maximum value reflects a higher leeway and, thus, the potential for reformulation within a given market offer (Liechti et al., 2022a,b). Thus, to identify the initial pathways for future reformulation of milk alternatives, we used feasible minimum and maximum nutritional values (i.e. Rayner's score, calories, and sugar content) and compositional values (i.e. number of additives, the percentage of unprocessed and processed plant sources). As this approach is based on realistic values from commercially available milk alternatives, it allows for deriving feasible pathways within a given market offer and product variety.

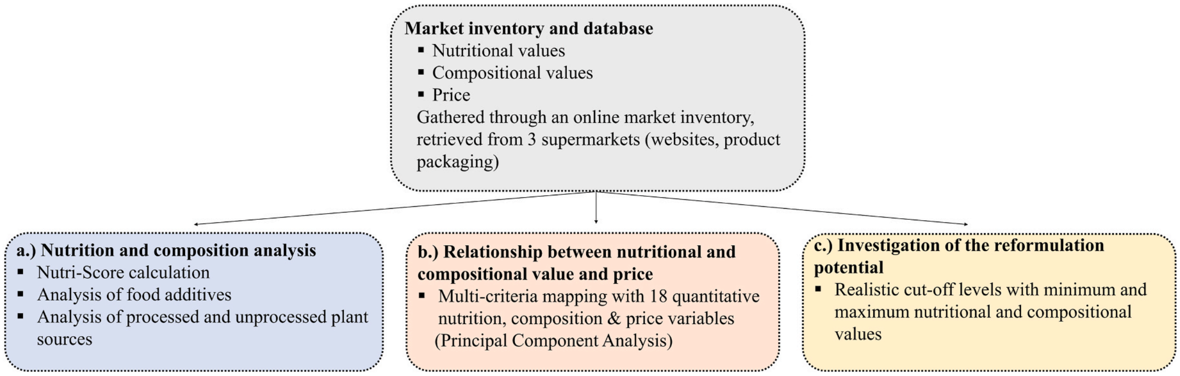

Fig. 1. Overview of the approach applied in this study to investigate the reformulation potential to develop healthier plant-based milk alternatives.

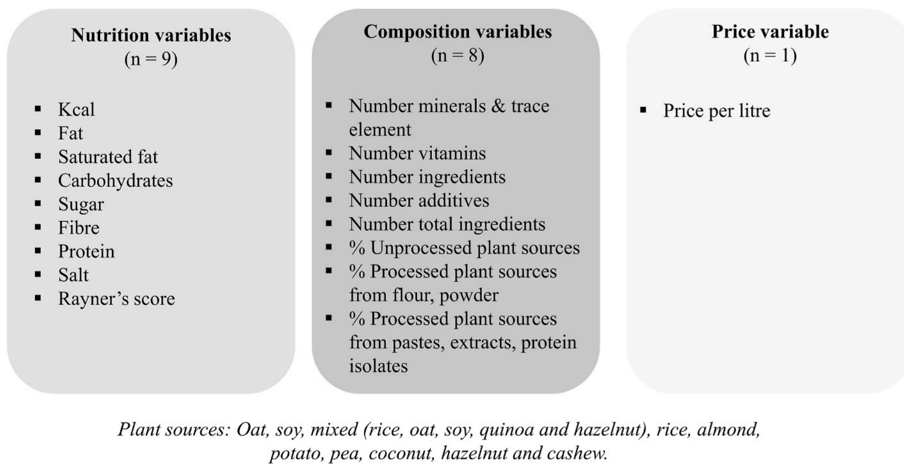

Fig. 2. Overview of the 18 quantitative nutrition, composition, and price variables included in the principal component analysis (PCA). From left to right, the variables for product nutrition (nutritional values in g per 100 ml and computed Rayner's score) (n = 9), composition (n = 8), and price per litre (n = 1).

2.3. Statistical analysis

For multi-criteria mapping, we used XLSTAT version 2023.1.6 (1410) (Addinsoft, New York, USA). In total, 63 milk alternatives were included in the statistical analysis due to three missing values for the composition variable '% unprocessed plant sources', which led to the exclusion of three products.

We performed a principal component analysis (PCA) with a total of 18 quantitative variables on a correlation matrix. Supplementary variables were plotted only after PCA computation. PCA is an appropriate method when dealing with multidimensional data to examine the correlations between variables (loadings) and samples (scores) (Alkarkhi & Alqaraghuli, 2019; Vidal et al., 2020). Here, we used the Pearson correlation with a significance level alpha = 0.05 with standardised data, while missing data were not included. For the validation axes, axes F1–F2 were considered.

We included 14 active variables in the PCA: 7 active nutrition variables (*fat, saturated fat, carbohydrates, sugar, fibre, protein, and salt content*) and 7 active composition variables (*number of minerals/trace element, number of vitamins, number of additives, number of ingredients, % unprocessed plant sources, % processed plant sources for flour, powder, % processed plant sources for pastes, extracts, and protein isolate*). As the variables *total ingredients, Rayner's score*, and *Kcal* were not independent variables within the correlation matrix, we treated them as supplementary variables within the PCA correlation matrix. Besides these independent variables, we included *price* as a supplementary variable.

To identify the potential for reformulation among different plant sources, we visualised the ranges of the minimum and maximum nutrition and composition values per plant source (oat, soy, mixed, rice, almond, pea, potato, coconut, hazelnut, and cashew). For this, we applied descriptive statistics (box plots).

