Escola Nacional de Saúde Pública
UNIVERSIDADE NOVA DE LISBOA

Nutrient Profile Models to Promote Healthier Food Choices for Children

Doctoral Programme in Public Health

Specialization in Health Promotion

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July 2022

Escola Nacional de Saúde Pública

UNIVERSIDADE NOVA DE LISBOA

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Dissertation submitted in compliance with the requirements for the degree of Doctor of Public Health - Specialization in Health Promotion carried out under the scientific supervision of Maria Isabel Loureiro MD, PhD and Ana Isabel Rito, PhD.

July 2022

“Eles não sabem, nem sonham,
que o sonho comanda a vida.
Que sempre que um homem sonha
o mundo pula e avança
como bola colorida
entre as mãos de uma criança.”

António Gedeão, in 'Movimento Perpétuo',1956

Acknowledgements

To Professor Maria Isabel Loureiro for her knowledge and guidance. For encouraging me to develop critical work and for her availability and words of encouragement that she always had to offer me.

To Professor Ana Isabel Rito for her guidance and for all the opportunities that allowed me to acquire both knowledge and experience.

To Filipa Matias and Ricardo Assunção who believed in my work, for being an example of intelligence, and good mood, and for encouraging me to finish this PhD. Thank you for making this journey so much easier.

To Dr. Isabel Castanheira, Head of the Department of Food and Nutrition for her support, suggestions and precious guidelines and kind remarks. Thank you for always having made available to me all the resources necessary for the progress of this thesis.

To Dr. Maria Antónia Calhau who was the Head of the Food and Nutrition Department when I started my PhD, for her encouragement and friendship.

To my colleagues of the Laboratory, Ana Cláudia Nascimento, Ana Cristina Bento, Cristina Flores, Fernanda Vilarinho, Maria João Pires, Susana Santiago, Tânia Fontes, for all the encouragement, help and work done, allowing me to dedicate to "my other life".

To the Department of Food and Nutrition and the National Institute of Health Dr. Ricardo Jorge INSA to give me the opportunity to do my PhD research.

To my mother, Joaquina, thank you for your unconditional love. To my father, António, who would have been very proud of this achievement.

And last (but not least) to my daughter Margarida and my husband, Jorge. Thank you for your love. Thank you for giving me faith, hope and strength every day. Without you, this thesis wouldn't have been possible.

Abstract

Introduction

Noncommunicable diseases (NCDs) are the leading cause of death worldwide, constituting one of the greatest global public health challenges of the 21st century.

According to the World Health Organisation (WHO), the incidence and prevalence of NCDs are conditioned by individual and social risk factors, namely smoking, sedentary lifestyle, overweight, inadequate eating habits and alcoholism, all of which are avoidable risk factors.

In Portugal, according to data estimated by the 2019 Global Burden of Diseases (GBD) study, inadequate eating habits are one of the top five factors contributing to the loss of healthy life years. Factors influencing consumers' eating behaviours range from environmental factors, personal and individual differences, to economic and political ones, such as the cost or availability of food. Information provided by food labelling, food marketing and policies that impact on food prices also influences food choice.

In this context, the implementation of measures to create healthy eating environments have been identified as actions that can influence food choices and the nutritional status of individuals, contributing to the promotion of healthy eating.

These measures include the development of nutrient profile (NP) models that serve as a basis for the implementation of actions to promote healthy eating environments. Several NP models have been developed with the specific aim of defining the nutritional quality of individual foods or groups of foods by classifying them according to their specific nutrient content or ingredients of interest. NP models can be applied to guide the reformulation of food products, the establishment of specific compositional standards, the regulation of the marketing of foods for children, the establishment of nutrition and health claims and the creation of food labelling logos.

This thesis aimed to investigate the application of NP models, in the domains of food labelling, food composition/reformulation and food marketing/promotion, to produce evidence to support policymakers and researchers in creating healthy food environments.

The research consisted of four studies that used a combination of different research methods to address the overall aims and objectives initially established.

Study 1 presented an overview of the guiding principles for implementing NP models, providing a better understanding of their importance as a tool for establishing public

health interventions regarding consumers' food choices. The topics revisited in the state-of-the-art were intended to support policymakers in setting food and nutrition policies based on objective, transparent and reproducible methods for assessing the nutritional quality of food and non-alcoholic beverages.

Study 2 applied the NP models in the domains of food composition/reformulation and food promotion, to assess and compare the World Health Organisation Regional Office for Europe (WHO-EURO), the EU food industry's commitment on advertising and marketing toward children (EU-Pledge), and the national model developed by the Directorate-General for Health (NPM-PT) performance in the classification of ready-to-eat cereals (RTECs) for children, available in Portuguese supermarkets according to their nutritional composition; analysed the potential for reformulation of RTECs identified as inadequate and assessed the impact of reformulating RTEC, on the quality of children's food in Portugal.

Study 3 assessed the application of NP models in the domain of food labelling and aimed to evaluate the nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score* algorithm and investigated consistency with the dietary recommendations for the Portuguese population.

Study 4 characterised the applicability of NP models in the food marketing/promotion domain, assessing the performance of the NP model developed by the WHO Regional Office for Europe for the evaluation of commercially available complementary foods for infants and young children up to 36 months of age and classified the degree of processing, according to the NOVA classification system.

Results

The NP models have a wide range of applications including front-of-pack (FoP) food labelling, regulation of food marketing to children, regulation of health and nutrition claims and school food standards. In response to the set of measures and agreements established between the food industry and policymakers, NP models have been developed, to modify the food environment by promoting healthier food choices.

Regarding the application of the NP models in the reformulation of food products, the results of the second study showed statistically significant differences between the scenarios without and with reformulation, for the estimated sugar and dietary fibre content in infant cereals. The reformulation scenario, based on the nutritional criteria of

the DGS Nutrient Profile Model (NPM-PT) showed a reduction of 43% in sugar content and an increase of 34% in fibre content, for the RTECs analysed.

Concerning the application of NP models in the food labelling domain, the third study showed that the *Nutri-Score* had a good performance to discriminate differences in nutritional quality between different food groups, between foods of the same group and between different subgroups. At least three categories were observed for 75% of foods and distribution by at least two *Nutri-Score* categories was identified. The classifications were consistent with the Portuguese nutritional and dietary recommendations (93.0% of Vegetables included in category A and 57.1% of Bakery Products included in category E).

The application of NP models in the food marketing/promotion domain, to evaluate the commercially available complementary foods for infants and young children up to 36 months of age, revealed the total sugar content of several categories was higher than recommended and in contradiction with the recommendations to restrict sugar intake in infants and young children. In addition, our study suggested that an early introduction of ultra-processed in infants and young children diet was probable.

Conclusions

This work has presented empirical evidence aimed to support policymakers to implement food and nutrition policies based on the application of NP models.

Nutrient Profile Model is a tool that in the field of food composition/food labelling allows the identification of food products and beverages that are high in energy, salt, sugar, saturated fatty acids and trans-fatty acids, providing evidence for the reformulation of various food categories, intending to promote healthy eating habits.

The implementation of measures aimed at modifying food environments, such as the restriction of food marketing and advertising to children, based on the NP model, represents a key area of intervention, to support a healthy diet for children and contribute to the fulfilment of the fundamental right to healthy food and adequate nutrition, to which all children are entitled.

The NP models enable food and nutrition policymakers to identify unhealthy products and implement measures to achieve healthier food environments.

Keywords: nutrient profile models; food labelling, food reformulation, food marketing; children; healthy eating

Resumo

Introdução

As doenças não transmissíveis (DNT's) são a principal causa de morte no mundo, constituindo um dos maiores desafios globais de saúde pública do século XXI.

Segundo a Organização Mundial de Saúde (OMS), a incidência e prevalência destas doenças é condicionada por fatores de risco individuais e sociais, dos quais se destacam tabagismo, sedentarismo, o excesso de peso, hábitos alimentares inadequados e o alcoolismo, todos eles fatores de risco evitáveis.

Em Portugal, de acordo com os dados estimados pelo estudo *Global Burden of Diseases* (GBD) de 2019, os hábitos alimentares inadequados estão entre os cinco fatores que mais contribuem para a perda de anos de vida saudável.

Os factores que influenciam os comportamentos alimentares dos consumidores vão, desde os fatores ambientais, pessoais e diferenças individuais, até aos económicos e políticos, tais como o custo ou a disponibilidade dos alimentos. A informação disponibilizada pela rotulagem alimentar, o marketing alimentar e as politicas que têm impacto no preço dos alimentos também influenciam as escolhas alimentares.

Neste contexto, a implementção de medidas direccionadas para a criação de ambientes alimentares saudáveis têm sido apontadas como medidas que podem influenciar as escolhas alimentares e o estado nutricional dos individuos, contribuindo para a promoção de uma alimentação saudável.

Entre essas medidas está a criação de modelos de perfil nutricional que sirvam de base na aplicação de medidas para promover ambientes alimentares saudáveis. Diversos modelos de perfil nutricional têm sido desenvolvidos com o objectivo específico de definir a qualidade nutricional de alimentos individuais ou de grupos de alimentos, classificando-os de acordo com o seu conteúdo específico em nutrientes ou ingredientes de interesse. Os modelos de perfil nutricional podem ser aplicados com a finalidade de orientarem na reformulação de produtos alimentares, na definição de padrões específicos de composição nutricional, na regulamentação do marketing de produtos alimentares dirigidos a crianças, no estabelecimento de alegações de saúde e nutrição e na criação de logótipos de rotulagem de produtos alimentares.

Esta tese visou investigar a aplicação dos modelos de perfil nutricional, nos domínios da rotulagem alimentar, composição/reformulação dos alimentos e marketing/publicidade alimentar, com o objetivo de produzir evidências de suporte aos decisores políticos e investigadores, na criação de ambientes alimentares saudáveis.

Materiais e Métodos

A investigação desenvolvida consistiu em quatro estudos que utilizaram uma combinação de diferentes métodos de investigação para abordar as metas e objectivos globais inicialmente estabelecidos.

O Estudo 1 apresentou uma visão geral dos princípios orientadores para a implementação do modelo de perfil nutricional, proporcionando uma melhor compreensão da sua importância como um instrumento para estabelecer intervenções de saúde pública, relativamente às escolhas alimentares dos consumidores. Os tópicos revisitados no estado da arte destinaram-se a apoiar os decisores políticos na definição de políticas de alimentação e nutrição baseadas em métodos objectivos, transparentes e reprodutíveis, para avaliar a qualidade nutricional dos alimentos e bebidas não alcoólicas.

O Estudo 2 avaliou e comparou o desempenho do modelo de perfil nutricional da OMS, EU-Pledge e o modelo desenvolvido pela Direcção-Geral da Saude (DGS), na classificação dos cereais de pequeno almoço consumidos por crianças, segundo a sua composição nutricional; avaliou o potencial de reformulação dos cereais identificados como não adequados e o impacto da sua reformulação, na qualidade nutricional dos cereais de pequeno almoço e na qualidade da dieta da crianças.

O Estudo 3 caracterizou a aplicabilidade dos modelos de perfil nutricional, no domínio da rotulagem de alimentar, de acordo com o algoritmo *Nutri-Score* e investigou a sua coerência com as recomendações alimentares para a população portuguesa.

O Estudo 4 caracterizou a aplicabilidade dos modelos de perfil nutricional, no domínio marketing/publicidade alimentar, avaliando o desempenho do modelo de perfil nutricional OMS – Europa, desenvolvido para alimentos comercializados para lactentes e crianças pequenas até os 36 meses de idade, e classificou o grau de processamento, de acordo sistema de classificação NOVA.

Resultados

Os modelos de perfil nutricional têm uma diversidade de aplicações, destacando-se os sistemas de rotulagem nutricional simplificada (FoP), regulamentação do marketing e publicidade alimentar dirigida a crianças, as alegações nutricionais e de saúde e a oferta alimentar em contexto escolar.

Como resposta ao conjunto de medidas e acordos estabelecidos entre a indústria alimentar e os decisores políticos, os modelos de perfil nutricional foram desenvolvidos, com a finalidade de modificar o ambiente alimentar promovendo escolhas alimentares mais saudáveis.

Quanto à aplicação dos modelos de perfil nutricional na reformulação de produtos alimentares, os resultados do segundo estudo revelaram existir uma diferença significativa entre os cenários sem e com reformulação, para teores estimados de açúcar e fibra alimentar nos cereais infantis. O cenário de reformulação definido, com base nos criterios nutricionais do modelo de perfil nutricional da DGS (NPM-PT) evidenciou uma redução no teor de açucar em 43% e um aumento no teor de fibra em 34%, nos cereais analisados.

Relativamente à aplicação dos modelos de perfil nutricional no domínio da rotulagem nutricional, o terceiro estudo demonstrou que o Nutri-Score, conseguiu discriminar diferenças na qualidade nutricional entre os diferentes grupos de alimentos, entre alimentos do mesmo grupo e entre subgrupos diferentes. Foram identificadas pelo menos três categorias para 75% dos alimentos e foi observada a distribuição por, pelo menos duas categorias do Nutri-Score. As classificações foram consistentes com as recomendações nutricionais e alimentares portuguesas (93,0% dos Produtos horticolas incluidos na categoria A e 57,1% dos produtos de pastelaria incluídos na categoria E).

Quanto à aplicabilidade dos modelos de perfil nutricional, no domínio marketing/publicidade alimentar, a avaliação dos alimentos comercializados para lactentes e crianças pequenas até aos 36 meses de idade, revelou um teor de açúcar total superior ao recomendado, em várias categorias de alimentos, estando em contradição com as recomendações para restringir a ingestão de açúcar em lactentes e crianças pequenas. A classificação do grau de processamento revelou ser provável uma introdução precoce de alimentos ultra-processados.

Conclusões

Este trabalho apresentou provas empíricas destinadas a apoiar os decisores políticos na implementação de políticas alimentares e nutricionais baseadas na aplicação de modelos de perfil nutricional.

O modelo de perfil nutricional é uma ferramenta que no dominio da composição nutricional/rotulagem alimentar permite identificar os géneros alimentícios e bebidas que contenham elevado valor energético, teor de sal, açúcar, ácidos gordos saturados e ácidos gordos trans, fornecendo evidências para a reformulação de determinadas categorias de alimentos, com o objetivo de promover hábitos alimentares saudáveis.

A implementação de medidas que visem a modificação dos ambientes alimentares nomeadamente a restrição do marketing e da publicidade alimentar dirigida a crianças, baseada no modelo de perfil nutricional constitui uma área de intervenção prioritaria, contribuindo para a uma alimentação saúdavel nas crianças e assegurando o seu interesse superior.

Os modelos de perfil nutricional permitem aos decisores politicos, com responsabilidade na definição de politicas de alimentação e nutrição, identificarem alimentos não saudáveis e implementarem medidas para tornar os ambientes alimentares mais salutogénicos.

Palavras-chave: modelo de perfil nutricional; rotulagem alimentar, reformulação de alimentos; publicidade alimentar; crianças; alimentação saudável;

Table of Contents

List of Tables

List of Figures

List of Abbreviations

BOP	Back of pack
CACFs	Commercially available complementary foods
DGS	Directorate-General of Health
DRV	Dietary Reference Values
EC	European Community
ECHO	Ending Childhood Obesity
EFSA	European Food Safety Authority
EIPAS	Integrated Strategy for the Promotion of Healthy Eating
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FBDG	Food-Based Dietary Guidelines
FOPL	Front-of-pack labelling
FOP	Front-of-pack
FSAm-NPS	British Food Standards Agency's Nutrient Profiling System
HFSS	High fat, sugar and/or salt (foods)
HLPE	High-Level Panel of Experts
IOM	Institute of Medicine
IYC	Infants and young children
NCDs	Non-Communicable Diseases
NP	Nutrient Profile
NPM-PT	Portuguese Nutrient Profile Model
PNPAS	National Programme for the Promotion of Healthy Eating
PT-TDS	Portuguese Total Dietary Study
RDAs	Recommended Dietary Allowances
RNI	Recommended Nutrient Intakes
RTECs	Ready-to-eat cereals
SDG	Sustainable Development Goals
SSBs	Sugar-Sweetened Beverages
UP	Ultra-processed
WHO	World Health Organization

Publications and conference abstracts arising from this thesis

Journal articles

Santos M, Rito AI, Matias FN, Assunção R, Castanheira I and Loureiro I, 2021**. Nutrient profile models A useful tool to facilitate healthier food choices: A comprehensive review**. Trends in Food Science & Technology, 110:120-131. https://doi.org/10.1016/j.tifs.2021.01.082

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Mariana Santos, Ana Isabel Rito, Ana Dinis; Carla Rascôa, Sofia Mendes, Isabel Loureiro, Isabel Castanheira **“School meals energy and nutritional composition**

according to age-specific nutritional guidelines - Eat Mediterranean Program” - American Society for Nutrition - Nutrition 2019, June 8-11, 2019 in Baltimore, Maryland.

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1. Introduction

This chapter introduces the research by providing an overview of the topic, set out the aims of the thesis, explains the significance of the research and outlines the thesis structure.

1.1. Overview

The term “nutrient profile” (NP) has been associated with several concepts arising from the need to regulate the choice of food products, and to allow consumers to make informed and healthier food choices. The use of NP models as a policy tool to improve public health nutrition and reduce the prevalence of non-communicable diseases is receiving increasing attention (1).

Nutrient profiles allow the categorisation of foods and drinks according to their overall nutritional composition. They are widely applied in Europe and around the world to guide consumers’ choices toward healthier items (2).

During the last decade, little research had been undertaken at the National level about nutrient profiling. In this context, it was a relatively new concept, where initially some aspects of nutrient profiling were included in voluntary food labelling.

The European Food Safety Authority (EFSA) initiated work to define nutrient profiles; and by 2006 the EFSA proposed Regulation (EC) No 1924/2006 on nutrition and health claims made on food, which came into force on July 01, 2007 (3) and in 2012 the Regulation (EU) No 1047/2012, which updates the nutrition and health claims, was approved (4).

In 2013, the Ministers of Health and representatives of the Member States of the WHO Regional Office for Europe, together with the WHO Regional Director for Europe, health experts, representatives of civil society, and intergovernmental organizations adopted the Vienna Declaration on “Nutrition and Noncommunicable Diseases in the Context of Health 2020” (5). This declaration includes the specific commitment to “take decisive action to reduce food marketing pressure to children concerning foods high in energy, saturated fats, trans-FA, free sugars or salt”; in addition to the development and implementation of policies to promote, among other things, the use of tools such as nutrient profiling (5).

The development of a nutrient profile (NP) model as a common tool for the use or adaptation to the Member States in Europe (on a voluntary basis and taking into account the individual national circumstances) has been identified as a key activity in the 2015-2020 Action Plan (6).

The model developed by the WHO Regional Office for Europe, in response to this plan, has been focused specifically on restricting the advertising directed at children. The 2013 report pointed out that some countries had completely implemented this restriction.

Moreover, the optimal progress of the policies has been hampered by the lack of suitable NP Models or other ways of food classification (7).

At the start of this thesis in September 2015, the prevalence of overweight in Portugal was high in adults and children. More than 50% of the adult Portuguese population were overweight (including obesity, body mass index ≥ 25 kg/m^2) whereas, for children aged between 6 and 8 years, this indicator reached 30%, categorising Portugal as one of the countries with the highest prevalence of child overweight in Europe (8).

Data from the last national health survey showed a higher prevalence of several chronic diseases in the lower educational level groups (diabetes: 12.2% in individuals with less than 4 years of education vs. 6.4% in individuals with more than 12 years of education; hypertension: 45.1% in individuals with less than 4 years of education vs. 25.6% in individuals with more than 12 years of education). The same pattern is observed for obesity (38.5% in individuals with less than 4 years of education vs. 13.2% in individuals with more than 12 years of education) (9).

Considering this epidemiology context, in 2012, Portugal implemented the first national food and nutrition policy – "National Programme for the Promotion of Healthy Eating" (PNPAS). PNPAS was approved by Order n.° 404/ 2012 of January 3, 2012, having been considered one of the eight priority programmes to be developed by the Ministry of Health (10).

PNPAS was created to fulfil the mission of improving the nutritional status of the population, stimulating the physical and economic availability of healthy foods and creating conditions so that the population can value, appreciate and integrate them into their daily routines. PNPAS was designed around 5 general objectives: **a)** to increase knowledge of the food intake of the Portuguese population, its determinants and consequences; **b)** to modulate the availability of some foods, namely in schools, workplaces and public spaces; **c)** to inform and empower citizens, especially those in more disadvantaged groups, for the purchase, cooking and storing of healthy foods; **d)** to identify and promote cross-sectional actions that promote the intake of high nutritional quality foods, articulating and integrating other sectors, namely agriculture, sports, environment, education, social security and municipalities, and **e)** to improve training and action of different professionals who, due to their activity, can influence knowledge, attitudes and behaviours towards food (11).

Therefore, to align and potentiate all the different approaches regarding the area of nutrition at a national level, a better articulation between Ministries in the Portuguese Government was required. On September 15, 2016, the Portuguese Council of Ministers, through the Deliberation of the Council of Ministers no. 334/2016, determined the creation of an interministerial working group on the promotion of healthy eating. In 2017, a formal structure, spearheaded by health and composed of 6 more ministries was created – The Integrated Strategy for the Promotion of Healthy Eating (EIPAS) (12).

The EIPAS' main objectives were to encourage healthier food consumption habits as well as to improve the nutritional status of the Portuguese population. This strategy was designed to address three main issues, namely (1) to modify the supply of certain foods, particularly those with high sugar, high salt and high-fat content; (2) to encourage actions of nutritional reformulation of food products through an articulated action with the food industry, food distribution and also with the food and beverage service providers; and (3) to empower citizens and professionals who work on or influence the consumption of food to encourage healthy food choices (13).

In summary, there is a need to fill the gap in the evidence base, for understanding the potential impact of food and public health policies based on the application of NP Models, in the domains of food labelling, food composition/reformulation and food marketing/promotion to create healthy food environments.

1.2. Significance of this research

The research incorporated in this thesis was conducted predominantly in Portugal. Accordingly, the focus of the thesis is on NP Models and their application to promote healthy food choices, with most of the examples and scenarios analysed in the Portuguese context.

The research findings are intended to make a substantial contribution to existing knowledge about the potential role and impact of nutrition profiling as a nutrition policy to promote healthier food environments and choices, and to provide evidence to support policymakers and researchers in addressing the effectiveness of using NP models to contribute to better public health. All of the research incorporated in this thesis was conducted between 2015 and 2021.

1.3. Research aims and research questions

This thesis aims to investigate the application of NP Models in the national context, regarding the domains of food composition/reformulation, food labelling, and food marketing/promotion. In addressing these aims, the thesis sought to answer the following main research questions:

"What is the potential role and impact of NP models as a nutrition policy to promote healthy food choices? What are the potential outcomes of the different applications of NP models in the national context?"

To tackle the main research questions four studies were planned and developed.

Study 1 – consists of a literature review to clarify the importance of NP models as a tool to establish public health interventions concerning consumers' food choices. This review was conducted by covering the main characteristics, advantages, disadvantages, and associated gaps of the considered NP models. This study addressed the following research questions:

1. What is nutrient profiling?
2. What are the assumptions used during the development of an NP model?
3. What are the gaps and opportunities for research concerning NP models?

Study 2 - addresses the adequacy of the Ready-to-eat cereals (RTECs) for children available in Portuguese supermarkets, applying three NP models - the NP model of the World Health Organization's Regional Office for Europe (WHO-EURO), the EU food industry's commitment on advertising and marketing towards children (EU-Pledge), and the national model developed by the Directorate-General of Health (NPM-PT); explore the potential for reformulation of the RTECs identified as not adequate and evaluate the impact of RTECs' reformulation on the nutritional quality of Portuguese children's diets. This study addressed the following research questions:

1. What is the compliance rate of the RTECs for children available in the Portuguese supermarket, considering three NP models designed to restrict food marketing and advertising to children—the NPM-PT, WHO-EURO and EU-Pledge?
2. What is the potential for reformulation of the RTECs identified as not adequate?
3. What is the impact of RTECs reformulation on the nutritional quality of Portuguese children's diets?

Study 3 - evaluated the nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score*, and investigate the consistency with the Portuguese food-based dietary guidelines, as a contribution to the validation of this FOPL in the national context. This study addressed the following research questions:

1. What is the discriminating performance of the *Nutri-Score* in terms of the foods consumed by the Portuguese population?
2. What is the consistency of the classification with the *Nutri-Score* with the Portuguese food-based dietary guidelines, as a contribution to the validation of this FOPL in the Portuguese context?

Study 4 - assess the application of the NP model proposed by the WHO Regional Office for Europe to identify which commercially available complementary foods (CACFs) are appropriate/inappropriate for promotion to IYC up to 36 months of age and what is the degree of processing, as defined by the NOVA classification system that classifies foods and food products to the degree of processing. This study addressed the following research questions:

1. What is the compliance of CACFs for IYC sold in the Portuguese marketplace according to the criteria of the NP model?
2. What is the degree of processing, as defined by the NOVA classification?
3. Are the findings adequate to provide a proposal for updated regulation and to promote the reformulation of foods for IYC?

The objectives set for the thesis are presented in detail in Chapter 3.

1.4. Thesis structure

This thesis is presented as a collection of manuscripts, each designed to stand on its own. However, when taken together, the manuscripts serve to address the research aims and objectives and answer the research questions presented above.

This chapter has provided an introduction to the research, set out the research aims and research question and outlined the thesis structure.

Chapter 2 outlines the context of the research and looked at the relevant literature concerning the applications of NP models in the domains of food labelling, food composition/reformulation and food marketing/promotion.

Chapter 3 presents the research objectives and the design, as well as an overview of the methods applied in each of the performed studies.

The manuscripts composing the bulk of the thesis are presented from Chapters 4 til 7. Each of the manuscripts is written in the conventional publication style for their target journals and they are presented as such. Because each manuscript is designed to stand alone, there is an inevitable degree of repetition when they are read together, particularly in the literature presented in their 'Background' sections.

The references for each manuscript are incorporated as part of the manuscripts. References cited in parts of the thesis that are not part of a manuscript are provided at the end of the thesis.

Chapter 8 consists of a Discussion on the main findings, the methodological strengths and limitations of the studies, and implications for public health and practice.

This thesis ends with Chapter 9 Conclusions which provides a synthesis of the research findings and proposes recommendations for future research, practice and policy.

Finally, using different outcome measures, different settings, different methods of data collection, and different research designs we aimed to gain insight on the effectiveness of using NP models to promote a healthy food environment, to help the consumers to make healthier food choices, to encourage the food product reformulation and improvement, and to contribute to better public health.

A schematic overview of the thesis chapters is shown in Figure 1.

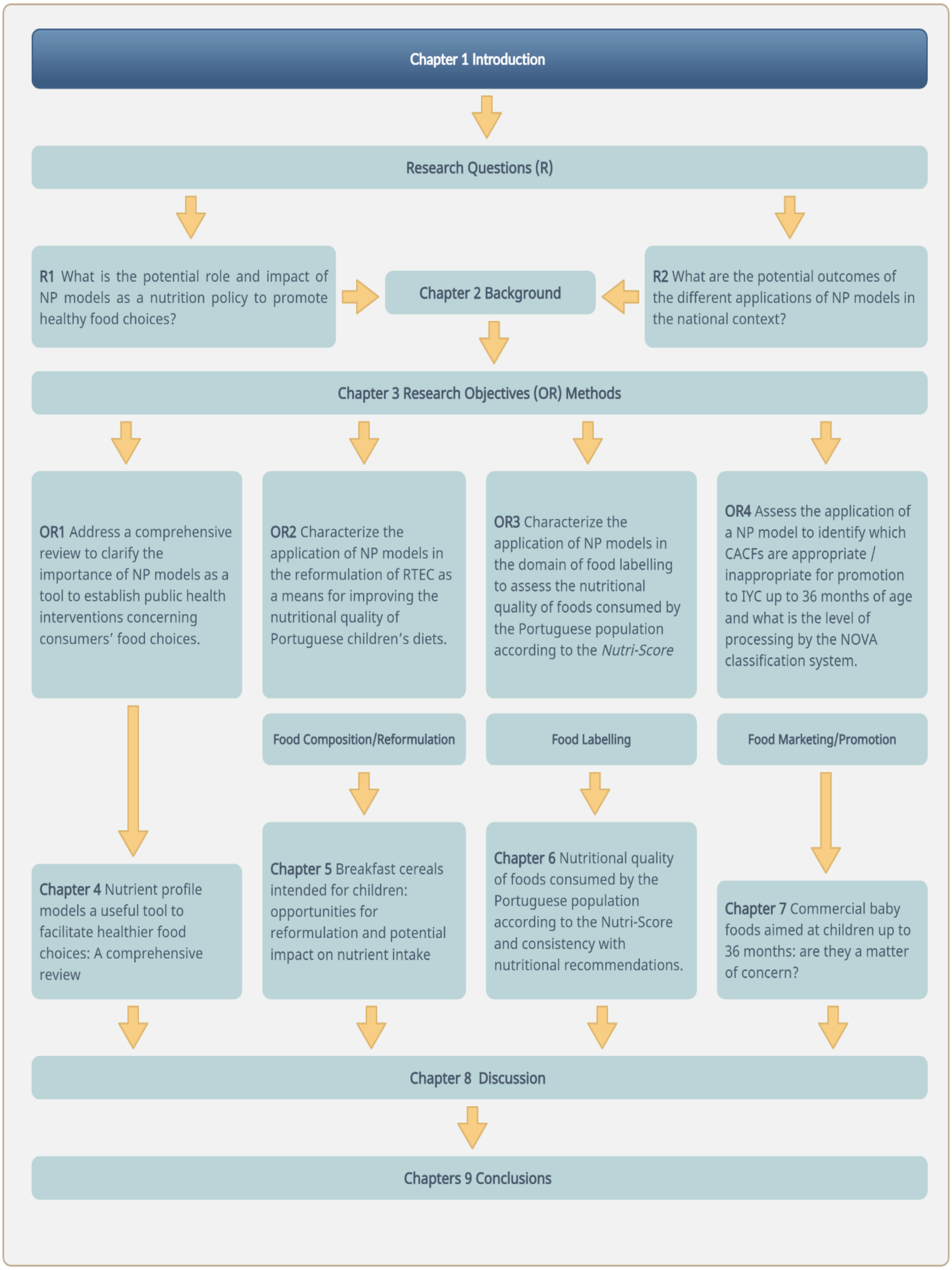


Figure 1. Structure of the thesis and outline of each chapter

2. Background

This chapter outlined the background to the importance of the research and looked at the relevant literature surrounding the applications of NP models in the domains of food labelling, food composition/reformulation and food marketing/promotion.

2.1. Food, nutrition, diet and non-communicable diseases

2.1.1. Diet-related health challenges

Non-communicable diseases (NCDs) are increasing worldwide and in Europe and constitute one of the major global public health challenges of the 21st century. NCDs, including 15 million people who die too young – between the ages of 30 and 70. The burden continues to rise disproportionately in low- and lower-middle-income countries while in all countries, these deaths disproportionally affect the poorest and most vulnerable. The majority of premature NCDs deaths in this 30–70 age group are the result of the four main non-communicable diseases: cardiovascular disease, cancer, diabetes and chronic respiratory disease jointly contributed to more than 70% of all deaths worldwide in conjunction with an economic impact (14,15).

According to World Health Organization (WHO), NCDs are caused by four key risk factors: tobacco use, harmful use of alcohol, unhealthy diet, and physical inactivity. Alternatively, the NCD risk factors have been categorised as modifiable behavioural (the harmful use of alcohol, physical inactivity, salt/sodium intake and tobacco use), non-modifiable factors (mainly age, gender, family history, ethnicity) and metabolic risk factors (raised blood pressure, raised blood glucose and obesity) (16).

Malnutrition and NCDs are closely linked and are now the biggest risk factor for NCDs. Malnutrition includes excessive and imbalanced intake, leading to overweight, obesity, and diet-related NCDs. It also includes nutritional disorders caused by deficient intakes of energy or nutrients, such as stunting, wasting, and micronutrient deficiencies. Poor-quality diets, malnutrition in all its forms, and NCDs are the logical consequences, among other factors, of major changes in the way food is produced, sold, marketed and consumed worldwide over the past 50 years (17).

According to the Food and Agriculture Organisation (FAO) report "State of Food Security and Nutrition in the World 2021", the world has not been generally progressing either towards Sustainable Development Goal (SDG) Target 2.1, of ensuring access to safe, nutritious and sufficient food for all people all year round or towards SDG Target 2.2, of eradicating all forms of malnutrition (18).

The progress towards the 2030 SDG targets was assessed using the 2030 targets proposed, as an extension of the 2025 global seven nutrition targets, which are summarized in Figure 2.

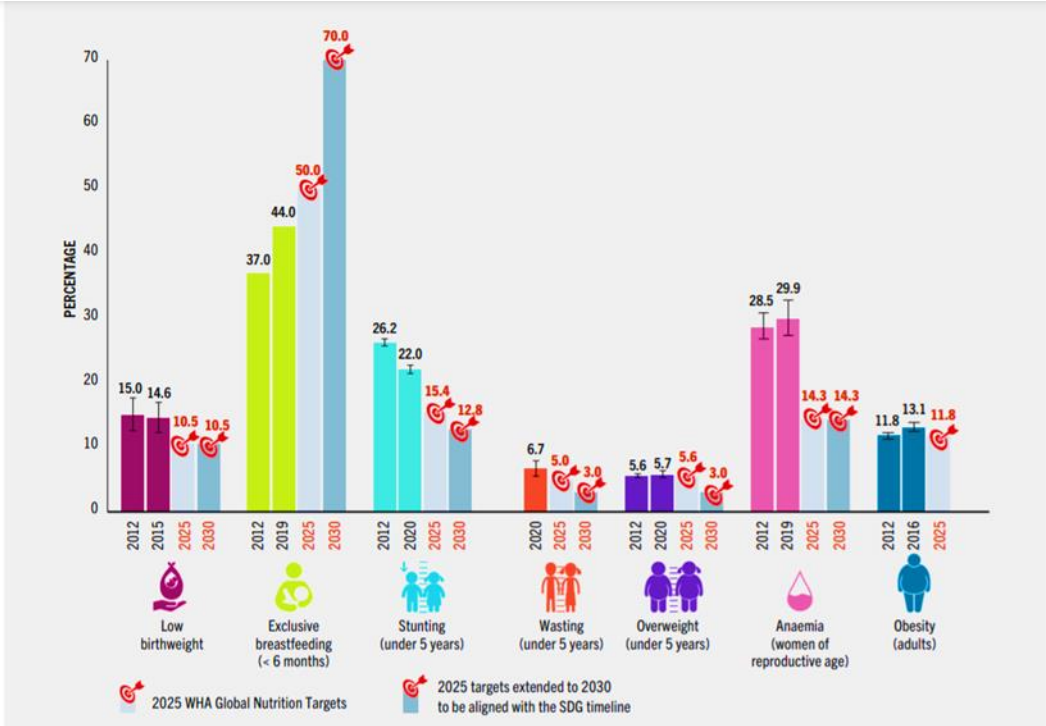


Figure 2. Progress towards each of seven nutrition indicators towards global nutrition targets.

Souce: THE STATE OF FOOD SECURITY AND NUTRITION IN THE WORLD 2021 (18).

Globally, malnutrition in all its forms also remains a challenge. Although it is not yet possible to fully account for the impact of the COVID-19 pandemic, in 2020, it is estimated that 22.0 % (149.2 million) of children under 5 years of age were affected by stunting, 6.7 % (45.4 million) were suffering from wasting and 5.7 % (38.9 million) were overweight (18).

The COVID -19 pandemic may also have led to increases in childhood overweight, especially in settings where food choices and physical activity were negatively influenced by its mitigation. Children and adolescents may have experienced circumstances that accelerated weight gain, including increased stress, irregular meal times, less access to nutritious foods, longer screen time and fewer opportunities for physical activity (19).

Adult obesity has also risen, with the global prevalence increasing from 11.7% in 2012 to 13.1% in 2016. All subregions showed increasing trends in the prevalence of adult obesity between 2012 and 2016 and are off track to meet the 2025 World Health Assembly target to halt the rise by 2025 (18).

Globally, progress is being made for some forms of malnutrition, but the world is not on track to achieve targets for any of the nutrition indicators by 2030. Nevertheless, notable improvements are occurring in some areas, with nearly two-thirds of countries seeing at least some progress towards the stunting target. In contrast, for overweight, about half of all countries have experienced no progress or are worsening (20).

The figure above shows progress towards the SDG 2.2 targets on stunting, wasting and overweight by the percentage of the global under-five population and the progress by percentage of countries globally (18).

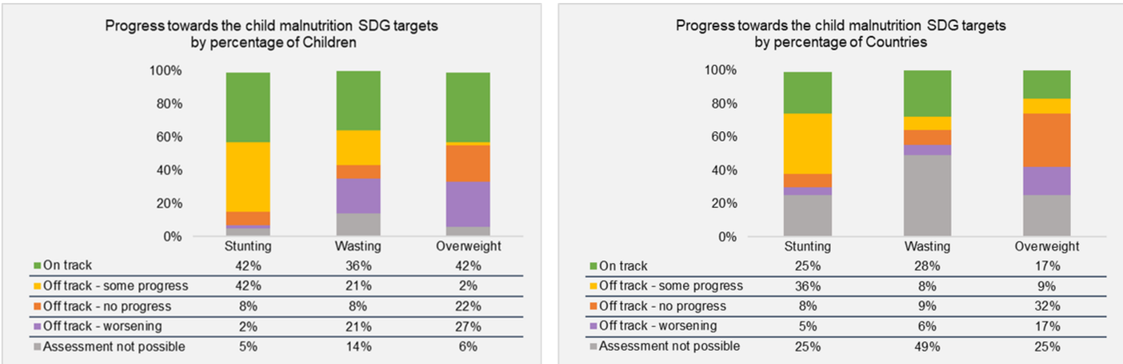


Figure 3. Progress towards child malnutrition SDG 2.2 targets on stunting, wasting and overweight by Children (under 5 years) and Countries (%).

Adapted from: THE STATE OF FOOD SECURITY AND NUTRITION IN THE WORLD 2021 (18).

When considering progress for children under five, almost 85% of children live in countries showing some progress towards the target of reducing stunting, with only 10% living in countries showing no progress or a worsening situation. The situation is more serious for overweight: half of all children (49%) live in countries showing no progress or worsening. For wasting, almost a third of children (29%) live in countries with no progress or a worsening situation (18).

2.1.2. Toward a Definition of Sustainable Healthy Diets

Healthy diets can be defined based on their capacity to meet nutrient needs, support growth and development, and reduce the risk for non-communicable diseases (21).

The World Health Organization defines a healthy diet as being one that has energy intakes in balance with energy expenditures. Fat intake should be no more than 30 %of total energy intake, with saturated fats making up one-third or less of total fat intake.

Added sugar should also be a low percentage of total calorie intake (less than 10 % of total calories, but better is lower than 5%), and salt consumption should also be low (below 5 grams).

A basic principle of a healthy diet is that it should contain a variety of items from several different food groups (i.e. a mix of fruits, vegetables, legumes, nuts, and whole grains). Fruits and vegetables should be made abundant enough to ensure adequate consumption of micronutrients (at least 400g (i.e. five portions) of fruit and vegetables per day). A healthy diet should be low in ultra-processed foods (21).

Healthy dietary patterns, as identified in most national food-based dietary guidelines, are built around a variety of nutrient-dense foods and beverages, including plant- and animal-sourced foods, while limiting foods containing excess fat, sugar and salt and foods of minimal nutritional value (22).

Sustainable diets are defined by the Food and Agriculture Organization of the United Nations (FAO) as nutritionally adequate and healthy, have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable (23).

Sustainable Healthy Diets aim to achieve optimal growth and development of all individuals and support functioning and physical, mental, and social wellbeing at all life stages for present and future generations; contribute to preventing all forms of malnutrition (i.e. undernutrition, micronutrient deficiency, overweight and obesity); reduce the risk of diet-related NCDs, and support the preservation of biodiversity and planetary health. Sustainable healthy diets must combine all the dimensions of sustainability to avoid unintended consequences (23).

Policy options to tackle the different forms of malnutrition and diet-related NCDs can also help create sustainable food systems, benefitting planetary health (17).

This thesis draws on two key conceptual frameworks: the conceptual framework of food systems for diet and nutrition (24) and the conceptual framework of food systems for children and adolescents 'Innocenti Framework' (25).

2.1.3. The concept of Sustainable Food Systems

By definition, food systems are complex adaptive systems, so addressing food systems to improve diets must necessarily include an analysis of the dynamics related to dietary outcomes and their interactions with other elements of food systems. The concept of food systems became central in food policy as a guiding framework for strategic thinking toward achieving diverse, safe and nutritious food for all (24).

FAO defined a food system as "encompass the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products that originate from agriculture, forestry or fisheries, and parts of the broader economic, societal and natural environments in which they are embedded (26).

The conceptual framework proposed by the HLPE (Figure 4) identifies three determinants of food systems, i.e. food supply chains, food environments and consumer behaviour that are essential elements of food systems that determine nutrition and the connection to health. It highlights the central role of the food environment (i.e. the physical, economic, political and socio-cultural context in which each consumer engages with the food system) in facilitating healthy and sustainable consumer food choices (24).

The structural factors (drivers) that need to be put in place for the food system to be able to provide nutritious, safe, accessible, affordable and sustainable diets include (1) demographic drivers (urbanisation, population growth, migration); (2) political and economic drivers (leadership, policies, trade); (3) innovation and technological drivers (technology, infrastructure, investment); (4) biophysical and environmental drivers (climate change, natural resource management); and (5) social and cultural drivers (norms, traditions, and underlying social dynamics) (24).

With urbanisation, globalisation and trade liberalisation, food systems are changing rapidly. Food environments are globally connected; supply chains are longer and more complex. These changes have a dramatic impact on the nutritional status of populations (17).

The way that people access food, the kinds of food they purchase, the methods of consumption and the culturally conditioned meanings of food and eating are also shaping food systems (27).

Many factors influence consumers' dietary behaviours, from personal such as culture, knowledge, skills dietary preferences, and time for food preparation—to economic and political such as the cost or availability of food. Information about food, whether through education or marketing, also influences choices. Marketing, labelling and policies that impact on price affect consumer demand. Economic and social protection policies determine whether they are vulnerable. The nutritional quality of the food available where we live affects the health of people and the planet. (17).