3. Results

3.1. Plant sources

We identified 66 milk alternatives based on cereals (47 %), legumes (18 %), mixtures (15 %), nuts (15 %), and tubers (5 %) (Fig. 3). Overall, these products originated from 10 different plant sources, such as oat (n = 25), soy (n = 10), mixed (rice, oat, soy, quinoa, and hazelnut) (n = 10), rice (n = 6), almond (n = 5), potato (n = 3), pea (n = 2), coconut (n = 2), hazelnut (n = 2), and cashew (n = 1). The 66 products characterised were from 14 different brands, including 7 national and 7 international brands.

3.2. Nutritional and compositional quality

3.2.1. Nutri-Score

Our findings showed that most of the products had a Nutri-Score D (44 %), which indicates poor nutritional quality. Some products had a better nutritional quality, with a Nutri-Score B (26 %) or C (26 %). No product had a Nutri-Score A, which would indicate the highest nutritional quality. Only a few products had a Nutri-Score E (4 %), which indicates the poorest nutritional quality.

Milk alternatives with a Nutri-Score B were particularly found among pea- (100 %), soy- (80 %), almond- (60 %), and coconut-based

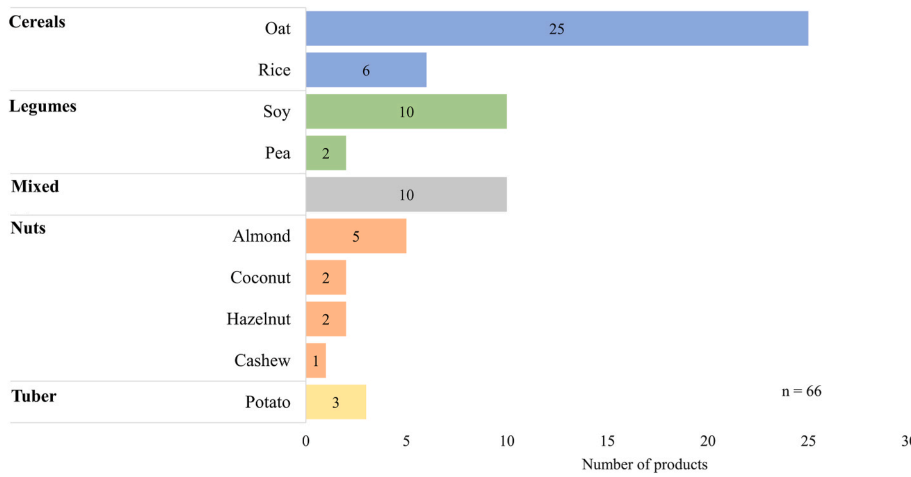

Fig. 3. Overview of the included plant-based milk alternatives in the database obtained through a comprehensive market inventory. A total of 66 products were included, with a representation of 10 different plant sources. Mixed milk alternatives contain plant sources from rice, oat, soy, quinoa, and hazelnut.

(50 %) products (Fig. 4). By contrast, rice-based (83 %) and mixed (70 %) products tended to have poorer nutritional profiles (Nutri-Score D). The poorest nutritional quality with a Nutri-Score E was only identified in oat-based products (12 %).

Notably, 21 % of the 66 products contained added sugars (including syrup) (Appendix B). Of the 14 products, the type of sugar was in most cases not specified (5 products). Some products were labelled as containing brown sugar (5 products), saccharose (2 products), or a combination of sugar with rice or agave syrup (2 products). Additional details on the nutritional and compositional characteristics of all 66 milk alternatives are provided in Appendices C and D. The front-of-pack label information of these products can be seen elsewhere (Liechti et al., 2025a). Furthermore, the database containing the nutritional and compositional information for all 66 milk alternatives is available on Zenodo (Liechti et al., 2025b).

3.2.2. Processed and unprocessed plant sources

Of the 63 products with the relevant information in our sample, more than two thirds (67 %) contained unprocessed plant sources. Products based on oat, soya, almond, hazelnut, and potato were most frequently presented in their raw and unprocessed state (Fig. 5). Further, 30 % contained processed plant sources, while 3 % contained processed and unprocessed plant sources. We found that milk alternatives based on coconut, cashew, and pea were fully composed of processed plant sources.

3.2.3. Number and types of additives

Among the 66 milk alternatives, 47 % contained additives, while 53 % were free of additives. Among the products with additives, we identified a total number of 51 additives. The types of additives were as follows: acidity regulators (potassium phosphate, calcium citrate, and calcium carbonate) (44 %), stabilisers (gellan, carob bean gum, xanthan, guar gum, and natrium citrate) (40 %), emulsifiers (lecithin) (8 %), and thickeners (carrageen, xanthan, gellan) (8 %). This study did not identify any use of non-nutritive sweeteners among milk alternatives. The most commonly used additives were potassium phosphate (acidity regulator) and gellan (stabiliser). Considering the presence of additives per plant source (Fig. 6), we found that all milk alternatives produced from