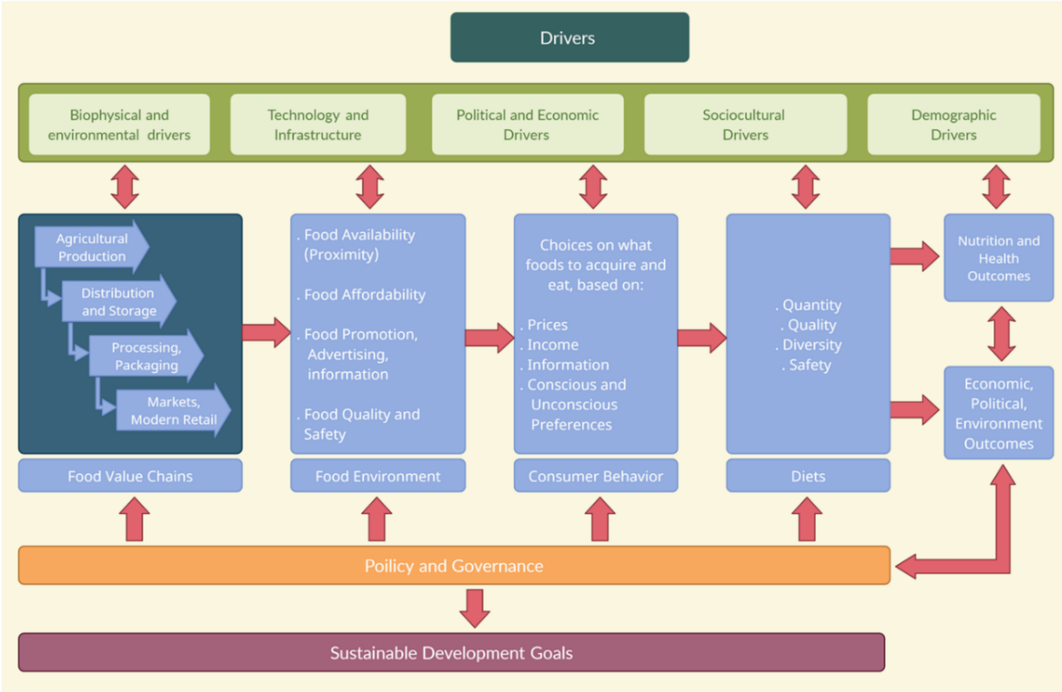


Figure 4. Conceptual framework of food systems for diet and nutrition.

Adapted from High-Level Panel of Experts on Food Security and Nutrition 2017 (24).

The FAO High-Level Panel of Experts (HLPE) defined a sustainable food system as "a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised" (28).

Sustainable food systems emphasise the role of diets as a central link between food, human health and nutritional outcomes. For effectively achieving the nutritional objectives it is necessary to adopt a holistic approach to sustainable food systems that considers their entirety, completeness and how they relate to environmental, social and economic dimensions and that all key sectors and actors embrace the same vision, align their policies and coordinate their actions for the needed nutritional outcome (29).

Increasing attention has been placed in recent years on transforming food systems to increase food security, providing healthy diets for all including children and adolescents, reducing the incidence of NCDs and enhancing the sustainable management of natural resources in the face of climate change (17). However, most of these efforts to transform food systems have not prioritized children and adolescents as key stakeholders (30).

Childhood and adolescence are periods of rapid growth and development. Children and adolescents are particularly susceptible to advertisements and marketing, which can influence their desire for certain diets as well as their future dietary preferences. Foods and beverages with added sugars (e.g., breakfast cereals, soft drinks, confectionery) and fats (savoury snacks, fast foods) are among the most common categories of foods promoted to children and are associated with increased demand for and consumption of those products (31,32).

Children and adolescents are also connected with school food environments and the food available around those environments and, as they get older, they become more independent and may select less healthy foods, due to the impact of their peers and other influencers (31). Establishing the diets of children and adolescents as the primary outcome of food systems helps to align actors across the food system towards the common goal of supporting the dietary needs of children and adolescents (30).

The conceptual framework food systems for children and adolescents 'Innocenti Framework' (25) takes a child- or adolescent-specific lens to consider interactions between the elements of food systems and nutrition and health outcomes (figure 5).

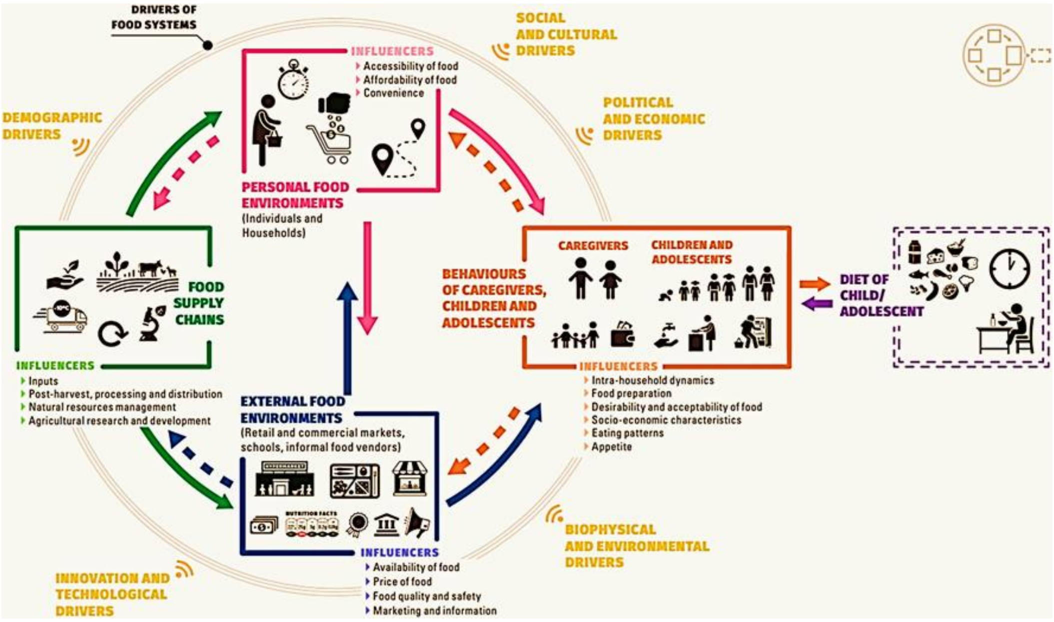


Figure 5. The Innocenti framework on food systems for children and adolescents.

Source: UNICEF and GAIN, 2019 (25).

Actors across food supply chains and food environments, and children, adolescents and their caregivers, play an important role in assuring the diets of children and adolescents. As such, they are central actors in a food systems approach and the food system framework for children and adolescents (30).

The role that food environments can play in shaping dietary patterns, especially in the context of the double burden of malnutrition, has gained traction in recent years (24). The food environment can be defined as “the interface that mediates people’s food acquisition and consumption within the wider food system. It encompasses external dimensions such as the availability, prices, vendor and product properties, and promotion information and personal dimensions such as the accessibility, affordability, convenience, and desirability of food sources and products” (24,27).

The environments in which we grow up, play, live and work have a significant impact on the development of our food preferences and choices and the overall nutritional quality of our diets, so more focused policies and interventions are needed to build healthier food environments (33).

Transitions to healthy food environments will need to be predominantly government-led including comprehensive regulations to restrict the promotion of high fat, sugar and salt (HFSS) foods to children, promote the reformulation of foods and beverages as well as efforts to increase the availability and promotion of healthy foods (e.g. in school settings) and improved health-related food labelling, and fiscal policies to better incentivize consumption of healthier foods and disincentivize consumption of unhealthy foods (33,34).

2.2. Policies to promote healthy diets and prevent obesity

A range of policy options exists across different food environment settings and through varying levels of governance, ranging from legislation passed by national governments to an informal strategy implemented by a food retail organization (35). Policies to counteract overweight and promote healthier lifestyles can be grouped into four broad categories: policies influencing lifestyles through information and education; policies modifying the cost of health-related choices; policies widening the set of healthy choice options and policies regulating or restricting actions promoting unhealthy choice options (36). Some areas can be highlighted.

2.2.1. Policies influencing lifestyles through information and education

Encourage the use of easy-to-understand or interpretative, consumer-friendly labelling on the fronts of packages and the population education on nutrition and healthy diets, media campaigns and defining food-based dietary guidelines, are policy options to promote healthy food choices and healthier lifestyles. Such approaches are widely and increasingly used and can also promote industry reformulations, to reduce product contents of sodium and artificial trans fat, which may have an important effect on longer-term health beyond immediate consumer behaviour (33,37).

Food labelling/Communication with the public /Nutrition literacy

Labels on pre-packed foods are designed to inform consumers about the nutritional value of the food. They may include "informative" labels containing a list of nutrients, normally placed on the back, or clearly visible "interpretative" labels providing nutrition information in a more easily understandable format, normally placed on the front (38).

As part of a comprehensive policy response to promoting healthier diets and preventing NCDs, WHO recommends that governments implement front-of-pack (FOP) nutrition labels. These labels, often in graphical format, provide simplified nutrition information on the front of the packaging of foods and beverages, complementing the detailed nutrition statements on the back of the package. A growing body of evidence suggests that such labels can help consumers understand nutritional quality, encourage the selection and purchase of healthier foods, and promote reformulation by industry (39).

Health-promoting mass media campaigns can be implemented through both traditional (television, radio, newspaper) or new media (online marketing, social networks [e.g. social media]) and have the potential to reach many people while affecting multiple overweight risk factors at the same time. Such campaigns can be implemented at the national level, or in some cases, they can be launched by local authorities (36). This issue will be covered in more detail in section 2.3.1.

2.2.2. Policies to modify the costs of health-related choice

Governments can affect food-related consumer behaviour by implementing targeted price policies. Most policy action in this field has focused on increasing the price of products high in sugar, saturated fats or salt.

Fiscal and Pricing policies

In contrast to education and information, fiscal incentives and disincentives aimed at consumers, producers, and retailers influence purchasing behaviour and consumption patterns. Fiscal and pricing policies may also catalyse changes in the food system, and be a starting point for the development and implementation of other policy actions to promote healthy diets (40).

Disincentives can include excise or sales taxes on unhealthy items such as sugar-sweetened beverages and junk food or removal of industry tax benefits for the development and marketing of unhealthy products. Disincentives on specific foods can be politically difficult, however, the rapid international expansion of taxes on sugar-sweetened beverages (SSBs) shows the growing acceptance of this approach (35,40).

2.2.3. Policies designed to widen choices

While policies that influence lifestyles through information and education are important, they may not be sufficient if the local environment presents limited opportunities to engage in healthy lifestyles. For example, recommending physical activity may be ineffective if there is a lack of safe, walkable and green spaces. Likewise, encouraging people to eat more fruit and vegetables via mass media campaigns may have limited value if opportunities to access healthy food are limited, or if skills in food preparation are lacking (36).

Procurement and quality standards

Procurement and quality standards are relatively sustainable, low-cost strategies for government to implement. A well-planned food procurement process will promote healthy diets, the balanced and adequate consumption of nutritious foods, and can encourage food reformulation and encourage those involved in the procurement process to consider health alongside economic, social and environmental aspects (41).

Improve the nutritional quality of foods and beverages available in supply, and establish specific targets for the reduction of important nutrients of public concern. For instance, product reformulation includes the ban or virtual elimination of industrially-produced trans-fatty acids from the global food supply, sugars and salt reduction programmes (33,42,43). The food reformulation issue will be covered in more detail in section 2.3.2.

School food nutrition

Schools play an important role in promoting healthy diets and good nutrition and can create an enabling environment for children. However, the school food environment is often not conducive to a healthy diet (44). Key issues include the availability of HFSS foods in the vicinity of schools, foods sold in "tuck shops", where confectionery and/or savoury snack foods may be sold, in addition to vending machines where sugar drinks are available (33).

School food and nutrition policies are implemented within complex systems (including the food system) that are largely country-specific. These policies are affected by the country's political, legal, economic, cultural and ethical contexts. To address this challenge several policy options were identified: nutrition standards or rules, direct food provision, marketing restrictions, nudging interventions and pricing policies. Examples include nutrition standards in the US, Canada, Mexico, Europe, and New Zealand. Free or low-price provision of fruits and vegetables, farm-to-school programmes, and the EU school fruit, vegetables and milk scheme (35,45,46)

2.2.4. Policies to regulate or restrict actions to promote unhealthy choice options

Marketing to children

The review undertaken in 2009 on behalf of the World Health Organization reveal that food marketing has an impact on nutrition knowledge, food preferences and consumption patterns, and food products promoted represent a "very undesirable dietary profile with a heavy emphasis on energy-dense, high fat, high salt and high sugar foods"(47).

In 2016, the WHO Commission on Ending Childhood Obesity (ECHO) concluded that the evidence was 'unequivocal' that the marketing of unhealthy food and sugar-sweetened beverages was related to childhood obesity (48).

Children are particularly susceptible to persuasive messages used in marketing communications as their cognitive development (cognition to recognise the selling and persuasive intent of marketing communications) is relatively limited. For example, children under 5 years cannot distinguish television advertising from regular programming, and children under 8 years believe what they see - they are unable to understand its persuasive intention (32,49).

The techniques used to market unhealthy foods to children are extensive, sophisticated and persuasive and target different vehicles of promotion (e.g., television, websites, games) via varying marketing techniques (e.g., product placement) (32).

The WHO and Institute of Medicine (IOM) recommended standards for marketing, such as limiting advertising to children of foods and beverages that do not comply with basic nutrition (50–52).

Several countries currently implement different forms of marketing restrictions from legally binding obligations to industry self-regulation and stakeholder cooperation platforms (35).

Across Europe, most of these actions are self-regulatory and relate to advertising restrictions of HFSS foods to children or adolescents in broadcast (television and radio), or to other media, such as digital social media platforms, apps or 'advergames' (an online game which in some way contains an advertisement), as well as restriction of food advertising in schools (33). Some countries expand mandatory restrictions to advertising across any kind of media and marketing techniques such as product placement, sponsorship and the use of licensed characters (53). This issue will be covered in more detail in section 2.3.3..

2.3. NP models to support health-promoting food policies

There is global consensus that well-designed food policies have substantial potential to significantly and sustainably improve diets at local, national and international levels, including among disadvantaged groups, and therefore have a key role to play in tackling the obesity pandemic (54).

It is not a simple task to draw between foods that contribute to a healthy diet and those that do not. Common sense suggests avoiding foods that are low in nutrients but high in some combinations of calories, fat, added sugars, and salt. In practice, distinguishing between healthy and unhealthy foods is not clear enough to drive the necessary changes to food environments to support healthy diets (1).

In reality, there is no way to change diets without changing the intake of specific foods. Food-based dietary guidelines (FBDG) are important tools for nutrition policies and public health (55). FBDG provide guidelines on healthy food consumption and is based on scientific evidence. In general, dietary recommendations are based on Dietary Reference Values (DRV) (also called Recommended Nutrient Intakes, RNI; or Recommended Dietary Allowances, RDAs), which relate to specific nutrients and their recommended intake for each specific group of the population to prevent nutritional deficiencies that may compromise health (56).

FBDG are primarily intended for consumer information, and as such, they should be appropriate for the region or country, culturally acceptable and practical to implement. In this context, the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) have promoted the development of food-based dietary recommendations in line with Sustainable Healthy Diets that consider the economic, cultural, social and environmental conditions of each country (23). FBDG are currently available for 90 countries globally: 7 in Africa, 17 in Asia and the Pacific, 33 in Europe, 27 in Latin America and the Caribbean, 4 in the Near East, and 2 in North America (57).

Related to the implementation of these guidelines in daily eating practices, consumers need to be able to discriminate between specific products and policymakers need to distinguish specific foods when introducing measures such as labelling controls, taxation, marketing restrictions or specifying collective catering standards. Hence, practical tools are needed to be able to define the nutritional quality of a specific product (1).

Nutrient profiling is a science of classifying foods or food products according to their nutritional composition to help implement interventions to improve nutrition and provide healthy diets (58). Nutrient profiling is currently being used as part of a range of nutritional policy applications worldwide, and the number of different NP models has expanded rapidly, in recent years (1). Nutrient profiling is operationalised by NP models, algorithms that take into consideration the amounts or the presence of nutrients and other related food components (e.g., whole grain), in a food product to characterize its degree of“healthfulness” through numerical scores or qualitative classifications. (59). NP models assess the nutritional quality of foods, not diets, and can be applied to improve the nutritional quality of diets (58). Maintaining various country-level food policies, with a well-designed NP model can support good regulatory practice and a consistent regulatory approach by providing a transparent basis on which to distinguish healthier and less healthy foods for policy application (60).

Whereas NP models should not be used to decide on the healthiness of diets, they represent a way to improve food choices, and hence overall dietary patterns, through a variety of public health applications (2). NP model can be used in a variety of situations both regulatory and non-regulatory. A systematic review indicated that the most common regulatory applications for NP models were for which foods should be made available in a school (school food guidelines/standards) (n=27,35%), front-of-package labelling schemes (n=12, 15%), the regulation of food marketing to children (n=10, 13%), regulation of health and nutrition claims on foodstuff (n=7, 9%), and food standards /requirements in health facilities (n=5, 6%) (2). More recently, NP model has been used to define thresholds for food taxation (61,62) and to guide food and beverage reformulation (63–65).

Various NP models have been developed by governments institutions (for example, the Swedish National Food Administration's ‘Keyhole’ scheme, the voluntary *Nutri-Score* FOP labelling scheme) (66,67), non-governmental organisations (for example, the WHO Nutrient Profile for Europe (WHO-EURO), the Choices International Foundation) (58,68) food and beverages companies (for example, the EU Pledge Nutrition Criteria White Paper) (69) and other organizations. Figure 6 shows the potential role of nutrient profiling applications to improve nutrition-related policies.

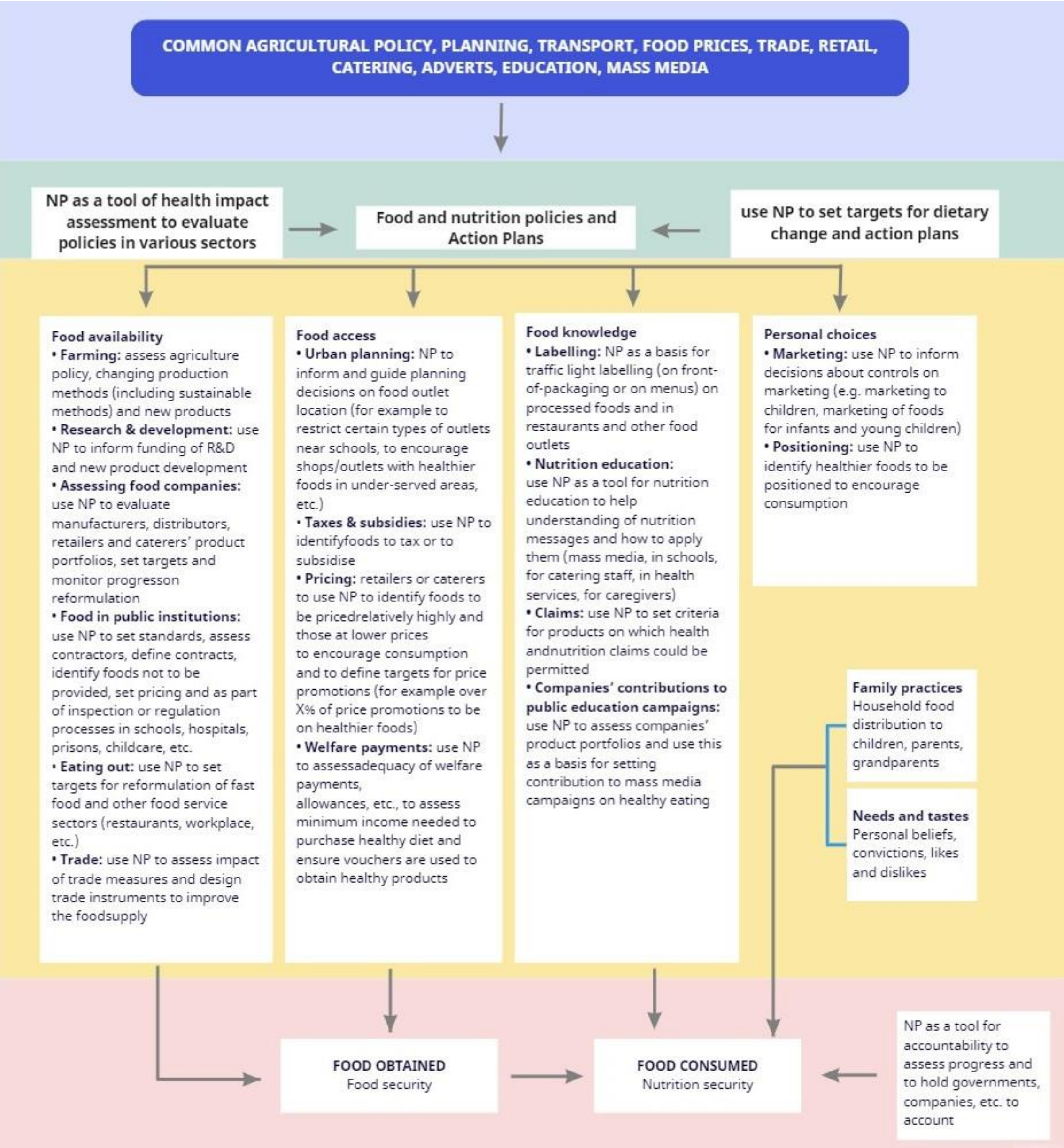


Figure 6. Potential role of nutrient profiling applications to improve nutrition-related policies.

Adapted from McColl, K., Lobstein, T., & Brinsden H, 2017 (1).

The next sections consider three potential applications of nutrient profiling: front-of-pack nutrition labelling (section 2.3.1), food composition/reformulation section (section 2.3.2) and regulating food marketing to children (section 2.3.3) Both of these applications have been widely cited as promising interventions for improving public health nutrition (2).

2.3.1. NP models in the domain of food labelling

Description of FOPL schemes

In 2014 at the Second International Conference on Nutrition (ICN2), governments affirmed that "empowerment of consumers is necessary through improved and evidence-based health and nutrition information and education to make informed choices regarding consumption of food products for healthy dietary practices" (70).

Nutritional profiling is the categorisation of foods according to their nutritional composition, using pre-defined criteria (58).

A common use of nutrient profiling is in FOPL schemes. Most FOPL schemes are based on nutrient profiling criteria which can be simple nutrient thresholds, for example, to define when a scheme will assign a green, amber or red colour, or more complex algorithms resulting in a summary score. Nutrient profiling criteria may apply to all food groups across the board or be specific to different product groups. As such, nutrient profiling criteria do not appear on labels. By definition, all evaluative FOPL schemes, whether nutrient-specific or summary indicators, are based on NP models (71).

According to the internationally accepted definition, a food label is any label, mark, brand, pictorial or other descriptive material, written, printed, stamped, marked, embossed or impressed on, or attached to, a container of food or food product. This information, which includes items such as ingredients, quality and nutritional value, may accompany the food or be displayed near the food to promote its sale (72).

Nutrition labels can either be on the back-of-pack (BOP) or front-of-pack (FOP). The first, and traditional type, is the 'nutrition facts table', a boxed table that lists energy (in kJ or kcal) and the amounts of fat, saturated fat, carbohydrates, sugars, protein and salt (in g). BOP was the most prevalent and mandatory label format worldwide in 2014. The second, and much more recent type, is the graphical nutrition label, which displays nutritional information in a more graphical, interpretative way (71).

One of the main drivers for nutrition labelling is the increased prevalence of diet-related non-communicable diseases. The WHO recommends Member States implement front-of-package labelling (FOPL) to guide consumers toward healthier food choices, as part of comprehensive strategies to tackle nutrition-related NCDs (39).

EU Regulation 1169/2011 has defined as mandatory the use of the nutrition declaration on the back of the packaging of marketed foods, i.e. the indication of absolute amounts of nutrients (e.g. saturated fat, sugar, salt and trans fat) per 100g or 100 ml (73). The use of front-of-pack interpretative nutrition labels was allowed, but only as an additional voluntary (for industry) way of expressing information in an easy-to-use way for consumers.

Several studies showed that food labelling reduces consumer dietary intake of selected nutrients and influences industry practices to reduce product contents of sodium and artificial trans fat (37).

FOPL systems aim to provide standard, clear information on the nutritional content of packaged food items so can help consumers in their ability to make healthy choices and, also can encourage food product reformulation to create healthier options (74). FOPL has been recognised as a cost-effective policy to address the rise in the prevalence of obesity as well as other NCDs (75). According to the OECD Report – 'The Heavy Burden of Obesity - The Economics of Prevention', population-wide interventions including food labelling have the largest gains globally (76). However, food labels are a challenge for most consumers, and the development of easily understandable labelling is essential when it comes to empowering consumers in making healthier food choices (77).

FOPL systems have now been implemented in more than 40 countries (where governments have led and supported their development), and systems are under consideration or development in many other countries. Most nutrition labelling systems introduced to date have been voluntary, although more mandatory systems have been introduced in recent years (71,78).

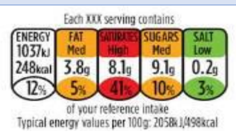
The WHO European Food and Nutrition Action Plan 2015-2020 and the EU Action Plan on Childhood Obesity 2014-2020 recommend the creation of positive nutritional environments and recommend the implementation of clear and user-friendly FOPL (7,79). However, to date, there is still no harmonized FOP system for all countries and there is variability in labelling schemes adopted between and within countries. In 2018, 15 countries in Europe, of which 11 were in the EU, were identified as having a government-endorsed policy on interpretive FOP labelling, with 13 of these adopting endorsement logos (39).

The various formats of FOPL currently in use can be organized, depending on the level of interpretation of nutritional composition provide to the consumers, into informative schemes if they only reproduce part of the information available on the BOP, nutrient-specific schemes (interpretative schemes), providing more or less detailed nutritional information on specific nutrients, and summary indicator schemes (summary labels) that rather provide a synthetic appreciation of the product's overall nutritional quality/healthfulness (71,80).

The nutrient specific-schemes focus on the content of energy and several nutrients, most commonly saturated fat, sugar, sodium (salt) and total fat. The amounts are stated per serving. The summary indicator schemes use an *algorithm* to translate the components of the food into a single value that indicates how healthy or unhealthy it is (81).

For the nutrient-specific schemes, the information can be sub-divided into 'numerical' and ‘colour-coded’ sub-categories. The 'summary indicator' schemes can be sub-divided into 'positive' indicators (endorsement logos) that can be applied only to foods complying with certain nutritional criteria, and 'graded' indicators that are providing global and graded information on the nutritional quality of foods and can be applied on all food products (80). Table 1 summarises some of the key characteristics that differentiate several FOPL schemes.

Table 1. Key characteristics of different types of FOPL schemes

Type	Characteristics	Classification (Category/subcategory)	Examples
Informative schemes	Provide factual information with no guidance to interpret how healthy/unhealthy a product is (Reductive (non-interpretative)	**Nutrient-specific Label/ Numerical**	 EU food industry Reference Intakes  NutrInform (“battery”) system (Italy)
	Provide a mix of factual information and interpretive elements (Evaluative (interpretative)	**Nutrient-specific Label/ Colour-coded**	 Traffic lights (UK) labels combine informative reference intakes and interpretive colour coding  Traffic lights

Interpretative schemes	**Summary indicator schemes** combine several nutritional criteria to show an overall indicator of the healthiness of the product.	**Graded indicators** (appear on all products and provide graded information on the nutritional quality of the product)	*Nutri-Score* (France, Belgium Germany, Spain, Netherlands, Luxembourg) Health Star Rating System (Australia/New Zealand)
		Endorsement logos (applied only to products with higher nutritional quality)	Finnish Heart Symbol (Finland) Healthy Choice (Czech Republic, Poland, Netherlands) Keyhole (Sweden, Denmark, Norway, Iceland, Lithuania)
	Nutrient-specific schemes provide information on a set of nutrients	**Colour-coded**	Traffic lights
		Warning Labels (Affixed on foods depending on their levels of certain nutrients)	Warning labels (Israel)

Based on the available research, it seems that interpretative schemes, such as colour-coded global FOPL that show judgements or recommendations appear to be most useful to consumers. These FOPL are easy-to-understand and quickly interpretably by all consumers at all levels of literacy, allow quick guidance of health-promoting purchasing decisions at the point of sale and simplify the nutritional information available at the back of the pack (39,80,82,83).

In Portugal, a Government-endorsed interpretative nutrition labelling policy has not yet been implemented. However, several national economic operators from the food sector are already using different FOPL schemes. For example, the adoption of the FOP-NL traffic light system by a Portuguese distribution operator on its own-brand products; or the adoption of other different schemes, such as a modified traffic light system (i.e. Nutri Pass) or the monochromatic schemes based on daily indicative quantities; or at 2019, the introduction of the Nutri-Score scheme by a Portuguese distribution operator on its own-brand products (84).

The existence of multiple nutrition labelling schemes on food products in Portugal in an unregulated way may not be conducive to consumer understanding and, the FOPL schemes used by different food industry operators may not be the most adapted to Portuguese consumers (84). The Integrated Strategy for the Promotion of Healthy Eating (EIPAS), in conjunction with the National Programme for the Promotion of Healthy Eating (PNPAS), has proposed a set of policy proposals in this area, including encouraging the use of FOPL schemes to facilitate food choices at the point of purchase, as well as some guidelines for food industry operators (10,85).

Recently, an Health Impact Assessment on nutrition labelling conducted in Portugal, appraised the impact of the adoption of a single FOPL, and which FOPL would be the most appropriate to promote healthy food choices and mitigate inequalities. The results of this study showed that although traffic light nutrition labelling appears to be the model that best enables Portuguese consumers to make healthy food choices, the results obtained for the other FOPL models (e.g. Nutri-Score, Guideline daily amounts, Health StarRating) suggest that all of them have the potential to contribute to healthier food choices (84,86).

The European Commission in its new ''Farm to Fork' strategy", launched in May 2020, includes a proposal to make FOPL harmonised and mandatory to enable consumers to make health-conscious food choices, by the end of 2022 (87).

In the period since 2017, the *Nutri-Score* has gained considerable traction across Europe, although concerns have emerged that the algorithm needs to be adapted and aligned with the FBDG. For example, in the Netherlands, one study concluded that for certain product groups *Nutri-Score* is not aligned with Dutch dietary guidelines (88). However, various studies have shown that the *algorithm* underlying *Nutri-Score* can discriminate the nutritional quality of foods, obtaining a score mostly in line with nutritional recommendations (89,90). Furthermore, *Nutri-Score*, when compared to other nutrition labelling models, was found to be the most effective in terms of encouraging consumers to make healthier food choices and simultaneously helping to assess the nutritional quality of products (91,92).

Nutri-Score is a scheme developed under the aegis of the French Ministry of Health and implemented in France in 2017 (67). It is an *algorithm* based on nutritional criteria, validated scientifically, which categorizes food products into 5 categories (expressed by a colour and a letter). Each colour is associated with a letter from A (dark green) to E (dark orange) to make the labelling more accessible and understandable to consumers (67,93). It is based on a modified version of the British Food Standards Agency's Nutrient Profiling System (FSAm-NPS), which was originally developed for the UK media regulator to regulate television advertising aimed at children (94). It has been promoted as a candidate to enable uniform food labelling systems across the European Union. Six EU countries have already endorsed the *Nutri-score* labelling: Belgium, France, Germany, Luxembourg, The Netherlands and Spain. Recognising the public health benefits of *Nutri-score*, the World Health Organization is also calling for an EU-wide adoption of this label (95).

The application of the nutrient profiling approach for FOPL should take into account dietary recommendations, the context in which they are going to be implemented, variability in dietary habits and traditions, public health outcomes and should also encourage food reformulation (74).

The design and development of FOPL is context-specific and shaped by many different factors and involve multiple stakeholders, including public health experts, technical experts, members of civil society organisations, academics and food industry representatives. To increase the effectiveness of the FOPL, it is important to protect the development of the FOPL from conflicts of interest to ensure that the final design is as robust as possible and can meet policy objectives (96).

Effects of FOPL on diet and health

Given the difficulty of establishing studies that directly measure whether FOP schemes improve consumers' diet and health in real life, there is a lack of empirical evidence to conclude the impact of FOP label use on the healthfulness of diets and on health itself (97,98). Alternatively, researchers use modelling approaches to extrapolate effects on purchasing behaviour to overall diet and diet-related health outcomes (78).

Some studies that have investigated associations between the quality of diets and nutrition-related diseases indicate that diet quality, evaluated by the dietary index underlying the *Nutri-Score* scheme, is associated with a lower risk of cancer (99), cardiovascular disease (100) and overweight (101).

Egnell et al, investigated the impact of various FOPL on portion size selection, specifically for less healthy products and concluded that the *Nutri-Score* scheme followed by Multiple Traffic Lights appears to be an effective tool to encourage consumers to decrease their portion sizes for less healthy products (102).

Another study, with five different FOP labels, concludes that FOPL schemes have the potential to help decrease mortality from diet-related non-communicable diseases, with effects depending on the type of label tested and whether *Nutri-Score* appears the most effective (103).

Finally considering the effects of FOPL on food purchasing behaviours, the systematic review conducted by Croker et al, provides evidence from both experimental and 'real-life' studies that FOPL schemes encourage healthier food purchasing behaviours. Labels including an interpretative message appear to have greater potential for impacting behaviour (104). Another study, which involved comparing food choices, objective understanding and perceptions of Belgian consumers in response to five different FOPLs, currently implemented in different countries internationally, concludes there were no significant differences in food choices among the different FOPL schemes, but *Nutri-Score* performed best for ranking food products according to nutritional quality. Perceptions of consumers were favourable for all FOPLs with no significant differences between the different FOPL schemes (105).

2.3.2. NP models in the domain of food composition/reformulation

NCDs and obesity continue to put an increasing strain on society, and governments around the world have committed to addressing this challenge. Reducing NCDs risk factors by creating healthier food environments, is a key objective that requires a complex set of policy considerations and engagements from multiple sectors (17).

Different public health and food policies are being developed to achieve healthy food environments to reverse this unfavourable status, including promoting breastfeeding, restricting the marketing of unhealthy foods and drinks to children in all media; supporting point-of-sale information through nutrition labelling with the addition of front-of-pack labelling to facilitate consumer understanding; reformulation, where practicable, of processed foods (106).

Encouraging reformulation (i.e. changing the composition) of foods to reduce the content of, free/added sugars, saturated fats, trans fats and salt/sodium is identified by the WHO as one of the key actions for implementation (107). Given that daily energy intakes from processed foods range from 32.6% in Portugal to 60.9 % in the United Kingdom, improving the nutrient composition of processed foods has health benefits for everyone and the evidence indicates that progressive, incremental changes to food composition are the best approach, to allow for consumer taste preferences to adapt (108).

Reformulation, in the context of the prevention of NCDs, becomes crucial to reduce the consumption of critical nutrients salt/sodium, and sugar, or to increase the content of health-promoting ingredients such as dietary fibre, whole grains, fruit, vegetables and unsaturated fats and NP models can provide the scientific basis to drive innovation and product reformulation by the food industry, to improve the overall nutritional quality of diets (64,109,110).

In recent studies, Vieux et al., Leroy et al. and Greenberg et al. develop NP models to assess the overall nutritional quality of packaged foods and to guide product innovation and reformulation and conclude the models can provide objective and realistic nutritional targets for reformulation and can be a powerful tool to guide industry in the improvement of food products to better meet the population dietary goals, with a focus on positive nutrition (111–113).

In the national context, several initiatives are promoting and monitoring the reformulation of food products, although none specifically target the reformulation of child-oriented food products. For example, a strategy (EIPAS) that included fiscal measures, co-regulatory agreements with the food industry, enhanced cooperation with municipalities, and measures to change food environments in public places, among many other initiatives (12). In December 2016, the Portuguese Parliament approved a tax on sugary drinks which has been associated with product reformulation. In 2019, the Portuguese Ministry of Health and food industry representatives signed a broad "Food Industry Co-regulation Agreement” for reformulation, of the main food products high in salt, sugar and trans fatty acids, as well as the main dietary sources of these nutrients for the Portuguese population although none specifically targeting the reformulation of child-oriented food products (114).

Children's diets are characterised by low fruit and vegetable consumption and an excess of products high in sugar, saturated fat and sodium (115). In particular, sugar consumption among children has raised concern worldwide, as it exceeds the recommended. The World Health Organization recommends reducing the intake of free sugars to less than 10 % of total energy intake as a 'strong recommendation', along with a 'conditional recommendation' to further reduce free sugars to below 5 % (116).

Published data shows that this recommendation is not met in most countries, for example in several European countries, total sugars ranged between 15 and 21% of energy intake in adults and between 16 and 26% in children. Added sugars contributed 7 to 11% of total energy intake in adults and represented a higher proportion of children's energy intake (11 to 17%) (117). In Portugal, the National Food, Nutrition and Physical Activity Survey reported that IYC (<5 years) had the highest energy contribution from total sugars (28 E%). School-aged children, including children aged 5–9 years and adolescents aged 10–17 years, showed the highest percentage of total energy intake from added sugars (9.6 and 9.5 E%, respectively) and free sugars (10.6 and 10.5 E%, respectively) (118).

The main food sources contributing to added and free sugars intake were for IYC (<5 years) milk, fruit, infant formula and yoghurts and in children from 5 years mostly processed foods, such as sweets, yoghurts, breakfast cereals, cakes and soft drinks (118). Considering these results, several responses have been undertaken to counteract this problem mainly through reformulating the sugar content in food and reducing the consumption of energy-dense foods/drinks, such as soft drinks, but also yoghurts and breakfast cereals, particularly among children and adolescents (119).

In this field, it is also important to consider the complementary feeding period and the complementary foods that are necessary for both nutritional and developmental reasons, and are an important stage in the transition from milk feeding to family foods (120). According to the recommendations of the global strategy for IYC feeding, infants should receive safe and nutritionally adequate complementary foods, solid, semi-solid and soft, while breastfeeding continues until 2 years of age or older (121). However, the role of these products in appropriate complementary feeding has been widely debated, driven by concerns regarding their nutritional content and potentially problematic marketing strategies used to promote these products (122,123).

The WHO Regional Office for Europe published a discussion paper in 2019 outlining the first steps in developing a NP model to drive changes in product composition and labelling in CACFs for IYC. This included recommendations for compositional, additional product labelling requirements and promotion restrictions (124).

An additional concern, in the area of food composition/reformulation, is the increasing proportion of ultra-processed foods in children's diets, as several researchers have found in recent studies. About 30% of daily energy intake is contributed by UP foods in the Belgian population, and young children consume the largest proportion of their daily energy intake from UP foods (125). Other studies, such as from the US, and Canada also found that UP foods represent more than 50% of the daily energy intake (126,127). UP foods are usually high in added sugar, trans-fat, sodium, and refined starch and low in fibre, protein, vitamins, and minerals (127). The consumption of ultra-processed foods during childhood has also been linked to obesity and cardiometabolic risk factors in children and adults (128,129).

Monteiro et al. developed the NOVA classification system that classifies foods and food products into four categories according to the degree of processing, including unprocessed and minimally processed foods (e.g. fresh fruit and vegetables), processed culinary ingredients (e.g. sugar and honey), processed foods (e.g. fruits in sirup and vegetables in brine) and ultra-processed foods (e.g. pizza and instant noodles) (130).

Several studies have evaluated the consumption of UP foods in paediatric populations (131,132) however, there is limited research on the evaluation of CACFs marketed for IYC up to 36 months of age, for the NOVA classification system (133–135).

The collection of data on CACFs will be useful to monitor their nutritional composition, assess the possible need for product reformulation or implement other measures, such as consumer-friendly labelling on the front-of-package or the application of rigorous nutrient profile criteria, allowing in the future to assess the impact of strategies on improving the characteristics of CACFs (136).

2.3.3. NP models in the domain of restricting the marketing of unhealthy food to children

Overweight and obesity among children and adolescents is a matter of concern in many countries and represents a serious health and social challenge with immediate negative consequences for the children concerned. Environmental factors, lifestyle preferences, genetic makeup and culture can all cause children to be overweight (137).

Children and adolescents who are overweight or obese are at a greater risk of poor health, and this effect persists into adulthood. Moreover, obesity among children and adolescents is often related to psychosocial problems such as poor self-esteem, bullying and underachievement at school, which can further worsen health and economic outcomes in adulthood (76).

Childhood obesity is particularly concerning as it is a strong predictor of obesity in adulthood, which is linked to diabetes, heart diseases and certain types of cancer (76,138).

In 2018, almost one in five (19%) 15-year-olds were either overweight or obese on average in EU countries, up from one in six (16%) in 2010. There is a three-fold variation in overweight and obesity rates among adolescents in EU countries, ranging from 12% in the Netherlands to 36% in Malta (137).

In all EU countries except Portugal, overweight and obesity are more prevalent in boys than in girls. On average across EU countries, the prevalence in 2018 was 23% in 15-year-old boys compared to 15% in girls. This gender difference is driven by a combination of biological, social and environmental factors. In Poland, Italy and Greece, overweight and obesity among boys are more than twice as prevalent as among girls (137).

According to the 2021 edition of the Joint Child Malnutrition estimates by UNICEF, WHO and the World Bank, in 2020 38.9 million children under the age of 5 years of age were overweight or obese. Once considered a high-income country problem, overweight and obesity are now on the rise in low- and middle-income countries (139).

Every child has the right to enjoy the highest attainable standard of health. As a result, governments have a legal obligation to address the underlying determinants of health and take all measures that are necessary to prevent child obesity and other diet-related NCDs (140).

There is strong and increasing evidence that the marketing of unhealthy foods influences children's preferences, purchase requests and consumption choices and, as such, contributes to childhood obesity, independent of other factors, i.e. even though screen time may also increase snacking and physical inactivity (32).

The marketing of HFSS products is a public health issue and establishing regulatory mechanisms to restrict marketing is a challenge for policymakers as marketing is a very broad concept. It includes, but is not limited to, broadcast and non-broadcast advertising, advertising in schools, retail shops, billboards, sports centres, sponsorship at sports and children's events, use of celebrities to attract the public, and food label claims and promotions (50,141). In addition, the digital environment is a rapidly evolving and changing area, providing new opportunities for advertisers to reach key audiences, including children and their carers, as well as new challenges for policymakers (142).

Children are particularly vulnerable to marketing and promotion techniques designed to influence their preference for HFSS products, particularly children under eight, as they are unable to distinguish between the programme content and the persuasive intent of the advertisement (143).

Cognitive defences continue to develop throughout adolescence, so adolescents also need protection from broadcast and non-broadcast media (e.g. internet games and advertising, text advertising, social media and sports sponsorship), as evidence shows that children over the age of 12 continue to be negatively influenced by HFSS marketing (142,144).