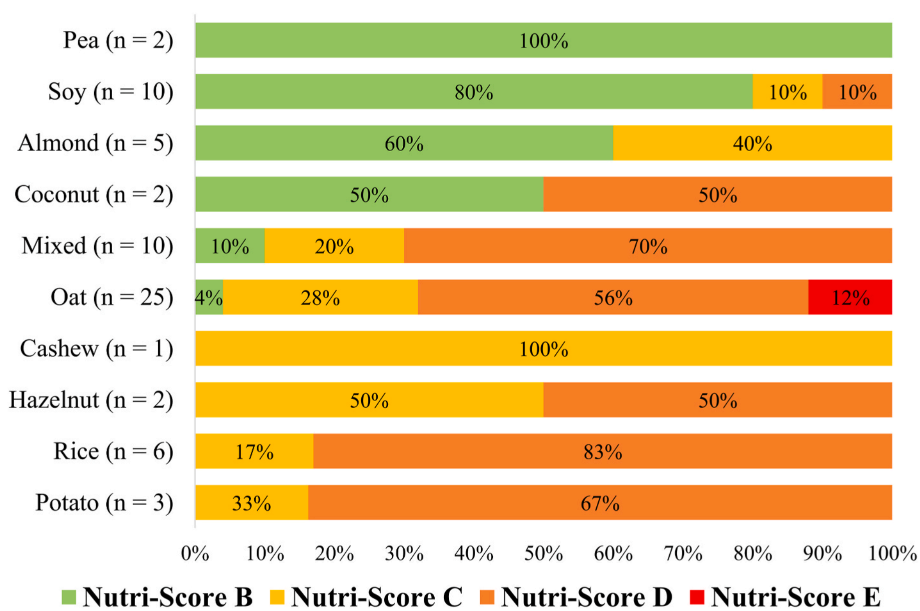

Fig. 4. An overview of the Nutri-Score (B: in green colour, C: in yellow colour, D: in orange colour, E: in red colour) obtained by applying the Rayner's score algorithm to all 66 products from the Swiss market inventory. None of the products in the sample achieved a Nutri-Score A. Mixed milk alternatives contain plant sources from rice, oat, soy, quinoa, and hazelnut.

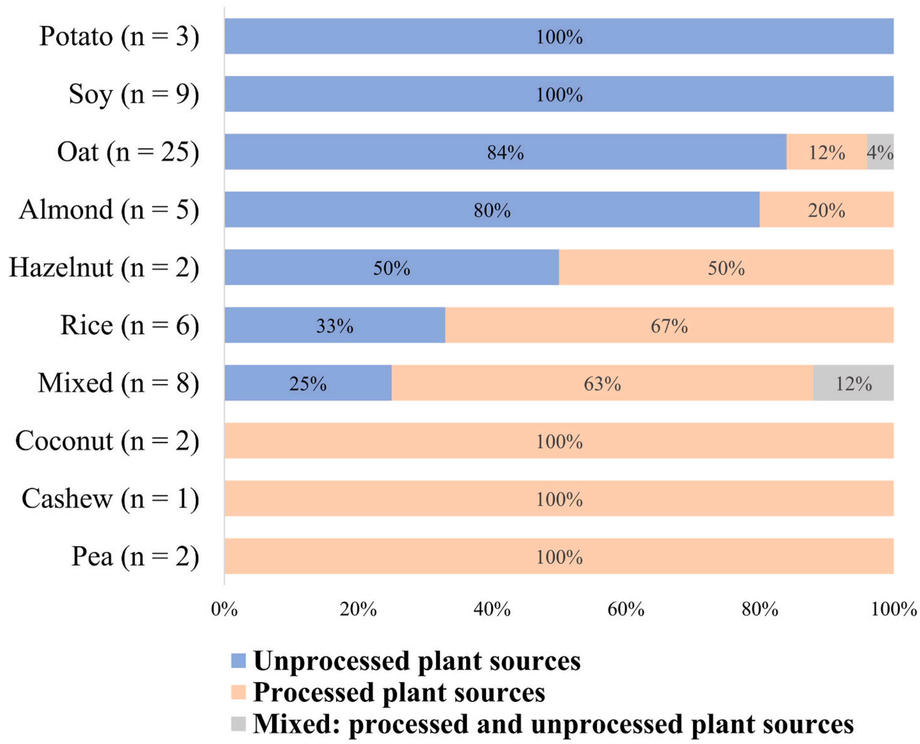

Fig. 5. An overview of plant-based milk alternatives (n = 63) from the market inventory, coloured based on composition, such as unprocessed plant source (in blue), processed plant source (in orange), and mixed with processed and unprocessed plant sources (in grey). Mixed milk alternatives contain plant sources from rice, oat, soy, quinoa, and hazelnut.

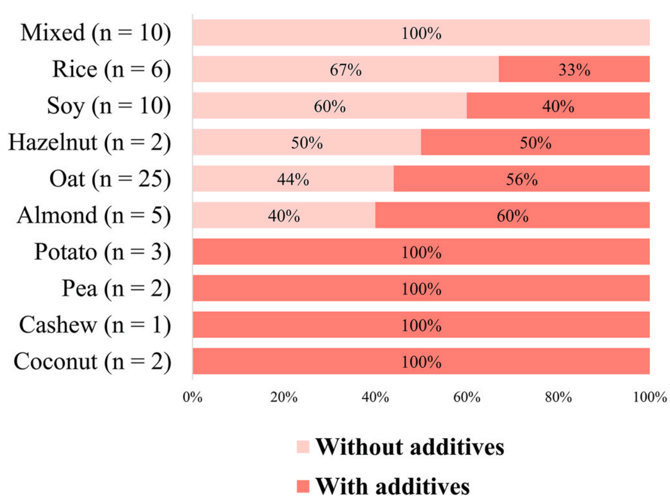

Fig. 6. An overview of plant-based milk alternatives (n = 66) from the market inventory, coloured based on composition, such as without additives (in light red) and with additives (in red). Mixed milk alternatives contain plant sources from rice, oat, soy, quinoa, and hazelnut.

potato, pea, cashew, and coconut contained additives. Interestingly, no additives were found in milk alternatives produced from mixed plant sources.

Furthermore, our results showed that the types of additives differed based on the plant source (Fig. 7). Stabilisers were particularly used for coconut-, hazelnut-, almond-, and soy-based milk alternatives, whereas acidity regulators were predominantly used in potato, pea, and oat products. Rice- and oat-based products contained three to four different additive types, while other milk alternatives were based on one to three additive types.

3.3. Relationships between nutritional and compositional values and price

We performed a PCA of 18 quantitative variables (with alpha = 0.05 as the significance level) to investigate the variables influencing the nutritional profile of the products. Therefore, axes F1–F2 were considered, as they included the largest (40.73 %) explained variability. The loadings in Fig. 8A (axes F1–F2) present the correlations between 14 active (7 nutritional values and 7 compositional values) and 4 supplementary (kcal, Rayner's score, total number of ingredients, and price) variables. Fig. 8B illustrates the observation plot of 63 milk alternatives labelled by plant source, obtained through a comprehensive Swiss market inventory.

Our analysis identified several variables that significantly influenced the Rayner's scores of the products. We found that an increased carbohydrate (r = 0.83), sugar (r = 0.76), and kcal (r = 0.65) content led to an increased Rayner's score. Further, products with a higher percentage of processed plant sources for flour and powder (r = 0.38) and a higher number of ingredients (r = 0.42) were associated with an increased Rayner's score. Products with a higher protein content (r = −0.69) were associated with a lower Rayner's score.

We also identified several variables that significantly influenced calorie and sugar content. Higher carbohydrate (r = 0.78), sugar (r = 0.54), fat (r = 0.32), and fibre (r = 0.35) contents were associated with higher calorie content. Moreover, an increased number of ingredients (r = 0.37) contributed to a higher kcal content. Furthermore, products with an increased sugar content were characterised by a higher carbohydrate (r = 0.76) and calorie (r = 0.54) content, while products with a higher percentage of unprocessed plant sources (r = 0.27) were associated with a higher sugar content. By contrast, the higher the fat (r = −0.37) and protein (r = −0.28) content of the products, the lower their sugar content. We also found that a higher percentage of processed plant sources for pastes, extracts, and protein isolates was associated with reduced sugar content (r = 0.25).

Notably, our analysis revealed additional variables that significantly

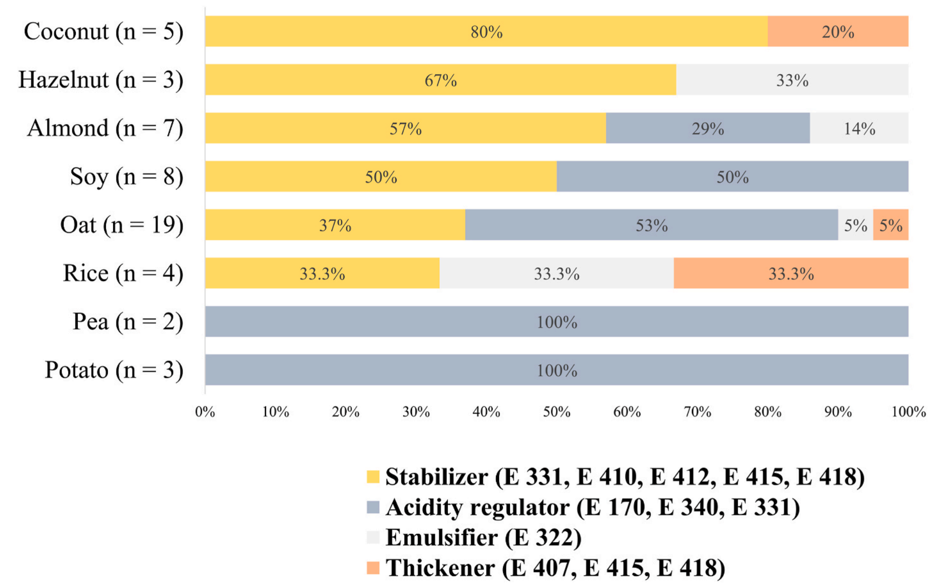

Fig. 7. Different types of additives (yellow: stabiliser, grey: acidity regulator, white: emulsifier, orange: thickener) among 31 plant-based milk alternatives. We identified a total number of 51 additives. The numbers in brackets indicate the total number of additives for each plant source (with E-numbers).