An increase in exposure to marketing in the often unregulated digital sphere has become an area of concern as the digital environment has changed significantly. Children's screen time has shifted from primarily broadcast media to phones, computers and tablets, where major media platforms are over-flooding cyberspace with advertising (142). In addition, the explicit marketing intent may be less clear in the digital media, and exposure may be prolonged; for example, games sponsored by HFSS food or beverage companies may attract children to websites for prolonged periods (142,144).

In this area, also concern has been growing that the inappropriate promotion of commercially produced baby and toddler foods may be undermining breastfeeding and/or parents' and carers' confidence in home-produced foods and that high levels of salt, saturated or trans fat and sugars in some baby or toddler foods may promote dietary habits that can encourage later obesity or NCDs (124).

Several studies that have investigated the nutritional aspects and packaging characteristics of CACFs have found the majority of such foods meet the current recommendations and regulations for salt and sodium but were largely sweet due to free sugars and relatively sweet ingredients (135,145–147). A large proportion of products marketed to children through product packaging are less healthy, and claims used on product packaging are confusing. Uniform guidance would avoid confusion on the nutritional quality of many popular foods (133,148). Hutchinson et al in a recent study found that the sugar content of baby foods across Europe was high and updated regulations and reformulation are needed (149).

The complementary feeding period from 6 to 24 months is a crucial part of the first 1000 days of development. It marks the transition from an exclusively milk-based liquid diet to the family diet and self-feeding. During this period, healthy food preferences and feeding practices are formed (150). Considering the extent to which CACFs are used for young child feeding and the influence of these shifting diet patterns on young child nutrition is an emerging topic for exploration.

Regulating children's exposure to unhealthy food marketing has been identified as a key challenge to which States must rise (151). Since 2003, the WHO and various nongovernmental organisations have published increasingly strong statements about the need to control marketing to children, as part of guiding and developing policy action at a national and global level (152).

Globally, various types of measures have been implemented at the national level to protect children from the marketing of HFSS food and drink. Most of these have adopted either a government-approved voluntary approach or mandatory approach (UK, Chile) or a mixture of both approaches for different marketing techniques (Ireland) (152).

Several industry players have additionally adopted a self-regulatory approach independent of government (e.g. the Children's Food and Drink Advertising Initiative in the US or the EU Commitment in Europe) (153).

Measures adopted also differ in the foods they include, which children are protected, and which communication channels and marketing techniques are covered in the range of media and types of marketing covered. Most of these protect children aged 12 to15 years or younger. Restrictions on TV advertising are most common, with most restrictions in effect during children's programs only. Schools are also a common setting (154).

Restrictions on media such as cinema, mobile, print, packaging, and the internet are uncommon. Most measures focus on limiting child-directed marketing strategies such as licensed characters, with little attention paid to other marketing strategies like health and nutrition claims (154).

In 2010, some national companies that produce and market food and beverages in Portugal have adopted a self-regulatory approach independent of the government – the Portuguese Pledge based on the EU Pledge. It is a voluntary initiative by leading food and beverage companies to change the way they advertise to children (155).

The EU Pledge consists of two central commitments: No advertising of products to children under 12 years, except for products which fulfil common nutritional criteria; No communication related to products in primary schools, except where specifically requested by, or agreed with, the school administration for educational purposes (156).

In April 2019, Portugal implemented mandatory regulations to restrictions on food advertising directed at those under 16 years of age (Law No. 30/ 2019 of 23 April). This law provides for a ban on the advertising of foods with high energy value and high sugar, saturated fatty acids, trans fatty acids and salt content (157).

With the approval of this law, the Directorate-General of Health (DGS) needed to define the NP model to restrict food advertising to children. The NP model was developed by PNPAS and published in August 2019 through Order No. 7450-A/2019 (158). This model was based on the NP model of the WHO Regional Office for Europe, in which modifications were introduced, to align the limits of some nutrients of certain food categories, with the values defined by the European Union legislation. The previously mentioned modifications refer to the impossibility of considering some food categories in which advertising of foods to children is not permitted in their entirety, and the inability to consider total fat content and added sweeteners as items to be taken into account for the NP model (159). Other amendments reflect the objectives of the agreements made by Portugal in the context of food reformulation, as well as an analysis of the nutritional composition of foods available on the Portuguese market and the limits imposed by Law No. 30/2019 of 23 April (157).

In response to the concerns related to the inappropriate promotion of commercially produced baby and toddler foods, the World Health Assembly in 2010 called on the Member States to end the inappropriate promotion of foods for IYC (160), and new global guidance was agreed in 2016 – The Guidance on Ending Inappropriate Promotion of Foods for IYC - to help countries take action on this issue (161). Operationalization of some aspects of the guidance is complex, and implementation needs to reflect national contexts and are in line with national dietary guidelines. Foods for IYC need to comply with various established nutrition and compositional criteria and meet all the relevant national, regional and global standards for composition, safety, quality and nutrient levels (161).

To address some of these problems, WHO conducted a study to develop a NP model for IYC aged 6–36 months to guide decisions about which CACFs are inappropriate for promotion. It has been validated against label information from packets, websites or online repositories against label information from 1328 products on the market in Denmark, Spain and the United Kingdom in 2016/2017 and pilot-tested in seven additional countries (Estonia, Hungary, Italy, Malta, Norway, Portugal and Slovenia) in 2018 with a further 1314 products (124,149). The NP model was developed with requirements for sugars, sodium, fats, protein and energy density. Labelling and marketing requirements were developed, including the age of introduction of product, product name and claims (124).

The proposed NP model could be a solution for governments to adapt and use to restrict the inappropriate promotion of CACFs for IYC in their own countries (162).

Complementary feeding is an important determinant of infant growth and development and is more than ensuring an adequate intake of nutrients; it also is about avoiding excess intakes of calories, salt, sugars, and unhealthy fats (120). In the national context, this topic is under consideration and further discussion and studies are needed, to improve understanding of the commercial baby foods currently on the market and to adapt and use the NP model proposed by the WHO Regional Office for Europe (124).

The Sustainable Development Goals (SDGs) are another important tool to drive government action. The goals include targets on ending malnutrition in all its forms (which includes obesity as well as undernutrition) in SDG 2.2 and reducing premature death from diet-related NCDs in SDG 3.4. (163). An important policy option to meet the SDGs is based on developing national responses to the global implementation of the SDGs and restricting the marketing of unhealthy foods (163).

3. Research Objectives and Methods

This chapter presents the research objectives and an overview of the methods applied in each of the four studies making up the thesis. The discussion of methods in this chapter is presented in summarised form, with more detail provided in the Methods section of each of the manuscripts presented in the following chapters.

3.1. Research objectives

This thesis addresses the application of NP models in the national context, as a tool to promote the reformulation of foods intended for children, in front-of-pack nutrition labelling and to regulate the marketing/promotion of foods for children including the commercial foods for infants and young children up to 36 months of age. More specifically, the objectives of this research were to:

OR 1. Address a comprehensive review to clarify the importance of NP models as a tool to establish public health interventions concerning consumers' food choices.

OR 2. Characterize the application of NP models in the reformulation of food products targeted to children as a means for improving the nutritional quality of Portuguese children's diets.

OR 3. Characterized the application of NP models in the domain of food labelling, to assess the nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score* and to investigate the consistency with the food-based dietary guidelines.

OR 4. Assess the application of the NP model proposed by the WHO Regional Office for Europe to identify which commercially available foods (CACFs) are appropriate/inappropriate for promotion to IYC up to 36 months of age and what is the degree of processing, as defined by the NOVA classification system.

3.2. Methods

A combination of different research methods was used, with each method selected based on its suitability to address the principal research objective in a practical, reliable and rigorous manner. The different methods used in addressing each of the research objectives are summarised in Table 2.

Table 2. Research objectives and the corresponding research methods used

Research objective	Manuscript	Research method
OR 1. Address a comprehensive review to clarify the importance of NP models as a tool to establish public health interventions concerning consumers' food choices.	1	**Research design**: A literature review. **Eligibility criteria:** Inclusion and exclusion criteria were used to assess the eligibility of the documents identified from the search. The inclusion criteria were: 1) focused approach on the various NP models; 2) detailed information on the principles used in the building process of a NP model; 3) systematized validation process of a developed NP model; 4) description and further evaluation of the different purposes and/or applications of NP model. The exclusion criteria included: documents where the term "nutrient profile/profiling" was related to 1) specific diets of individuals and specific populations; 2) nutritional or health conditions of the population 3) nutritional content of specific food or product label. **Information sources:** Data collection was performed by a literature search of articles available on Pubmed/Medline, Scielo and Scopus databases as well as on websites of national and international governmental agencies. **Search:** The terms included in the search were: for PUBMED the MeSH term (Medical Subject Headings) “Food labelling” and for the other databases the free terms: “Nutrient Profiling”, “food scoring system”, “nutrient scoring system”, “marketing and children”.

		Data extraction/collection: The outputs of the searching process were exported to the Mendeley Desktop software. A standardized spreadsheet, with the NP models information included in this review, was created using Microsoft Excel 2016 (Microsoft, Washington, WA, USA) (164).
OR 2. Characterize the application of NP models in the reformulation of RTECs, as a means for improving the nutritional quality of Portuguese children's diets.	2	**Research design**: An observational descriptive study of cross-sectional design, with a convenience sample. **Setting:** RTECs were chosen according to the Portuguese National Survey on Food, Nutrition and Physical Activity (IAN-AF) data reported as consumed by Portuguese children between 3 and 10 years old. **Data collection:** RTECs were collected in the supermarkets from the Lisbon region. From each product, different information was collected, namely brand name, commercial product name, descriptive name, serving size, ingredient list, package marketing, and nutrition labelling information. Nutrition claims (presence or absence of gluten) and organic certification information were also registered. When needed, the data collection was also complemented through the extraction of information from corporate brand websites and online supermarkets. Data per portion size were obtained from packaging information or calculated based on the recommended serving size. All data collected (packaging information and their classification) were recorded on standardized spreadsheets using Microsoft Excel 2016 (Microsoft, Washington, WA, USA) (164).

		Data Analysis: Data were analyzed by using the Statistical Package for Social Sciences software (IBM SPSS Statistics, Version 26.0, IBM corp., Chicago, IL, USA) (165). The Kolmogorov–Smirnov test was used to test the normality of the distribution of the variables to decide between parametric or nonparametric analyses for comparisons. Variables were expressed as the median (interquartile range). The energy (kcal/100 g) and nutrient contents per 100 g of products were compared by the Mann–Whitney non-parametric test for two independent samples and using the Kruskal–Wallis non-parametric test with multiple pairwise comparisons (for differences among cereals categories). The Bonferroni correction was applied. The level of convergence between the models was evaluated using the Cohen co-efficient κ (166). A result was considered statistically significant if the p-value was less than 0.05 and highly statistically significant for an observed p-value of less than 0.01.

OR 3. Characterize the application of NP models in the domain of food labelling, to assess the nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score* and to investigate the consistency with the food-based dietary guidelines.	3	**Research design** An observational descriptive study of cross-sectional design, with a convenience sample. **Setting:** Different groups and subgroups of food products were included in the PT-total dietary study (PT-TDS). The selection of foods was based on food consumption data from the Portuguese Population's Food Habits and Lifestyles study conducted in 2009 by the Portuguese Society of Food and Nutrition Sciences. The design of one 24-h recall was used and data were collected for 3529 individuals from all regions of the country, including the islands, both sexes and ages 18–93 years (167). A food list was established based on the foods as consumed, that contributed to at least 90% of the total consumption. **Data collection:** For each food product analysed the following data was computed in the database: total energy (kJ), total protein (g), total carbohydrates (g), total sugars (g), total fat (g), saturated fatty acids (g), total dietary fibre (g) and sodium (mg). For each food product, the *Nutri-Score* was applied, assigning points based on the nutritional composition per 100 g or 100 ml of the product (beverages). Positive points were attributed for the amounts in elements that should be limited, including energy (kJ), total sugars (g), SFA (g), and sodium (mg) (0 to 10 positive points for each). Negative points were attributed to the amount in elements that should be promoted, including protein (g) and dietary fibre (g), percentage of fruits, vegetables, legumes, nuts (FVLN %), walnut, rapeseed and olive oils) (0 to 5 negative points for each). The FVLN % was

		estimated for each product, according to the methodology described by Vergeer et al (Vergeer et al., 2020). The total score of the product was calculated by subtracting the "negative" (nutrients to limit) points from the "positive" (nutrients to encourage) points. Thus, the final FSAm-NPS score for each food/beverage was based on a scale that could range from - 15 (most healthy) level, to +40 (least healthy) (67). The consistency of food classification using *Nutri-Score* with the Portuguese food-based dietary guidelines was assessed by comparing the distribution of foods in the different *Nutri-Score* categories, with the recommended consumption frequency of the group (55). **Data Analysis** Data were analyzed by using the Statistical Package for Social Sciences software (IBM SPSS Statistics, Version 26.0, IBM corp., Chicago, IL, USA) (165).
OR 4. Assess the application of the NP model proposed by the WHO Regional Office for Europe to identify which CACFs are appropriate/inappropriate for promotion to IYC up to 36 months of age and what is the degree of processing, as defined by the NOVA classification system.	4	**Research design**: An observational descriptive study of cross-sectional design, with a convenience sample. **Setting:** Nutritional and packaging information on CACFs targeted to infants aged <3 years of age, collected from 8 supermarket chains in the Lisbon Metropolitan area, which holds almost 80% of the market share in Portugal. **Data collection:** CACFs target to infants aged <3 years of age were photographed and nutritional and packaging information was collected including information about the ingredient list from the products in-store or on the supermarkets' websites. A Microsoft Excel template was created for

		recording the different variables studied, including information on basic information (brand name, product name, product category), packaging information (recommend age, serving size, nutrition-related messages, composition claims and health claims), nutritional content (total energy (kJ/kcal), protein (g), carbohydrates (g), total sugars (g), fat (g), saturated fatty acids (g), and sodium (mg)) and visual information (e.g. cartoons, pictures of infants/young children). All the nutritional analysis was per 100g product. Foods were classified and evaluated according to the nutrient composition standards, labelling requirements and promotion restrictions to be met by the proposed NP model to identify products for IYC up to 36 months (124). All the CACFs were also classified according to their processing level, minimally processed (MP), processed or Ultra-processed (UP) based on the NOVA classification system (130). **Data Analysis** Data were analyzed by using the Statistical Package for Social Sciences software and included frequency distribution, descriptive statistics, and correlation (IBM SPSS Statistics, Version 26.0, IBM corp., Chicago, IL, USA) (165). Descriptive statistics were used to report the proportion of CACFs in each food category, food processing (NOVA classification), age and claims messages. Tests for normality on the nutritional values of foods were performed with the Kolmogorov-Smirnov test and confirmed that data were not normally distributed; therefore, non-parametric testing was undertaken.

		The categorical variables were presented as relative and absolute frequencies. Median, standard deviation (SD), P25, and P50 values for nutritional information were calculated from the labels. Pearson's chi-square test (χ2 test) was used to evaluate the associations between two variables (for example, between the food categories, nutrition/composition claims). Kruskal– Wallis non-parametric test with multiple pairwise comparisons was performed to test for differences in levels of nutrients between food categories and food processing (NOVA classification). The Bonferroni correction was applied. A result was considered statistically significant if the p-value was less than 0.05 and highly statistically significant for an observed p-value of less than 0.01.

4. Nutrient profile models a useful tool to facilitate healthier food choices: A comprehensive review

Chapter 4 is constituted by a manuscript that provides an overview of the guiding principles for implementing an NP model, allowing for a better understanding of the importance of the NP models as a tool to establish public health interventions regarding consumers' food choices. The topics covered in the state-of-the-art review are intended to support policymakers regarding the choice of an applicable model to be considered when setting nutrition-related policies.

Manuscript 1

Article published in the Journal *Trends in Food Science & Technology*.

Santos, M., Rito, A.I., Matias, F.N., Assunção, R., Castanheira, I., Loureiro, I., 2021. Nutrient profile models a useful tool to facilitate healthier food choices: A comprehensive review. Trends Food Sci. Technol. 110, 120–131. https://doi.org/10.1016/j.tifs.2021.01.082

Trends in Food Science & Technology 110 (2021) 120–131

Contents lists available at ScienceDirect

Trends in Food Science & Technology

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

Nutrient profile models a useful tool to facilitate healthier food choices: A comprehensive review

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ARTICLE INFO

Keywords:
Nutrient profile models
Nutrient profiling
Public health
Food choice
Healthy food

ABSTRACT

Background: The term "nutrient profile" (NP) has been associated with several concepts arising from the need to regulate the choice of food products, and to allow consumers to make informed and healthier food choices. The use of NP models as a policy tool to improve public health nutrition and reduce the prevalence of non-communicable diseases, is receiving increasing attention.
Scope and approach: To clarifying the importance of NP models as tools to establish public health interventions concerning consumers' food choices, a literature review of the guiding principles to implement NP models was conducted. The covered topics include main characteristics, advantages, disadvantages, and associated gaps of the considered NP models.
Key findings and conclusions: From the selected studies, a total of 85 documents were included. Nutrient profiling has a wide range of applications including front-of-pack (FoP) food labelling, regulation of food marketing to children, regulation of health and nutrition claims and school food standards. Sodium, saturated fatty acids (SFA), and total sugars were the nutrients most frequently to limit; on the contrary fibre was the most used qualifying nutrient. This review gathers, through a holistic approach, the scientific basis behind the development of the NP model, reinforcing the importance of these tools, and enabling regulators with information to establish an appropriate model.

1. Introduction

Among different risk factors, an unhealthy diet is one of the four main drivers for non-communicable diseases (NCDs) in all World Health Organization (WHO) regions, with the largest burden on the European region (WHO Regional Office for Europe., 2016). Several facets could be considered in the establishment of an unbalanced diet. Overnutrition has increased markedly over the past few decades, and it is anticipated that, one fifth of the world's adults will be obese by 2025 (Forouzanfar & Alexander, 2015). The availability and accessibility to healthy foods will be a challenge that will be influenced by income, individual preferences and beliefs, cultural traditions and geographical and environmental aspects, including climate change (WHO, 2015a, pp. 1–6).

The majority of the general population does not have a healthy dietary pattern, with consumption of elevated levels of processed foods that are high in fats, sugars and sodium and with a low fruit and vegetable consumption (WHO, 2013). The WHO European Food and Nutrition Action Plan (2015–2020) has highlighted that the consumption of energy-rich foods, micronutrient-poor foods and non-alcoholic beverages should be restricted, as part of a healthy diet to achieve population-level food targets (WHO, 2015b).

Food policies designed to promote healthy diets can play a vital role in consumers' choices in alignment with their desire to live a healthy life. Examples of such practices include FoP food labelling, limiting the advertising of unhealthy foods and drinks to children and also the availability of healthy foods in all public institutions (Roberto & Gorski,

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https://doi.org/10.1016/j.tifs.2021.01.082
Received 26 October 2019; Received in revised form 14 January 2021; Accepted 28 January 2021
Available online 5 February 2021

2015).

At the WHO Ministerial Conference on Nutrition and Non-communicable Diseases in the Context of Health 2020, important commitments to health promotion and NCDs prevention were agreed including the development and implementation of common policy approaches that promote, among other things, the use of harmonized nutrient profiling tools (WHO Regional Office for Europe., 2013; World Health Organization (WHO), 2015).

The potential to use nutrient profiling as a tool for assessing individual food products in their contribution to healthy dietary patterns has led to several definitions over the recent years. WHO proposed in 2015 the definition currently accepted: "the science of classifying or ranking foods in keeping with their nutritional composition for reasons associated with preventing disease and promoting health". In this context, NP is a term that has been associated with the content of a food or diet and can be a useful instrument to assist consumers in choosing healthier foods (EFSA Panel on Dietetic Products Nutrition and Allergies, 2008; World Health Organization (WHO), 2015). NP models assess the nutritional quality of foods, not diets, and can be applied to improve the nutritional quality of diets, distinguishing between foods that can constitute healthy and unhealthy diets (Scarborough, P., Rayner, M., 2007; WHO, 2015a, pp. 1–6).

Nutrient profiling is currently being used as part of a range of nutritional policy applications worldwide, and the number of different NP models has expanded rapidly in the recent years. NP models now have several applications including supporting consumers to make healthier food choices by way of the food labelling systems, to determining which food products should be available for sale in schools, to establishing the regulation of health or nutrition claims, and to implementing restriction of food marketing to children (Labonté et al., 2018; Sacks, Rayner, et al., 2011; World Health Organization, 2010).

Nutrient profiling is operationalised by NP models, algorithms intended to classify or score food products according to their nutritional composition and their impact on health (5). NP models development is based upon a specific need and its successful implementation requires political commitment, engagement from stakeholders and support from experts in nutrition science (Nutrition & Avery, 2018).

The increase of different NP models around the world and their multiple potential applications and specificities can lead to risks of discrepancies between models, and confusion for regulators, manufacturers and consumers. Consequently, and taking into consideration the initiatives established in the last years concerning the development and application of different nutrient profiling tools, the main aims of this paper include: detailing the process of developing a NP model, and the different methods used for its validation, and identifying the potential role of nutrient profiling applications in promoting healthier food choices. This state-of-the-art review intends to contribute to a better understanding of NP models and to support policymakers regarding the choice of an applicable model once the establishment of nutrition-related policies would benefit from the utilization of NP models.