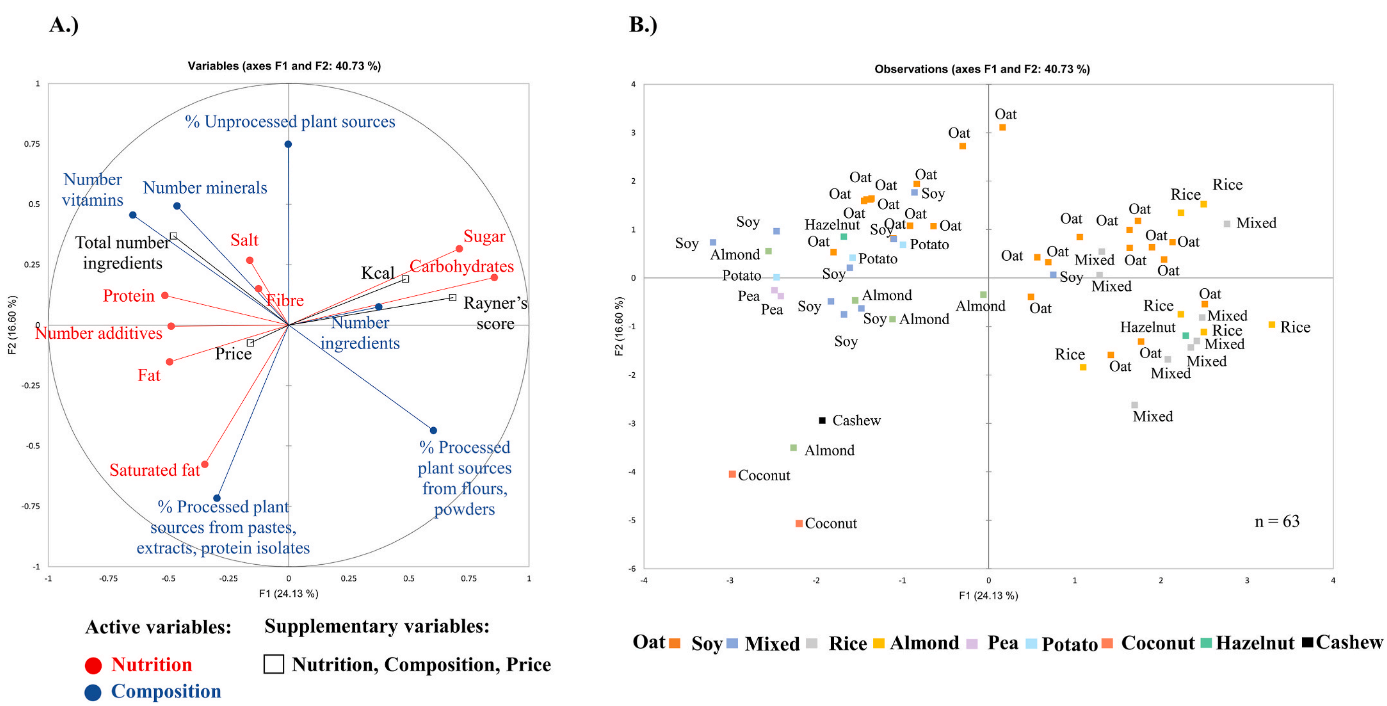

Fig. 8. Principal component analysis (PCA) with axes F1 and F2 on the left panel (A) and the correlation matrices with 18 quantitative variables (14 active variables, such as nutritional values in red and compositional values in blue; 4 supplementary variables, such as kcal, Rayner's score, total number ingredients and price per litre). On the right panel (B), the observation plot containing 63 plant-based milk alternatives from a comprehensive Swiss market inventory, coloured to show 10 different plant sources.

influenced the composition of the products. Products with higher numbers of additives tended to have a higher number of vitamins (r = 0.43) and total ingredients (r = 0.62), while those with increased carbohydrate (r = −0.33), kcal (r = −0.34), and sugar (r = −0.30) content were found to have fewer additives. Products with more processed plant sources for powder and flour tended to have higher carbohydrate (r = 0.53) and calorie content (0.42), lower protein content (r = −0.28), and fewer minerals (r = −0.26), vitamins (r = −0.38), and total ingredients (r = −0.26). Milk alternatives with more processed plant sources for pastes, extracts, and protein isolates were associated with increased saturated fat (r = 0.63) and reduced carbohydrate (r = −0.31) content.

Furthermore, we identified some nutrition and composition variables that were significantly correlated with the price of the products. Overall, products with higher fat (r = 0.33) and fibre (r = 0.26) content, more processed plant sources for pastes, extracts, and protein isolates (r = 0.26), and more minerals (r = 0.38), vitamins (r = 0.35), ingredients (r = 0.28), and total ingredients (r = 0.46) were associated with higher prices. In contrast, products containing more protein (r = −0.37) and unprocessed plant sources (−0.26) were cheaper.

Fig. 8B shows the large variability in nutrition, composition, and price between 63 milk alternatives from 10 different plant sources. In particular, oat products showed large variability in nutrition, composition, and price. This might indicate a higher overall potential for reformulation. Milk alternatives on axes F1 (on the left side) are characterised by a higher number of vitamins and a higher protein and fat content. Many of these products use soy, nuts (almond, hazelnut), potato, or pea as plant sources. Some of these plant sources have higher levels of naturally occurring protein content. By contrast, products on axes F1 (on the right side) tended to have more products with an increased carbohydrate and sugar content and more processed plant sources for flour and powder. Many of these products are cereal-based, with higher naturally occurring carbohydrate and starch content and lower naturally occurring protein content. Moreover, some of the products tended to have a higher Rayner's score. Most of the products had oat, rice, or mixed plant sources. Products on axes F2 (on the top), which were predominantly oat-based, tended to have a higher content of unprocessed plant sources. Finally, products on axes F2 (on the bottom), which were particularly made from nuts, were characterised by a higher content of saturated fats and paste, extract, and protein isolates.

3.4. *Reformulation potential*

To identify the potential for reformulation among milk alternatives from this market inventory, we used the delta between the maximum and minimum nutritional and composition values, including the Rayner's score. We illustrate product variability per plant source with their mean, minimum, and maximum values for nutrition and composition properties in Fig. 9. The delta between the minimum and maximum values reflects the realistic frame and cut-off levels for reformulation of commercial milk alternatives from this market inventory. Considering the Rayner's score, we found the largest variability—and thus the potential for reformulation within this given market offer—for soy-based products (reduction of 12 points), mixed products (reduction of 11 points), and oat-based products (reduction of 9 points).