2. NP models

2.1. Purpose of developing a NP model

Modelling a diet is usually supported by dietary guidelines for energy and nutrients based on scientific knowledge, contributing significantly to the consumers' health. Although there is a consensus that a balanced pattern of food consumption and diversified diets are determining factors for nutritional health, a healthy diet requires an informed and adequate selection of foods by the consumer (Verhagen & Van Den Berg, 2008).

NP models can be based on different criteria and approaches as they have been developed and can be applied for different purposes. NP models developed in the recent years considered different purposes including food and nutrition policy, public education, fiscal policies, taxation of selected food products product reformulation, labelling regulations and claims, marketing restrictions for children, restrictions on point-of-sale promotion and food procurement (European Heart Network, 2015; Scarborough, P., Rayner, M., 2007).

Valid information that demostrates the link between diet and health should be the basis for the development of NP models (Foltran et al., 2010).

Various NP models have been proposed around the world to assess the nutritional quality of a given food based on its nutrient content. Several food companies have developed their own nutritional criteria by creating a series of different models to guide their product development or to distinguish their healthy options (Vlassopoulos et al., 2017). The Choices International logo (no.6) and the Nordic Keyhole (no.7) were developed to identify foods able to carry a positive FoP logo (National Food Agency (Sweden)., 2015; A. J.C. Roodenburg, Popkin, & Seidell, 2011). The Nutrient Profiling Scoring Criterion (NPSC) score (no.9) in Australia and New Zealand was developed to identify foods eligible to health claims (Food Standards Australia New Zealand (FSANZ), 2016). The Health Star Rating system (no.8), a FoP labelling system that awards a rating of between half a star and five stars for overall nutritional quality. Similarly Nutri-Score (no.5) scores foods according to a letter and a color code, from dark green (A) indicating higher nutritional quality, to dark orange (E), indicating lower nutritional quality (Australian Government Department of Health, 2018; Chantal, J., & Hercberg, 2017). The SAIN, LIM system (no. 20) developed in response to the EU Regulation on nutrition and health claims, which classifies foods into four classes based on a threshold placed on each of two scores, a nutrient density score, called 'SAIN' and a nutrient limit score called 'LIM' (Agence Française de Sécurité Sanitaire des Aliments., 2008).

Using non-interpretative formats in which numerical information is declared directly or with symbols appearing next to the nutrient values were also developed, such as the warning octagons of the stop sign in Chile (no.10) or the multiple traffic light in the United Kingdom (no.11) (Department of Health, Food Standards Agency, & British Retail Consortium., 2013, p. 27; Diario Oficial de la Republica de Chile., 2015).

The FSA-Ofcom model in the United Kingdom (no.12) and the EU-pledge (no.14) in the European Union (EU) were developed to identify foods that were suitable for advertising to children (Department of Health (UK)., 2018; EU Pledge., 2018). The NHSC (no.17) consists of a traffic light spectrum food categorization system to determine which foods and drinks can be sold in school canteens (Australian Government Department of Health., 2014).

The decision points taken into consideration in the development of a NP model will be presented in the following sections.

2.2. Decision points in the development of a NP model

The development of a NP model involves a process that should be systematic, clear and rational and can be based on different criteria and approaches, depending on its objectives (Scarborough, P., Rayner, M., 2007). Given this, when designing a NP model, it is important to follow specific science-driven rules. The decision points taken into consideration in the development of a NP model are presented in Fig. 1 and described in the following sections.

2.2.1. Selection of nutritional criteria

The nutrients selected for NP models are based on policy-driven considerations, on dietary guidelines and nutrition recommendations and expert consensus (Iberoamerican Nutrition Foundation (FINUT)., 2017; Rayner, 2017). This implies the identification of two types of nutrients/ingredients/food groups: i) disqualifying nutrients, for those that have a negative impact on health, when consumed in excess (fat, sugars and sodium), ii) qualifying nutrients, identified as beneficial for health when consumed in appropriate amounts (fibre, vitamins, minerals, proteins, omega-3 fatty acids) (Garsetti, de Vries, Smith, Amosse, & Rolf-Pedersen, 2007). The list of these nutrients can be defined based

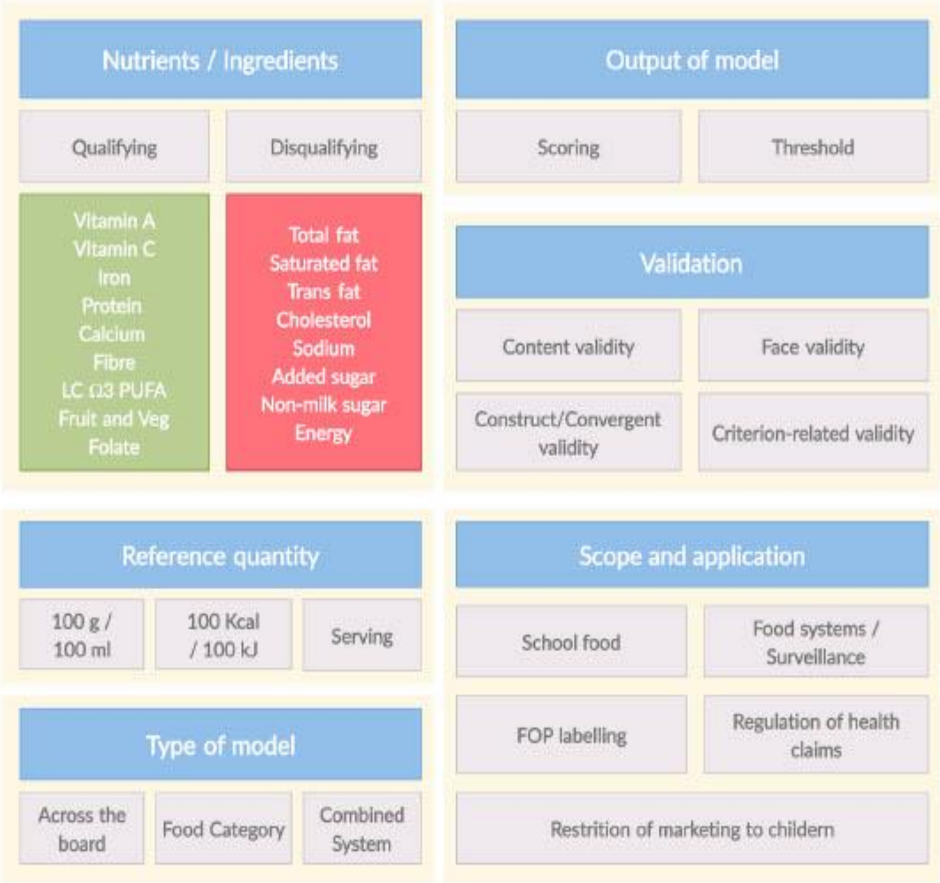

Fig. 1. Decision points take into consideration in the development of a NP model.

on WHO recommendations and the available scientific literature.

With the introduction of the Regulation on the provision of food information to consumers (EU Regulation 1169/2011), nutrition labelling became obligatory and food producers had to deliver the information on energy and six nutrients: fats, SFA, carbohydrates, sugars, proteins and salt. Other nutrients (i.e. monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), polyols, starch, fibre, vitamins and minerals) are also included (European Commission, 2011). These are considered "priority nutrients" as a result of either their consumption levels by the population or sub-population or relevance to public health (Scarborough, P., Rayner, M., 2007).

2.2.2. *Reference quantity*

Each NP model should specify whether it applies to foods sold or consumed as such and, if so, how they should be consumed (Scarborough, P., & Rayner, 2014).

The content of nutrients in food is often expressed in different ways. NP models usually consider nutrient levels in foods using a reference quantity or quantities; these are generally: weight (per 100 g), and or volume (per 100 mL), or energy (per 100 kcal or 100 kJ) or per dose (as consumed) or a recommended amount. It is possible to use more than one reference quantity in a single model (Scarborough, P., Rayner, M., 2007).

Drewnowski, Maillot, and Darmon (2009) suggested that systems based on 100 g are better at assessing "negative" nutrients and systems based on portion sizes and 100 kcal are chosen for scoring "positive" nutrients (Drewnowski et al., 2009).

Currently, in the EU, as a result of the portions not yet being harmonized for the different food categories, the NP models are expressed based on 100 g and 100 kcal of food. In the US, the Food and Drug Administration (FDA) defines common consumption reference quantities (RACC values) for each food that can be used in NP models (Drewnowski, A., & Fulgoni, 2008).

2.2.3. *Classification*

NP models differ in their design, and it is possible to distinguish 3 different types of model: i) presenting the possibility of having identical nutritional criteria for all foods (across-the-board or scoring system), ii) distinct criteria according to the food category (category-based or categorical system) or iii) combined systems.

The across-the-board systems apply the same criteria to define the NP of foods that can be naturally different. These models are known as scoring systems that provide a food classification and use an association algorithm for the content of each nutrient. The generated scores will be used, along with threshold scores, to classify foods in one or more ways, providing more accurate prioritisation of foods, supported by the particularities of each system (EFSA Panel on Dietetic Products Nutrition and Allergies, 2008).

Categorical models distinguish foods and beverages into different classes. These models have specific criteria for different nutrients and/or food components and produce a single overall score or categorization. Categorical models are the predominant type of NP models (Agence Française de Sécurité Sanitaire des Aliments., 2008; Rayner, Scarborough, & Kaur, 2013).

Combined NP models can also be considered on a cross-sectional or food category basis. With this system, a NP model is defined for all foods and depending on the results of the classification, modifications are made to certain categories based particularly on expert opinions in the light of incorrect classifications observed (Agence Française de Sécurité Sanitaire des Aliments., 2008; Rayner et al., 2013).

2.2.4. Calculation method

NP models requires the definition of the criteria and the establishment of the classification method of the food products. There are models based on the definition of thresholds for each nutrient and those based on the definition of an overall score (Agence Française de Sécurité Sanitaire des Aliments., 2008; Iberoamerican Nutrition Foundation (FINUT)., 2017).

A threshold for a qualifying nutrient is based on a minimum content in the food while for a disqualifying nutrient it is based on a maximum content for a food to obtain a claim. The thresholds can be derived from intake recommendations expressed on an energy basis, food consumption or food composition data (Agence Française de Sécurité Sanitaire des Aliments., 2008; Iberoamerican Nutrition Foundation (FINUT)., 2017).

The calculation of scores corresponds to the points attributed to foods when they meet the criteria for each nutrient that are part of the NP model and these points are finally combined to obtain the final score (Agence Française de Sécurité Sanitaire des Aliments., 2008; Iberoamerican Nutrition Foundation (FINUT)., 2017).

2.2.5. Validation approaches

The validation of a NP model refers to the model's ability to assess the purpose for which it was designed, and can be tested in various ways (Iberoamerican Nutrition Foundation (FINUT)., 2017). The literature suggests different ways to validate a NP model that includes: i) using food indicator panels to assess whether or not the model classifies foods according to dietary recommendations (content validity); ii) comparing whether the model approach classifies foods according to the opinions of nutritionists (face validity); iii) comparing the convergence of the classifications of food using NP models that have been designed for similar purposes (construct/convergent validity); iv) assessing the system's ability to adequately characterize diets and relate them to future health outcomes (criterion-related validity) (Cooper, Pelly, & Lowe, 2016; Townsend, 2010).

3. Literature search strategy and methods used

The literature search was undertaken to identify the documents which were relevant to the research question, i.e. what is nutrient profiling? And what are the assumptions used during the development of nutrient profiling? What are the gaps and opportunities for research?

Data collection was performed by a literature search of articles available on Pubmed/Medline, Scielo and Scopus databases as well as on websites of national and international governmental agencies. The literature search was carried out between November 2018–February 2019.

The terms included in the search were: for PUBMED the MeSH term (Medical Subject Headings) "Food labelling" and for the other databases the free terms: "Nutrient Profiling", "food scoring system", "nutrient scoring system", "marketing and children". The outputs of the searching process, i.e., the obtained articles, were exported to the Mendeley Desktop software.

The search of original articles was limited to articles published mainly during the last five years, however it also included articles and reports from governmental agencies recognized as relevant, independently of the date of publication.

Inclusion and exclusion criteria were used to assess the eligibility of the documents identified in the search. The inclusion criteria were: 1) focused approach on the various NP models; 2) detailed information on the principles used in the building process of a NP model; 3) systematized validation process of a developed NP model; 4) description and further evaluation of the different purposes and/or applications of NP models. The exclusion criteria included: documents where the term "nutrient profile/profiling" was related to 1) specific diets of individuals and specific populations; 2) nutritional or health conditions of the population and 3) nutritional content of specific foods or product labels.

4. Nutrient profile models – overview of main results

4.1. Main literature outputs

The search found 981 documents that addressed the topic of interest. After removing duplicates and records that did not fulfil the eligibility criteria, a total of 85 documents were considered relevant to the research questions (Fig. 2).

The full-text assessment allowed the exclusion of duplicated models found within these 85 documents and permitted the identification/selection of 20 NP models that reflected the characteristics related to the development of NP models, which were included in this review.

Table 1 provides the main output related to the development of each NP model assessed from the literature search. The models listed in Table 1 differ from each other within the Scope and Application, Nutrients to limit, Ingredients/nutrients to encourage, Type of model, Output, Reference quantity and forms of Validation. The NP models under study were mainly promoted by government or intergovernmental organizations/agencies and originated from: United States (n = 2, 10%), Europe (n = 11, 55%), Australia and/or New Zealand (n = 3, 15%), international and other countries (n = 4, 20%). Most of the NP models consider at least two types of reference quantity or quantities (n = 15, 75%), particularly: per 100 g and/or 100 mL; 100 g and/or 100 mL per serving.

Within the studies gathered in the present literature search, different authors have identified several possibilities for the application of NP models (Lehmann, Charles, Vlassopoulos, Masset, & Spieldenner, 2017; McColl, K., Lobstein, T., & Brinsden, 2017; Rayner, 2017; Annet J. C. Roodenburg, 2017; Sacks et al., 2011). These main applications include: Food labelling (n = 11, 55%), Restriction of marketing to children (n = 4, 20%), School food standards (n = 3, 15%), Food systems/surveillance and Regulation of claims (n = 2, 10%).

All models include nutrients or food components whose consumption should be limited. The three limiting nutrients included in the various models were SFA (n = 18, 90%), sodium (n = 19, 95%) and sugars (total/added) (n = 19, 95%). In addition, 13 models (65%) comprised nutrients or food components whose consumption should be promoted. The three most encouraging nutrients or food components were: " Fruits, vegetables, nuts and legumes (FVNL), " (n = 5, 25%), fibre (n = 12, 60%) and fibre and protein (n = 6, 30%).

Most NP models involve the definition of food categories. Models that include one (all foods) or two categories (foods and beverages) are usually referred to as "across-the-board" and represent 40% (n = 8) of the NP models under study (e.g., Overall Nutritional Quality Index (no.1), Nutrient-Rich Food Index (NRF 9.3) (no.2); Simplified Nutritional Labelling System (SENS) (no.4)). Models with more than two classes are often mentioned as "food category-specific" models and represented 55% (n = 11) of the models evaluated (e.g., Health Star Rating (HSR) (no. 8); Mexican Nutrition Seal (MNS) (no.15)).

The output of the NP models can be used for setting thresholds that meet a given nutritional guideline, defining algorithms for the evaluation of the overall NP of foods or basing criteria on nutrient reference values. The output of 10 models (50%) consists of a classification based on a specified threshold, seven models (35%) apply the classification of a score and three models (15%) apply a combined classification based on specified thresholds following the calculation of a score (e.g., Nutrient Profiling Scoring Criterion (NPSC) (no.9), FSA/Ofcom (no.12). SPARE (no.18)).

With respect to the validation of the NP models, the applied approaches were the comparison and assessment of the agreement with a reference standard identified (construct/convergent validity) (n = 17, 85%) and identification of how models predict changes in dietary intake

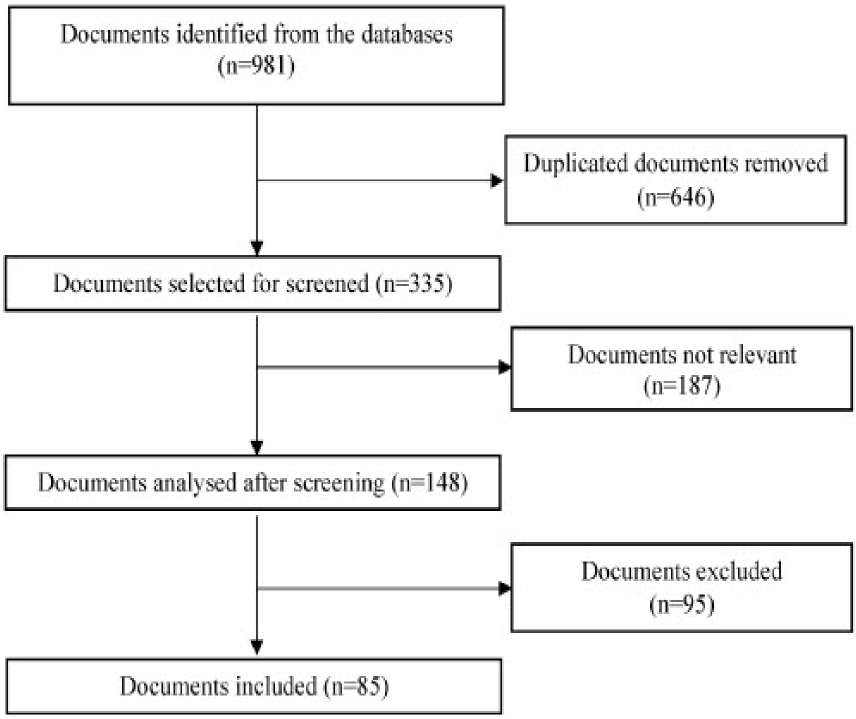

Fig. 2. Flow diagram of the revised search strategy.

(n = 9, 45%).

4.2. Advantages, disadvantages, and remaining gaps

The increasing development of multiple NP models and different interpretations of the concept NP can lead to confusion of both the consumer and the policymaker, therefore, there is an urgent need to optimize NP models (WHO, 2011).

The lack of harmonisation at the regional (European) level for the definition of food groups implies the creation of many food groups to embrace all foods/food products. Therefore, the major weakness of the NP model is the challenge of adjusting and tackling a wide variety of food groups and classifying each food without ambiguity (Drewnowski, A., & Fulgoni, 2008; Iberoamerican Nutrition Foundation (FINUT)., 2017). A small number of categories (e.g. FSA/Ofcom model (no. 12) use 2 food categories: foods and drinks) are easier to define and apply, leaving less room for subjectivity in the classification of food products. However, it is less likely to explain the natural variation in the nutritional composition of foods between food categories. On the other hand, the selection of food categories is often culture-specific and harmonizing cultural differences, defining food groups, and selecting an appropriate NP for each food category or food group is another important topic for further research (Labonté et al., 2018; Rayner et al., 2013; Sacks, Rayner, et al., 2011; Scarborough, P., Rayner, M., 2007).

There are some strengths and weaknesses of each reference quantity used in the development of NP models. Using per 100 g or per 100 mL (e. g. Chilean Warning Octagons (no.10), WHO-EURO (no. 13), Czech Republic draft decree (no.16)) is in line with food labelling and it is simple to standardise, however, a model based on this reference quantity could penalise a food that is rich in nutrients per 100 g and is consumed in small amounts and/or occasionally (Drewnowski, A., & Fulgoni, 2008). A NP model based on units of energy (e.g. Overall Nutritional Quality Index (ONQI) (no. 1), Nutrient-Rich Food Index (NRF9.3) (no.2), the Nordic Keyhole scheme (no.7)), would be consistent with the public health issue of overconsumption of energy-dense foods and facilitates the comparison between foods of different energy density, such as solids and liquids. However, this reference quantity may have issues for foods that are very low-energy and is difficult for consumers to understand it (European Food Safety Authority (EFSA), 2008). The approach based on portion (e.g. Traffic-light labelling (color coded % RI (no.11), Mexican Nutrition Seal (MNS) (no.15)), gives the best reflection of how food is consumed and/or purchased and could be an incentive to reduce energy content. Nevertheless, defining the portion size for the different foods is a challenge, it requires a prior definition of the "portion", which varies depending on product type, individual, eating occasion, dietary cultures and culinary traditions (Scarborough, P., Rayner, M., 2007).

In the development of a NP model, it is important to test the nutrients and food components that can be markers of important nutrients or foods and those that do not need to be included (e.g., total fat was not included in the FSA/Ofcom model algorithm as it was in concordance with energy) (Rayner, M., Scarborough, P., & Stockley, 2004; Rayner, 2017). Nevertheless, there are some controversies regarding the selection of these nutrients. Existing models need to be improved, e.g. free or added sugars should replace the total sugars (Labonté et al., 2018).

Another challenge in this field is the validation of NP models. For a correct classification of foods and their eligibility to use nutrition claims, the validation/testing of the NP models is a crucial step. However, many models have been developed and applied with insufficient testings to demonstrate their validity (Arambepola, C., Scarborough, P., & Rayner, 2008; Cooper et al., 2016; Garsetti et al., 2007). A recent systematic review of 78 NP models identified that only 42% had performed validity testing and the first models to be considered validated were those designed to limit advertising to children, to regulate claims and vending machine specifications (Labonté et al., 2018). Among the models in which validation schemes were identified, construct validity was the most common scheme reported (Cooper et al., 2016).