Focusing on the calorie content, we identified a maximum reduction of 36 kcal/100 ml for oat-based milk alternatives and a maximum reduction of 31 kcal/100 ml for almond-based milk alternatives. Regarding sugar content, we found that oat- and soy-based products had the greatest potential for sugar reduction (8 g/100 ml for oat and 7 g/100 ml for soy products). Milk alternatives with added sugar (particularly soy products) had an overall higher mean for the total sugar content (3.9 g ± 2.1 g/100 ml) compared to milk alternatives without added sugar (2.9 g ± 2.4 g/100 ml) (Appendix B). Soy-based milk alternatives with added sugar showed the largest leeway for a potential sugar reduction, up to 4.9 g/100 ml (Appendix B).

In addition to pathways that could improve the nutritional profile, we identified leverages to improve the compositional profile of the products. We found the potential to remove up to three additives from several of the milk alternatives made from oat, rice, soy, almond, and hazelnut. Products made from rice, oat, and mixed sources had the potential to be reformulated with higher levels of unprocessed plant sources—up to 15 % (rice), 13 % (oat), and 12 % (mixed). Considering the reduction of processed plant sources, products made from mixed plant sources had the greatest potential for reduced flour and powder content—up to 17 %—followed by rice- and oat-based milk alternatives, with a 14 % reduction potential. Almond-based milk alternatives had the largest potential (7 %) for reduced use of processed plant sources for paste, extract, and protein isolates, followed by mixed (3 %) and coconut (2.6 %) products.

4. Discussion

The aim of this study was, first, to analyse the nutritional and compositional quality of milk alternatives on the Swiss market, focusing on their Nutri-Score, number and types of additives, and percentage of processed/unprocessed plant sources. Second, we aimed to identify the factors influencing the nutritional and compositional quality of the products. Therefore, we examined the correlations between the

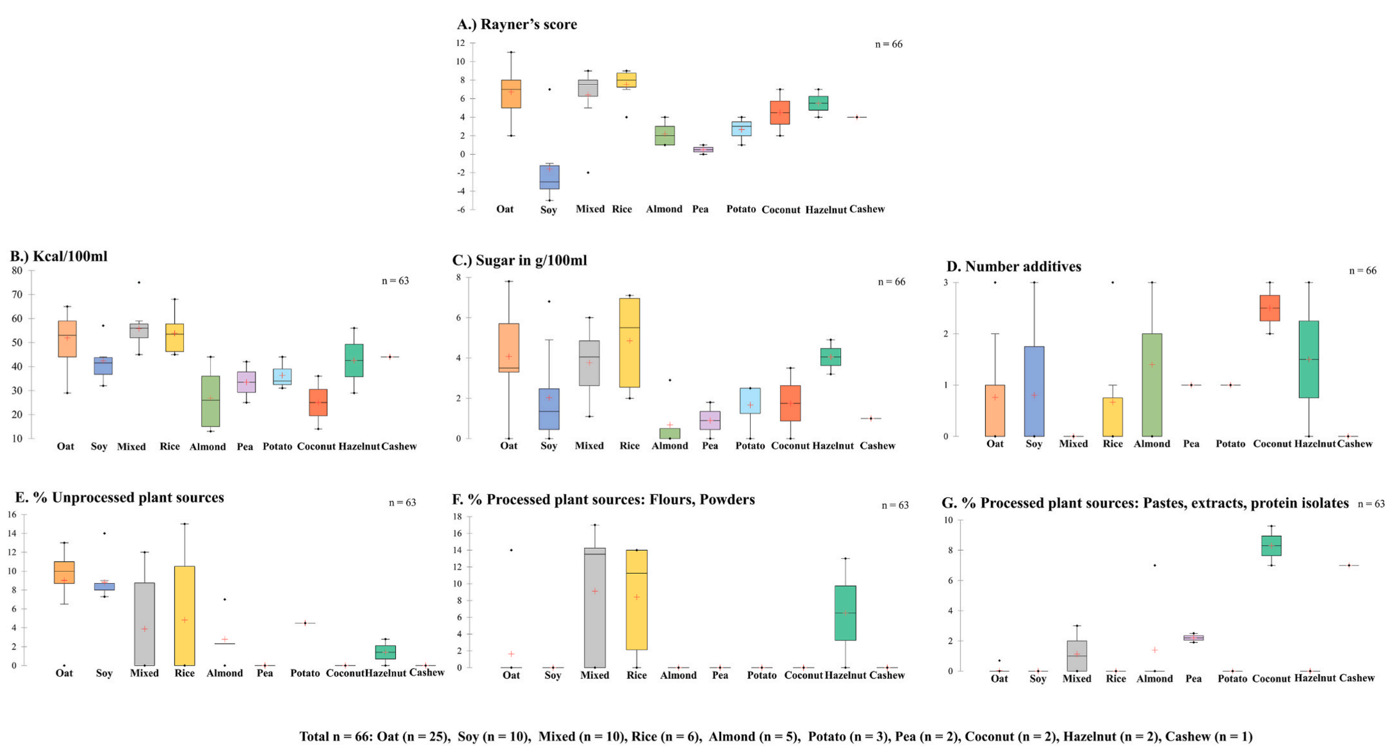

Fig. 9. The Rayner's scores and nutritional (kcal and sugar) and compositional (number additives, % unprocessed and % processed plant sources) values (mean, minimum, and maximum values) for plant-based milk alternatives from 10 different plant sources (oat, soy, mixed, rice, almond, potato, pea, coconut, hazelnut, and cashew), illustrated as box plots.

nutrition, composition, and price characteristics of the products. Third, we investigated the potential for reformulating healthier milk alternatives using realistic nutritional and compositional cut-off levels. We used a Swiss database containing information on 66 products. Product properties, such as nutrient content, composition, and price, were retrieved from the packaging on the websites through a comprehensive market inventory of commercial milk alternatives.

4.1. Nutritional and compositional quality

Almost half of all products investigated had a Nutri-Score of D. Similar results were observed in a study conducted in the USA on 1042 milk alternatives, where only 11.2 % met the nutrient standards for several nutrient profiling methods (Drewnowski, 2022). We identified sugar content as one of the target nutrients, which led to an increased Rayner's score. Indeed, this study showed that around one fifth of all products contained added sugars. Other studies have also confirmed a high percentage of milk alternatives with added sugars (Clegg et al., 2021; Walther et al., 2022). However, in addition to added sugar, milk alternatives also contain high levels of natural sugar (Jeske et al., 2017). The reason for this is starch hydrolysis during processing. Thus, milk alternatives with a high starch content are high in maltose or glucose. In particular, rice-based products (high in maltose and glucose) and oat-based products (high in maltose) contained high levels of sugar (Antunes et al., 2023; Jeske et al., 2017).

We also found that the sugar levels in our sample were highest in the rice- and oat-based products. The overall high sugar content (from natural and added sugars) and the type of sugar can also affect the glycaemic index (GI) of a food, which is a measure of the impact of food on human blood glucose levels. Indeed, cow milk (mainly composed of natural sugar lactose) showed a GI of 47 (medium), while the GI of milk alternatives (composed of maltose, glucose, sucrose, and fructose) ranged from 53 to 99 (high), with rice having the highest value (Antunes et al., 2023; Jeske et al., 2017).

A high consumption of added sugar is associated with an increased risk of overweight and obesity (Magriplis et al., 2021). Furthermore, a diet composed of high glycaemic foods has been associated with an increased risk of cardiovascular disease, diabetes, and death (Jenkins et al., 2021). Therefore, directly or progressively reducing the added sugars, as well as reducing the natural sugar content during processing, is a key factor in improving the health and nutritional profile of milk alternatives. Thus, considering starches with a lower glycaemic load and adapting processing technologies to reduce starch hydrolysis might be relevant pathways for the future. Further, applying multi-sensory integration strategies (e.g. odour–taste interaction or colour–taste interaction) might be future solutions to help maintain sensory perception and liking while reducing products sugar content (Chen et al., 2022). Furthermore, it is important to note that consumers do not always prefer the sweetest option (Liechti, 2022a; Liechti et al., 2024), and sugar reduction might not necessarily lead to disliking, even with changed sensory perception. This might be promising for a successful sugar reduction, although the perception and the liking depend on the specific food or beverage matrix.

Going beyond macronutrient modification, this study identified several milk alternatives that were fully based on already processed ingredients (rice: flour, powder; pea: protein isolate; mixed: powder; and cashew: paste). Moreover, our study identified up to 13 ingredients in the milk alternatives, which is a high number compared to milk. According to a study from the USA, around 90 % of all 641 milk alternatives were identified as ultra-processed foods according to the NOVA criteria (Drewnowski, 2021). Consequently, milk alternatives are classified as ultra-processed foods, although consumer demand for more natural products is increasing. Furthermore, the consumption of ultra-processed foods has recently been associated with an increased risk of diet-related non-communicable diseases, such as overweight and obesity (Askari et al., 2020; Monteiro et al., 2018). A recently published multinational cohort study showed that the consumption of ultra-processed foods is associated with cancer and cardiometabolic diseases (Cordova et al., 2023) and highlighted the relevant role of food additives in these outcomes. The present study identified a large number of additives among milk alternatives from this market inventory, confirming earlier reports (Walther et al., 2022). Developing more natural products that are less processed and that contain fewer additives thus seems crucial for future reformulation targets.

4.2. Relationships between nutritional and compositional values and price

As the sugar content was strongly correlated with an increased Rayner's score, we consider reducing the total sugar content to be a key pathway for improving the Rayner's score of milk alternatives. By contrast, an increased protein content (with a high biological value) is favourable for improving the Rayner's score of the products. Besides the reduction of target nutrients, we emphasise that compositional aspects (processed ingredients, number of ingredients) should also be considered in the process of reformulation to enhance the nutritional profile of milk alternatives. Although the Rayner's score calculation only recently included additives, milk alternatives with higher Rayner's scores from this market inventory did not necessarily contain more additives. This can be explained by the fact that only non-nutritive sweeteners are included in the Rayner's score calculation. As the milk alternatives from this study did not contain any non-nutritive sweeteners, the number of additives did not have an impact on the products' Rayner's scores. However, to reduce the overall use of additives among milk alternatives, including other food additives besides non-nutritive sweeteners in the Rayner's score calculation may be even more plausible.

Furthermore, we found that products with less sugar contained more additives. Sugar is typically added to milk alternatives to sweeten these products and enhance their sensory properties (Cooper, 2020; Manzoor, 2017). However, the role of sugar goes beyond the sweetening effect. Sugar also contributes to how a products' flavour and mouthfeel are perceived. Processing steps for beverages, such as pasteurisation, can reduce a product's flavour due to the thermal destruction of flavour compounds (OSullivan, 2016). Sugar is known to enhance the mouthfeel of beverages (Miele et al., 2017). Replacing sugar with additives that help maintain or mimic sugar's functional properties is a well-known strategy for reducing industrial sugar (Luo et al., 2019). However, due to various health concerns and the increasing consumer trend towards cleaner and natural products (Asioli et al., 2017), the use of additives should be reduced in milk alternatives. Furthermore, our findings show that products with an increased fibre, mineral, and vitamin content tended to be more expensive than the remaining products. Therefore, we strongly emphasise that healthier versions of milk alternatives should be accessible and affordable.