Table 1
Summary of the main outputs of the literature search regarding the NP models.

Model number (no)	Model name	Country/Organization	Scope and Application	Nutrients to Limit	Ingredients/Nutrients to Encourage	Type of model	Output	Reference Quantity	Validation	Reference
			Food Labelling							
1	Overall Nutritional Quality Index (ONQI)	United States/University	Rank foods by relative nutrition and healthfulness. Food labelling	Saturated fat; *Trans* fat; Sodium; Sugar (total/added) Cholesterol;	Fibre; Folate: Vitamin A; Vitamin C; Vitamin D; Vitamin E, Vitamin B12; Vitamin B6 Potassium; Calcium; Zinc, Omega-3 fatty acids; Total bioflavonoids; Total carotenoids; Magnesium; Iron	Across the board	Scoring	100 kcal/serving	Agreement with a reference standard.	(Katz et al., 2009) (Katz, Njike, Rhee, Reingold, & Ayoob, 2010)
2	Nutrient-Rich food Index (NRF 9.3)	United States/University	Ranks foods based on their nutrient content. Is based on the concept of nutrient density. Food labelling	3 nutrients to limit: Saturated fatty acids; Added sugars; Sodium	9 nutrients to encourage: protein, fiber, vitamin A, vitamin C, vitamin E, calcium, iron, magnesium, and potassium	Across the board	Scoring	100 kcal/100 g/FDA Serving size [reference amounts customarily consumed (RACC)]	Change in dietary intake.	(Drewnowski, A., & Fulgoni, 2008; Glanz et al., 2012; Sluik, Streppel, van Lee, Geelen, & Feskens, 2015)
3	Limited Nnutrient Score (LIM)	France/University/	Classifying and/or ranking food products based on their nutrient composition. Food labelling	Saturated fatty acids; Added sugars; Sodium	n/a	Across the board	Scoring	100 kcal/100 g/FDA Serving size [reference amounts customarily consumed (RACC)]	Agreement with a reference standard.	(Fulgoni, Keast, & Drewnowski, 2009; Maillot, Darmon, Darmon, Lafay, & Drewnowski, 2007)
4	Simplified Nutritional Labelling System (SENS)	France/French Trade and Retail Federation	SENS algorithm has been tailored and simplified from the SAIN, LIM system by integrating specificities of food categories, reducing the number of nutrients, ranking the four categories, and introducing EU reference intakes. Food labelling	Saturated fatty acids; Free sugars; Sodium.	Beverages: Fruit and Vegetables (FV) and Vitamin C. Added fats: Alpha-linolenic acid (ALA) and monounsaturated fatty acids (MUFA). Other solid foods: FV, Proteins and Fibre.	Across the board	Scoring	100 kcal for the SAIN and 100 g for the LIM	Agreement with a reference standard.	(Darmon, Sondey, Azaïs-Braesco, & Maillot, 2018; Tharrey, Maillot, Azaïs-Braesco, & Darmon, 2017)
5	Nutri -Score/5-NCL (Five - Nutri Color Label)	France/National Nutrition and Health Program (PNNS) of ANSES (Agence Nationale de Sécurité Sanitaire del'Alimentation, del' Environnement et du Travail)	The Nutri-Score, a five-color nutrition label based on the Nutrient Profiling System of the British Food Standards Agency (modified version) (FSAm-NPS) score. Is described by a scale of 5 colours, from green indicating food products with the highest nutritional quality to red for products with lower nutritional quality, with a corresponding	Energy, sugar, saturated fatty acids, sodium	Fibres, proteins, and Fruits, vegetables, nuts and legumes (FVNL)	Across the board	Scoring	100 g	Agreement with a reference standard. Predicted change in dietary intake. Agreement between NP models.	(Chantal, J., & Hercberg, 2017; Hercberg & Julia, 2013; Poon et al., 2018)

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Table 1 (*continued*)

Model number (no)	Model name	Country/Organization	Scope and Application	Nutrients to Limit	Ingredients/Nutrients to Encourage	Type of model	Output	Reference Quantity	Validation	Reference
			letter (from A on green to E on red). Food labelling.							
6	Choices programme (Healthy Choice logo)	Belgium, Czechia, Netherlands (withdrawn 2016), Poland/The Choices International Foundation	The Choices programme is a product-group-specific-nutrient-profiling approach with a distinction between basic and discretionary foods. The basic product groups are the most contributors of essential and beneficial nutrients and are based on international dietary guidelines. Food labelling.	Saturated fatty acids, *trans*-fatty acids, sodium (salt) and sugars and, for some food product groups, energy.	Dietary fibre	Food category Specific	Threshold	100 g	Agreement with a reference standard; Predicted the change in dietary intake. Agreement between NP models	(Choices International Foundation, 2016; Roodenburg et al., 2011, 2013)
7	The Nordic keyhole scheme (Keyhole logo)	Denmark, Iceland, Lithuania, Norway, Sweden/Swedish National Food Administration/ Norwegian Directorate of Health and Norwegian Food Safety Authority, Danish Veterinary and Food Administration	The Keyhole is a green symbol food label that identifies healthier food products within a product group. Food labelling.	Total fat, saturated and *trans*-fatty acids, added sugar, salt.	Dietary fibre and whole grains	Food category Specific	Threshold	100 g/Kcal/% Energy	Agreement with a reference standard; Predicted the change in dietary intake.	(Larsson, Lissner, & Wilhelmsen, 1999; National Food Agency (Sweden)., 2015; Trichterborn, Drossard, Kersting, Harzer, & Kunz, 2012)
8	Health Star Rating (HSR)	Australia and New Zealand/Australian and New Zealand Government in collaboration with industry, public health and consumer groups.	HSR system was developed to assist consumers to identify healthier products within the same category. Food labelling.	Energy, saturated fat, sodium and total sugars.	Fruits, vegetables, nuts and legumes (FVNL), fibre, and protein content	Food category Specific	Scoring	100 g/mL	Agreement with a reference standard; Agreement between NP models.	(Australian Government Department of Health, 2018; Dickie, Woods, & Lawrence, 2018; Mhurchu CN; Mackenzie, T; Vandevijvere, 2016)
9	Nutrient Profiling Scoring Criterion (NPSC)	Australia and New Zealand/Food Standards Australia New Zealand (FSANZ)	NPSC was developed to determine whether or not a food is appropriate to make a health claim, based on its nutrient profile. Food labelling	Energy, saturated fat, total sugars and sodium	Fruits, vegetables, nuts, legumes (FVNL), coconut, spices, herbs, fungi, algae and seeds and in some cases, dietary fibre and protein.	Food category Specific	Scoring and Threshold	100 g/mL	Agreement with a reference standard; Agreement between NP models.	(Devi et al., 2014; Food Standards Australia New Zealand (FSANZ), 2016; Labonté et al., 2017)
10	Chilean Warning Octagons (CWO)	Chile/Ministry of Health	CWO give information to the consumer on nutrients that, when consumed in excess, can cause health problems. Food labelling.	Energy, saturated fat, total sugars and sodium	n/a	Food category Specific	Threshold	100 g/mL	Agreement between NP models.	(Arrúa et al., 2017; Contreras-Manzano et al., 2018; Diario Oficial de la Republica de Chile., 2015)
11	Traffic-light labelling (Color -coded %RI)	United Kingdom/Food Standards Agency/ Department of Health	Traffic-light labelling is a scheme that communicates information	Energy, total sugar, total fat, saturated fatty acids, sodium	n/a	Across the board	Threshold	100 g/mL and Serving size	Agreement with a reference standard;	(DiarioOficialde laFederación, 2014; Sacks, Rayner, & Swinburn, 2009; Sacks,

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Table 1 (*continued*)

Model number (no)	Model name	Country/Organization	Scope and Application	Nutrients to Limit	Ingredients/Nutrients to Encourage	Type of model	Output	Reference Quantity	Validation	Reference
			concerning the content of key nutrients and indicates whether or not they are considered as low, medium or high, using text descriptors and color code. Food labelling. **Restriction of the promotion/ marketing of foods to children**						Predicted the change in dietary intake. Agreement between NP models	Tikellis, Millar, & Swinburn, 2011)
12	FSA score/Ofcom (United Kingdom Office of Communication nutrient profile model)	United Kingdom/Ofcom (broadcast regulator) and Department of Health (British Food Standards Agency) (FSA)	FSA score was developed in order to regulate the advertising of foods and beverages to children within the UK. Restriction of the promotion/marketing of foods to children	Energy, total sugar, saturated fatty acids, sodium	Fibres, proteins, and fruits/vegetables/nuts/ legumes (FVNL)	Across the board	Scoring and Threshold	100 g	Agreement with a reference standard; Predicted the change in dietary intake. Agreement between NP models.	(Department of Health (UK)., 2018; Julia et al., 2014)
13	WHO- EURO model	International/WHO Regional Office for Europe in collaboration with the Department of Nutrition for Health and Development at WHO headquarters	The model is basically based on two existing models developed by (Norway) or endorsed by (Denmark) government and used for voluntary restrictions in the respective country. The model was developed for the restriction of promoting unhealthy foods and beverages to children. Restriction of the promotion/ marketing of foods to children	Energy, total fat, saturated fatty acids, *trans*-fatty acids (industrially produce) total sugars, added sugar, salt, non-caloric sweeteners,	n/a	Food category Specific	Threshold	100 g/mL	Agreement with a reference standard; Predicted the change in dietary intake. Agreement between NP models.	(Poon et al., 2018; World Health Organization (WHO), 2015)
14	EU-pledge	EU/Developed by EU Pledge members companies.	The EU Pledge is a voluntary initiative by leading food and beverage companies to various food and beverage advertising to children below the age of 12 on TV, print and internet in the EU. Restriction of the promotion/marketing of foods to children.	Sugars, saturated fatty acids, sodium.	Depending on the food or beverage category.	Food category Specific	Threshold	100 g/mL	Agreement between NP models.	(EU Pledge., 2018; Scarborough et al., 2013)
15	Mexican Nutrition Seal (MNS)	Mexico/Mexican Ministry of Health	MNS was developed for restriction on the		Fibre	Food category Specific	Threshold	100 g/mL and Serving size		(Diario Oficial de la Federación, 2014;

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Table 1 (*continued*)

Model number (no)	Model name	Country/Organization	Scope and Application	Nutrients to Limit	Ingredients/Nutrients to Encourage	Type of model	Output	Reference Quantity	Validation	Reference
			promotion of food and non-Alcoholic beverages advertising in television and cinemas targeted to children. Restriction of the promotion/ marketing of foods to children **School food standards**	Energy, sodium, saturated fat and total sugar.					Agreement between NP models.	Rincón-Gallardo Patiño et al., 2016)
16	Czech Republic draft decree	Czech/Ministry of Education, Youth, and Physical Education and the Ministry of Health	This decree regulates requirements for foods that advertising is allowable and which might be offered for sale and sold in schools and educational institutions.	Salt, fat and sugars	n/a	Food category Specific	Threshold	100 g/mL	Not identified	(Czech Republic Ministry of Education, Youth and Physical Education and Ministry of Health, 2016)
17	National Healthy School Canteens (NHSC) project	Australia/Australian Government Department of Health	The project has developed national guidance and coaching to assist canteen managers to create healthier food and drink choices for school canteens	Saturated fat, added salt, added sugars and alcohol	Fibre	Food category Specific/ Classification	Threshold	100 g/mL and Serving size	Agreement between NP models.	(Australian Government Department of Health., 2014; Walker, Woods, Rickard, & Wong, 2007)
18	System of Planning and Evaluation of School Meals (SPARE)	Portugal/Academic (Faculdade de Ciências da Nutrição e Alimentação of the Universidade do Porto)	The System of Planning and Evaluation of School Meals (SPARE) is a software that was developed to plan school meals in an effective and organized method, according to the main national and international standards for food and nutrition. **Food systems/ Surveillance**	Energy, carbohydrate, fat and protein	n/a	System of classification	Scoring and Threshold	Serving size	Not identified	Rocha et al. (2014)
19	Health Canadian Surveillance Tool tier system (HCST)	Canada/Health Canada	HCST was developed to assess the adherence of the dietary intakes of Canadians to the dietary guidance provided by Canada's Food Guide (CFG). Food systems/ Surveillance. **Regulation of Health claims**	Total fat, saturated fat, Na and total sugars	n/a	Food category Specific	Threshold	Serving size	Agreement with a reference standard; Predicted the change in dietary intake.	(Health Canada, 2014; Jessri, Nishi, & L'Abbe, 2016; Jessri, Nishi, & L'Abbé, 2015)
20	SAIN, LIM	France/French Food Safety Agency (AFSSA)	Classifies foods based on a qualifying		Protein; Fibre; Vitamin C; Calcium; Iron, and the	Across the board	Scoring	100 kcal for the SAIN and	Agreement with a	(Agence Française de Sécurité Sanitaire des

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Table 1 (*continued*)

Model number (no)	Model name	Country/Organization	Scope and Application	Nutrients to Limit	Ingredients/Nutrients to Encourage	Type of model	Output	Reference Quantity	Validation	Reference
			nutrients score, the SAIN (score for the nutritional adequacy of individual foods) and a disqualifying-nutrients score, the LIM (score of nutrients to limit. Regulation of health claims	Saturated fatty acids; Added sugars; Sodium	optional vitamin D, vitamin E and a-linolenic acid			100 g for the LIM	reference standard; Predicted the change in dietary intake. Agreement between NP models.	Aliments., 2008) (Darmon, Vieux, Maillot, Volatier, & Martin, 2009) (Trichterborn et al., 2012)

n/a - not applicable.

5. Complementary strategies to promote healthier food choices - future directions

NP models have various applications and most of them are nutrient-based, focused on selected nutrients (fat, saturated fats, sugars, and salt), although failing to capture the true nutrient density of a food and the relative healthiness of foods (Drewnowski, Dwyer, King, & Weaver, 2019). A possible improvement is the development of a hybrid nutrient profiling approach that takes both nutrients and all appropriate food groups and food ingredients into account (Drewnowski et al., 2019; Maillot, Sondey, Braesco, & Darmon, 2018). In addition, in order to encourage healthier food choices, a hybrid NP model may provide better alignment between quantitative measurements of nutrient density and their policy applications. This synergy can improve dietary guidance, linked to a robust nutritional policy, and ultimately better public health (Drewnowski et al., 2019).

FoP nutrition labelling is one of the "best buy" policy measures that can be implemented in conjunction with educational campaigns to promote healthy eating and prevent diet-related chronic diseases (WHO, 2015b; World Cancer Research Fund International., 2019). However, some consumers are confused with the interpretation of the information on food labels. In this context, it is important to strengthen educational interventions to improve consumer understanding by increasing the impact of this information on dietary health and nutrition literacy (Gomes, Nogueira, Ferreira, & Gregorio, 2017, p. 58; Moore, Donnelly, Jones, & Cade, 2018).

NP models have also reformulation as a possible application (Chantal, J., & Hercberg, 2017; Choices International Foundation, 2016). To achieve this goal, the food industry must be involved and the reformulation of food products must be encouraged, with nutrition labelling as a tool to further incentivise the development and production of healthier products. The nutrients listed in food labels should be amenable to reformulation concerning the target population (Hawkes et al., 2015). Policymakers should formally recognise NP models as a tool to guide food reformulation and monitor their potential impact on improving diets and shaping people's food choices (Labonté et al., 2018).

6. Conclusions

This paper provides an outline of the guiding principle to implement a NP model, the concept, the criteria, the steps involved in developing a NP model, including validation, limitations and potential applications.

A holistic approach should be taken for the development and sustainable application of a NP model. The existence of valid data supporting the relationship between diet and health should be considered in the framework for its development.

Current NP models may not fully capture the health impact of foods, being an opportunity to develop a hybrid nutrient profiling approach that takes both nutrients and all desirable food groups and ingredients.

Additional and complementary studies are still needed on the appropriateness of these models and how they will be aligned with national circumstances.

NP models represent a useful instrument for an effective decision-making process within the field of public health nutrition interventions and to assist consumers to make healthier food choices. This review provides policymakers and health authorities with the guiding principles underlying the development of a NP model and the conditions for reaching the real potential of NP models.

Author contributions

MS: Conceptualization and study design, Data collection, Data analysis, Writing. FNM: Data collection, Data analysis. AIR: Data analysis, feedback on the paper. RA: Conceptualization, Methodology, Writing - review & editing. IC: Data analysis, feedback on the paper. IL:

Data analysis, feedback on the paper. The final manuscript was read and approved by all the authors.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgements

This manuscript was developed under the scope of WHO Collaborating Centre on Nutrition and Childhood Obesity-National Institute of Health Dr. Ricardo Jorge.

Ricardo Assunção thanks FCT/MCTES for the financial support to CESAM (UIDP/50017/2020+UIDB/50017/2020), through national funds.

Abbreviations

FoP	Front-of-Pack
LC	Long chain
MUFA	Monounsaturated fatty acids
NP	Nutrient profile
PUFA	Polyunsaturated fatty acids
SFA	Saturated fatty acids
WHO	World Health Organization

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5. Breakfast cereals intended for children: opportunities for reformulation and potential impact on nutrient intake

Chapter 5 consists of a manuscript based on the application of NP models in the domain of food composition/reformulation. This study aims to **1)** assess the adequacy of the ready-to-eat cereals (RTECs) for children available in Portuguese supermarkets, applying three NP models - the NP model of the World Health Organization's Regional Office for Europe (WHO-EURO), the profile of the private-sector EU Pledge (EU-Pledge), and the national model developed by the Directorate-General of Health (NPM-PT) – **2)** explore the potential for reformulation of the RTECs identified as not adequate and **3)** evaluate the impact of RTECs reformulation on the nutritional quality of Portuguese children's diets.

Manuscript 2

Article published in the Journal *Foods*.

Santos M, Matias F, Rito AI, Castanheira I, Torres D, Loureiro I, Assunção R. Breakfast Cereals Intended for Children: Opportunities for Reformulation and Potential Impact on Nutrient Intake. Foods. 2021 Jul 30;10(8):1772. https://doi.org/10.3390/foods10081772 PMID: 34441549; PMCID: PMC8394760.

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Article

Breakfast Cereals Intended for Children: Opportunities for Reformulation and Potential Impact on Nutrient Intake

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Citation: Santos, M.; Matias, F.; Rito, A.I.; Castanheira, I.; Torres, D.; Loureiro, I.; Assunção, R. Breakfast Cereals Intended for Children: Opportunities for Reformulation and Potential Impact on Nutrient Intake. *Foods* 2021, *10*, 1772. https://doi.org/10.3390/foods10081772

Academic Editors: Li Wang and Christopher John Smith

Received: 22 April 2021
Accepted: 28 July 2021
Published: 30 July 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Abstract: Ready-to-eat cereals (RTECs) have become a popular breakfast option claiming to provide important nutrients to children's diets, despite being a source of excess sugar and, therefore, a health concern. Thus, food reformulation constitutes an important public health strategy that could benefit from inputs provided by nutrient profiling. This study aimed to assess the adequacy of the RTECs for children available in Portuguese supermarkets, applying three nutrient profile models (NPMs)—the nutrient profile model of the World Health Organization's Regional Office for Europe (WHO-EURO), the profile of the private-sector EU Pledge (EU-Pledge), and the national model developed by the Directorate-General of Health (NPM-PT)—in order to explore the potential for reformulation of the RTECs identified as not adequate and evaluate the impact of RTECs' reformulation on the nutritional quality of Portuguese children's diets. In total, 78 RTECs intended for children were assessed and two scenarios—current (not considering reformulation) and alternative (considering reformulation to accomplish the nutrient profile requirements)—were considered to assess the impact of reformulation on nutritional quality. Across all RTECs, only 5.1% could be promoted to children according to the considered NPMs. The most common nutrients requiring reformulation were sugar, saturated fatty acids (SFA), salt, and dietary fiber. The scenarios of reformulation considered could reduce the RTECs average content of total sugars, SFA, and salt by 43%, 8.7%, and 1.1%, respectively, and dietary fiber intake could be increased by 34%. Thus, these results support policies to implement reformulation strategies for developing healthier food products to be promoted to children.

Keywords: breakfast cereals; nutrient profile; reformulation; food selection; children; health impact

1. Introduction

The benefits of breakfast, the first meal of the day, as part of a healthy and balanced lifestyle, are widely known from a nutritional, psychological, and societal point of view. The breakfast meal is related to several critical health factors that include healthy body weight, especially among children and adolescents [1]. The last "Health Behavior in School-aged Children" (HBSC) study, published in 2018 by the World Health Organization (WHO), revealed that the proportion of boys and girls eating breakfast on school days has declined since 2014, with just one out of two adolescents eating breakfast daily on school days. According to the same study, the proportion of Portuguese boys and girls who are 11 years old who eat breakfast on school days are 81% and 77%, respectively [2]. Among school children, ready-to-eat cereals (RTECs) seem to be one of the most popular components of the breakfast composition meal (66.5%) [3].

Breakfast cereals include several products grouped into processed cereals such as a porridge-type breakfast, and RTECs or "cold" breakfast cereals such as cornflakes and muesli [4]. In our study, we focused on RTECs such as flakes, puffed, and extruded cereals.

Several studies highlight that breakfast cereal consumption may be associated with improved cognitive functioning, with lower measures of overweight or obesity and reduced risk of hypertension [5].

RTECs consumption (compared with low/no consumption) is associated with higher nutrient intakes in the diets of European children and adolescents [6].