4.3. Reformulation potential of milk alternatives

This study shows a need to reformulate milk alternatives towards healthier products, as almost half of all products had an insufficient nutritional profile (Nutri-Score D). This is mainly explained by the high natural and added sugar content. Of particular concern are milk alternatives made from rice, mixed plant sources, and oat. Besides enhancing the nutritional profile, we recommend reducing processed plant sources (particularly for milk alternatives made from mixed plant sources, rice, and oat) and additives (particularly for milk alternatives made from coconut, hazelnut, and almond).

Given the nutritional and compositional differences between milk alternatives from the different plant sources identified in our study, it is essential to implement distinct reformulation strategies tailored to the specific plant origin of the product. A large variability among milk alternatives was also recently confirmed, with differences in nutritional composition found not only between product types but also between brands (Antunes et al., 2023; Sterup Moore et al., 2024; Walther et al., 2022). In addition to the nutritional and compositional heterogeneity between products with different plant sources, we also identified large nutritional and compositional variability within products of the same plant origin. This variability allowed us to derive pathways for improving the nutritional and compositional profiles of commercial milk alternatives. In particular, among oat products, we identified the largest potential to reduce the Rayner's score (−12 points), the calorie (−36kcal/100 ml) and the sugar content (-8g/100 ml). This large variability and potential for reformulation might be explained by the large offer, given the overrepresentation of oat-based products in our study. However, this reflects the preference for oat products among Swiss consumers (FOAG, 2022). Furthermore, among milk alternatives that contain added sugar, soy-based products exhibited the greatest potential for sugar reduction, allowing for a decrease of 4.9 g per 100 ml. We also revealed opportunities to reduce the number of additives by up to three in milk alternatives made from oat, rice, soy, almond, and hazelnut. We further found the possibility of reducing processed ingredients, particularly among products with mixed plant sources (−17 %) and those made from rice (−14 %) and oat (−14 %).

5. Limitations and outlook

This market inventory was conducted in Switzerland using products from three of the country's largest supermarkets. Therefore, the results may not be generalisable for food offers from different countries and brands, particularly niche brands. However, this study included products from 14 different brands, with half being international brands and around 82 % of the products originating from countries in the EU region. As product composition might change between countries due to different consumer preferences and food policies, more national screenings of milk alternatives are needed. This will help to develop harmonised nutritional standards for milk alternatives to enhance the nutritional quality of food offers. Furthermore, most of the products included in this study were oat-based products, which might have led to larger nutritional and compositional diversity. More research is needed with representative numbers of different plant source varieties, particularly cashew-, hazelnut-, coconut-, pea-, and potato-based milk alternatives. As this study focused on nutritional aspects, such as Nutri-Score, calorie, and sugar content, future studies could investigate pathways for reformulation to modify the total fat, saturated fat, salt, fibre, protein, vitamin, mineral, and trace element content of these products.

This study identified the theoretical potential for reformulation of milk alternatives based on product nutrition and composition information. However, reformulation is a multidimensional approach. For successful reformulation and to anticipate possible barriers to reformulation, sensory, physicochemical, and liking information are highly important and essential during the process of reformulation. This might help maintain or even improve sensory perception among consumers and avoid disliking (with potential negative financial outcomes for industries) while reformulating towards a healthier product.

To enhance the nutritional and compositional profiles of milk alternatives, future reformulation studies should focus on the reduction of added and natural sugars. In particular, more research is needed to explore starch sources with a lower glycaemic load, to adapt the processing to reduce starch hydrolysis, and to direct or progressively reduce the sugar content with multi-sensory integration. Further, it might be of interest to study the impact of processed plant sources (flour, powder, pastes, etc.) on the calculated GI and protein quality (using complementary proteins in mixed products) of milk alternatives.

6. Conclusion

This study identified promising reformulation potential for milk alternatives from different plant sources. Thus, the use of a market inventory as a basis for identifying the potential for reformulating milk alternatives was successful. The findings highlight the need to transform milk alternatives into healthier products, as most of the products had insufficient nutritional profiles. Future reformulation should target soy-, mixed-plant sources, and oat-based products, as this study identified them as categories with the greatest potential for improving the overall nutrition profile (Nutri-Score). Based on the large nutrition and composition heterogeneity, it was possible to investigate a feasible threshold for reformulation. The highest potential for reformulation was found for oat-based milk alternatives. For future reformulation studies, we recommend a reduction in total sugar content (added and natural sugars) and an increase in protein content and quality. Further, including product compositional properties in the process of reformulation (such as reducing the percentage of processed ingredients and reducing the number of additives and ingredients) seems crucial. By using a complete database with commercially available milk alternatives, this study provides a solid basis for setting feasible reformulation targets and conducting in-depth sensory, physicochemical, and liking analyses on a reduced subset selected from this market inventory. Milk alternatives are seen as important products to help transform our food system towards a more sustainable one; however, their nutritional profile must be improved. Therefore, more harmonised and stricter recommendations for mandatory reformulation goals for milk alternatives are needed.

CRediT authorship contribution statement

Carole Liechti: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Gabriele Mack:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Barbara Walther:** Writing – review & editing. **Jeanine Ammann:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2025.117787.

Data availability

Data is available on Zenodo: https://zenodo.org/records/15076751.

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