The consumption of RTECs has been associated with enhanced intakes of many vitamins and minerals in adults and children, either directly through its consumption or through its co-consumption with milk [7,8].

RTECs are high in carbohydrates and contain dietary fiber, proteins, vitamins, and minerals, which enables the recommended nutritional requirements of some nutrients to be met. Much of this effect is probably due to the fortification of many breakfast cereals [5].

RTECs may also contain high levels of salt and sugar, identified as risk factors for numerous chronic diseases when excessively consumed [9]. Observational and experimental studies indicated an association between high intake of added/free sugars and body weight [10], as well as with an increased risk factor for dental caries [11], and risk of developing several chronic diseases, namely type 2 diabetes [12] and cardiovascular diseases [13].

Initiatives are ongoing across the world to improve food environments and systems and to facilitate healthier children's diets. Aligned with WHO recommendations, national governments across the globe are committed to developing efforts to limit the marketing of unhealthy foods to children [14,15].

The nutrient profile appears as one of the most relevant strategies to combine personal preference with a food healthy environment. Over the last years, nutrient profile models, which are tools to facilitate healthier food choice, have multiplied, and have been recognized by the industry and governments as a transparent and reproducible way of evaluating the healthfulness of foods. [16,17]. A large number of nutrient profile models have been developed covering different policy applications, highlighting those for regulating nutrition and health claims, marketing of foods for children, front-of-pack labelling (FOPL) systems, and food reformulation [18].

Focusing the restriction of food marketing and advertising to children, the WHO Regional Office for Europe (WHO-EURO) developed a nutrient profile model, and at the European Union (EU) level, several major international companies have signed the so-called EU-Pledge, as a collective self-regulation initiative establishing a code of conduct for marketing activities directed towards children [19,20].

At the national level, and in line with international recommendations, the Directorate-General of Health (DGS), developed a nutrient profile model (NPM-PT), adapting the WHO-EURO and adjusting the limits of some nutrients in certain categories of foods to align with the values defined by European Union legislation. Changes were also introduced to reflect the commitments established in Portugal regarding the food products' reformulation [21].

The reformulation of food products becomes crucial to reduce the consumption of salt/sodium, sugar, and other nutrients relevant to public health and NP can be used as a tool to improve the overall nutritional quality of diets. On the other hand, reformulation should also consider ways to promote the consumption of positive nutrients like dietary fiber.

At the national level, the use of NPMs as tools to identify foods that can (or cannot) be marketed to children constitutes an emerging area of research in different countries. The purpose of this study is to add evidence on the validity of the NPM-PT, a NPM developed in Portugal, to correctly identify healthy foods, by comparing it with other models, as well as to test the capacity of the NPM-PT to guide a theoretical reformulation of RTECs marketed to children.

Particularly, the study aimed to answer the following questions: (i) what is the compliance rate of the RTECs for children available in the Portuguese supermarket, considering three nutrient profile models designed to restrict food marketing and advertising to children—the NPM-PT, WHO-EURO, and EU-Pledge; (ii) what is the potential for reformulation of the RTECs identified as not adequate; and (iii) what is the impact of RTECs reformulation on the nutritional quality of Portuguese children's diets. Data from the present study intend to assist and support the industry companies, nutrition professionals, and policymakers to identify new avenues of research and regulatory actions associated with the implementation of reformulation strategies for developing healthier food products to be promoted to children. Especially at the European level, considering the European Single Market, there is a movement of goods, including foods. This means that any reformulation occurring in Portugal could have a reflection, and consequently, an impact, in other countries. Additionally, this contributes to promoting the harmonization of foods and nutrition-related policies across countries. At the national level, this research serves as a call for policymakers to consider the NPM-PT as a tool to promote the reformulation of RTECs and other child-targeted foods available in the market.

2. Materials and Methods

2.1. Breakfast Cereals Samples Selection

Overall, 78 children's RTECs were selected from the available RTECs in the supermarkets from the Lisbon region. These products were chosen according to data from the Portuguese National Food, Nutrition, and Physical Activity Survey (IAN-AF) [22] for the consumption of RTECs by Portuguese children aged between 3 and 10 years old. The RTECs with gluten as a nutrition claim and organic labelling were also reported, according to data consumption from the Portuguese National Food, Nutrition, and Physical Activity Survey (IAN-AF). It was decided to also investigate these cereal categories (e.g., gluten-free (GF) and RTECs labelled organic for children), to assess their nutritional quality, as some studies reveal that products (RTECs) with a GF claim or labelled as organic are or are not nutritionally superior to regular products (RTECs) [23–25].

RTECs were identified when specifically remarked with 'child' or 'children' within the name or on the packaging; if the package enclosed puzzles or games directly geared toward children; if they presented direct claims or relevance fun or play; and if they were advertised for children on TV, films, or PC games [3,26,27]. The exclusion criteria for product selection were (i) incomplete images of the nutrition declaration or list of ingredients, (ii) unclear images on all sides of the package, and (iii) items that were marked as "product currently unavailable" on the website or in the supermarkets.

From each product, different information was collected, namely brand name, commercial product name, descriptive name, serving size, ingredient list, package marketing, and nutrition labelling information. Additionally, nutrition claims (presence or absence of gluten) [28] and organic certification information [29] were also registered. When needed, the data collection was also complemented through the extraction of information from corporate brand websites and online supermarkets. Data per portion size were obtained from packaging information or calculated based on the recommended serving size and nutrition labelling information about nutrient content; energy, total sugars, fat, saturated fatty acids, sodium, protein, and dietary fiber were also collected. Total sugars were considered as the amount of (total) sugars in prepacked foods to be listed, under carbohydrates in grams per 100 g, according to Regulation (EU) No 1169/2011 on the provision of food information to consumers. The contents of sodium per 100 g were estimated through the formula salt g per 100 g/2.5 [30].

RTECs were grouped according to the following categories as described by Goglia, R. et al. [31]—chocolate-flavored cereals, honey/caramel sweet cereals, filled cereals, and cornflakes/other plain cereals. The type of brand comprised two categories: national and store brand. Children RTECs without organic labelling were considered as conventional children RTECs. Some products such as plain oats, granola, and muesli with no added salt and/or sugar were excluded, as they did not fit into the defined categories (e.g., oat porridge). As the focus of the study was on product reformulation, the breakfast cereals sample selection only included RTECs with non-whole grain cereals (refined cereal flours).

All data collected (packaging information and their classification) were recorded on standardized spreadsheets usingMicrosoft Excel 2016 (Microsoft, Washington, WA, USA).

2.2. Nutritional Quality Assessment of RTECs Using Nutrient Profile Models

The marketing adequacy of the RTECs for children was assessed according to nutritional criteria established by three nutrient profile models, WHO-EURO [19], NPM-PT [21], and the most recent version of the EU-Pledge [20].

In the present study, the selected models reflect a category-based approach, supported by criteria for key nutrients. The compliance/non-compliance with the established criteria for the nutrients present per 100 g of food was evaluated, and each food product was classified as suitable/not suitable for promotion for children. These models were selected as they were developed to limit food marketing and publicity to children under 12–16 years, since they have a corresponding European/national scope. Characteristics of the three nutrient profile models used in this study are provided in Table A1.

2.3. Impact of Nutrient Profile Models on the Daily Nutrient Intake

RTECs that could be potentially reformulated were identified based on the NPM-PT criteria (presenting the most restrictive profile model), in combination with the dietary fiber criterion from the EU-Pledge, that considers a minimum value of 3 g of dietary fiber per 100 g of product. The dietary fiber criterion was included since the increased intake of fiber has been associated with the improvement of the overall quality of the diet among children and adults [32]. Furthermore, dietary fiber intake is usually below the dietary reference values, despite any improvement in its consumption, particularly in children, which is expected to be associated with health benefits [22,33].

For the consumption of RTECs by the Portuguese children aged between 3 and 10 years old, data from the Portuguese National Food, Nutrition, and Physical Activity Survey (IAN-AF) conducted from October 2015 to September 2016 were used [22]. Under the IAN-AF, the dietary intake was obtained via two non-consecutive one-day food diaries and with an additional personal interview with parents or other caregivers for more details related to the description and quantification of food [34]. Then, the intake of each food component was calculated and compared with the dietary reference values, established by the EFSA [35] and WHO [36]. Additionally, 20% of the daily energy and nutrient requirements for each age group was assumed as the reference intake for the breakfast meal [37]. Combining the nutrient contents and the consumption of these RTECs, the intake of each food component (total fat, saturated fatty acids, total sugars, salt/sodium, and fiber) was assessed. Nutrient contents corresponded to the amounts present in the product labels (for those products following the established criteria) or, alternatively, corresponding to the highest (salt, total sugar, total fat, and saturated fatty acids) or the lowest (fiber) amount established in the respective model (for those products that were not in accordance with the established criteria). Current (not considering reformulation) and alternative (considering reformulation to accomplish the nutrient profile requirements) scenarios were compared to assess the attainment of dietary recommended values (DRV) and, consequently, how these values could be impacted by a potential reformulation of RTECs.

2.4. Statistical Analysis

Once all RTECs information was collected, the reported 78 breakfast cereals were grouped into different categories regarding the ingredients (flavors), type of brand, and presence/absence of the gluten claim and organic labelling. This information was processed using different statistical methods. The Kolmogorov–Smirnov test was used to test the normality of the distribution of the variables to decide between parametric or nonparametric analyses for comparisons. Variables were expressed as the median (interquartile range).

The energy (kcal/100 g) and nutrient contents per 100 g of products were compared by the Mann–Whitney non-parametric test for two independent samples (for differences between the gluten and gluten-free categories and conventional and organic labelling categories, respectively) and using the Kruskal–Wallis non-parametric test with multiple pairwise comparisons (for differences among cereals categories). The Bonferroni correction was applied.

The level of convergence between the models was evaluated using the Cohen coefficient κ. The degree of agreement was scored as follows: 0.00–0.20 "light", 0.21–0.40 "fair", 0.41–0.60 "moderate", 0.61–0.80 "substantial", and 0.81–1.00 "almost perfect" [38,39].

Data were analyzed by using the Statistical Package for Social Sciences software (IBM SPSS Statistics, Version 26.0, IBM corp., Chicago, IL, USA). A result was considered statistically significant if the *p*-value was less than 0.05 and highly statistically significant for an observed *p*-value of less than 0.01.

3. Results

Table 1 summarizes the different categories of RTECs considered in the present study. Chocolate-flavored cereals (32, 41%) were the most represented, followed by the honey/caramel sweet cereals (19, 24%), cornflakes/other plain cereals (19, 24%), and filled cereals (8, 10%). Regarding the type of brand, the national brand (47, 60%) corresponded to the majority of RTECs considered, compared to the store brand (31, 40%). The presence of the gluten claim (68, 87%) and absence of organic labelling (conventional) (67, 86%) were represented the most.

Table 1. RTECs samples distribution per category according to common characteristics.

Type of Cereals	*n*	%
Chocolate-flavored cereals	32	41
Honey/caramel sweet cereals	19	24
Filled cereals	8	10
Cornflakes/other plain cereals	19	24
	Organic/conventional	
Children RTECs (conventional)	67	86
Children RTECs (organic labelling)	11	14
	Nutrition claim (gluten)	
Children RTECs (presence of gluten)	68	87
Children RTECs (gluten-free)	10	13
	Type of brands	
National brand	47	60
Store brand	31	40

Table 2 presents the observed variability in nutritional composition across all the categories of considered RTECs, concerning energy, total sugars, fats and saturated fatty acids, sodium, protein, and fiber.

Table 2. Energy, macronutrients, and sodium across the different children RTECs categories considered in the study.

Categories			Energy kcal/100 g	Total Sugars (g/100 g)	Fat (g/100 g)	Saturated Fatty Acids (g/100 g)	Sodium (mg/100 g)	Protein (g/100 g)	Fiber (g/100 g)
Category	Children's RTECs (n = 78)	median (25th–75th percentile)	385 (380–402)	28.3 (24.0–31.0)	3.1 (2.0–7.2)	1.1 (0.6–2.0)	230 (123–312)	7.3 (6.0–8.4)	4.6 (3.0–6.0)
		SD	26	9.5	4.8	1.6	155	1.6	2.8
		p-value	0.002	0.003	0.029	0.01	0.040	0.584	0.43
Type	Chocolate-flavored cereals (n = 32)	median (25th–75th percentile)	383 (378–394)	29.0 (27.0–32.0)	2.7 (2.5–4.5)	1.3 (1.0–2.0)	200 (161–276)	7.6 (6.5–8.9)	5.1 (3.5–6.5)
		SD	24	4.7	3.9	1.2	101	1.2	1.9
	Honey/caramel sweet cereals (n = 19)	median (25th–75th percentile)	388 (380–399)	28.0 (24.1–33.0)	3.0 (1.50–5.0)	0.6 (0.3–1.3)	280 (12.0–392)	6.9 (6.0–8.3)	4.5 (3.2–5.5)
		SD	13	7.9	2.8	0.6	166	1.3	1.7
	Filled cereals (n = 8)	Median (25th–75th percentile)	444 (440–449)	30.0 (27.1–32.7)	15.0 (14.2–15.9)	4.6 (3.9–6.4)	294 (135–414)	7.5 (7.0–8.5)	3.7 (3.0–4.2)
		SD	13	3.3	2.3	1.5	155	1.1	1.1
	Cornflakes/other plain cereals (n = 19)	Median (25th–75th percentile)	381 (379–385)	22.3 (1.1–27.0)	2.2 (1.4–7.1)	0.6 (0.3–1.3)	260 (12.0–400)	7.0 (6.0–8.4)	3.8 (2.2–6.6)
		SD	19	11.9	3.6	1.0	217	2.4	4.8
		p-value	0.000120	0.000113	0.000053	0.00000017	0.666	0.445	0.341
Nutrition claim (gluten)	Children's RTECs (presence of gluten) n = 68	Median (25th–75th percentile)	386 (380–408)	28.9 (24.7–31.8)	3.2 (2.1–7.4	1.0 (0.6–2.3)	230 (125–312)	7.3 (6.5–8.5)	4.7 (3.0–6.0)
		SD	28	9.3	5.0	1.7	140	1.6	2.0
	Children's RTECs (gluten-free) n = 10	Median (25th–75th percentile)	382 (379–385)	21.7 (11.3–28.4)	2.5 (1.4–7.3)	1.3 (0.6–1.7)	228 (21.0–363)	7.5 (6.2–8.4)	4.1 (3.2–9.8)
		SD	5	9.1	3.5	0.6	244	1.3	5.7
		p-value	0.173	0.010	0.402	0.934	0.994	0.905	0.828
Organic/conventional	Children's RTECs conventional n = 67	Median (25th–75th percentile)	388 (380–409)	28.8 (24.9–31.0)	3.2 (2.2–9.3)	1.2 (0.6–2.3)	240 (140–312)	7.3 (6.5–8.4)	4.7 (3.2–6.0)
		SD	26	6.1	5.0	1.7	148	1.1	2.7
	Children's RTECs organic n = 11	Median (25th–75th percentile)	378 (357–384)	4.2 (1.0–24.0)	2.2 (1.4–3.6)	0.6 (0.3–0.7)	8.0 (4.0–256)	7.6 (6.6–11.0)	3.6 (2.6–9.0)
		SD	16	14.2	1.8	0.4	148.2	2.9	3.3
		p-value	0.003	0.000254	0.066	0.002	0.003	0.235	0.818

Table 2. *Cont.*

Categories			Energy kcal/100 g	Total Sugars (g/100 g)	Fat (g/100 g)	Saturated Fatty Acids (g/100 g)	Sodium (mg/100 g)	Protein (g/100 g)	Fiber (g/100 g)
National/ Store/	Children's RTECs national *n* = 47	Median (25th–75th percentile)	384 (378–402)	25.0 (21.0–29.0)	3.2 (2.1–7.6)	1.1 (0.6–2.0)	280 (80.0–392)	7.2 (6.0–8.1)	4.6 (3.0–6.2)
		SD	26	10.5	4.6	1.3	177	1.8	3.3
	Children's RTECs store brand *n* = 31	Median (25th–75th percentile)	390 (380–406)	30.0 (27.0–32.9)	2.6 (2.0–5.0)	1.1 (0.7–2.3)	200 (140–280)	7.5 (6.6–9.0)	4.5 (3.0–5.6)
		SD	27	5.3	5.2	1.9	112	1.3	1.7
		p-value	0.158	0.000446	0.721	0.487	0.254	0.240	0.646

Values are expressed as median (25th–75th percentile); SD = standard deviation; *p*-value obtained with Kruskal–Wallis tests for independent samples with multiple pairwise comparisons (breakfast cereals categories) or with the Mann–Whitney test for two independent samples (gluten/gluten-free; conventional/organic labelling; national/store brand).

Overall, the median energy value of RTECs was 385 kcal/100 g, but it varied widely among the cereal types (p = 0.0001). The energy content ranged from a median of 381 kcal/100 g for cornflakes/other plain cereals to 444 kcal/100 g for filled cereals.

The total sugars and total and saturated fatty acids contents diverged among the types of cereals (p < 0.0001), with the highest contents in filled cereals presenting 30.0, 15.0, and 4.6 g/100 g, respectively.

No statistically significant differences in protein (p = 0.445) and fiber (p = 0.341) contents were detected across the cereal types. Chocolate-flavored cereals presented the highest content of protein and fiber, at 7.6 and 5.1 g/100 g, respectively.

There were no statistically significant differences (p = 0.666) in the sodium content for the various types of cereals, with the chocolate-flavored cereals presenting the lowest content at 200 mg/100 g, and filled cereals presenting the highest content with 294 mg/100 g.

Regarding the remaining categories, comparing gluten-free products with gluten counterparts, the total sugars content showed statistically significant differences (p = 0.010). Overall, products carrying organic labelling presented lower total sugars at 4.2 g/100 g, total fat at 2.2 g/100 g, saturated fatty acids at 0.6 g/100 g, and sodium content at 8.0 mg/100 g. No statistically significant differences in fat (p = 0.066), protein (p = 0.235), and fiber (p = 0.818) contents were observed among the conventional children's RTECs and children's RTECs with organic labelling.

With the emphasis on the type of brand, the results revealed the highest values for energy, total sugars, and protein content for the store brand. The national brands presented the highest sodium content (280 mg/100 g). Statistically significant differences (p = 0.0004) within the type of brand in the total sugars content were found.

Figure 1a,b presents the compliance of nutrient content of each RTECs compared to the criteria established in the three nutrient profile models, which considered the percentage of RTECs not adequate (%) to be promoted for children (in discordance with the criteria, at least for one nutrient).

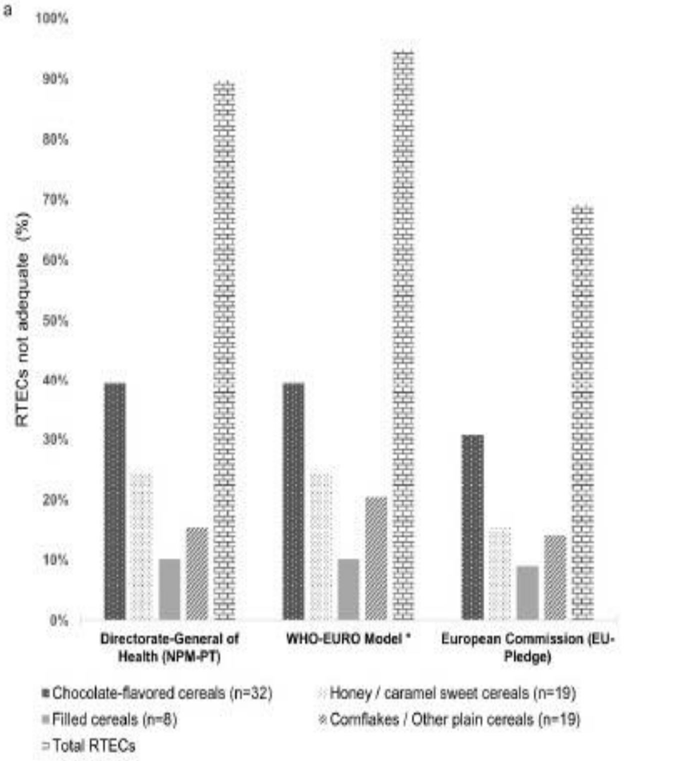
Across all RTECs, the WHO-EURO model classified 95% (74) of the 78 cereals analyzed as non-adequate to be promoted for children. The corresponding figures for NPM-PT and EU-Pledge were 90% (70) and 69% (54), respectively, for all the products. The number of RTECs (n = 78) that met the three nutrient profiles developed to regulate food marketing to children was low; only 5.1% (n = 4) could be promoted to children according to the NPM-PT, WHO-EURO, and EU-Pledge models.

The conventional RTECs (n = 67) represent 86% of the cereals analyzed and the non-compliance rate was lower in the EU-Pledge model (n = 48, 62%) when compared to the NPM-PT and WHO-EURO models (n = 66, 85%).

The organic (n = 11) and gluten-free (n = 10) labelling of children's RTECs represent 14% and 13% of the cereals analyzed, respectively, and gluten-free cereals showed a higher non-compliance rate (n = 8, 10%) compared with the organic RTECs (n = 4, 5.1%) for the NPM-PT. The EU-Pledge revealed a non-compliance rate similar for both categories of RTECs, 7.7% and 8.9%, respectively. The national RTECs brands (n = 47) represent 60% of the cereals analyzed and did not comply with the criteria of the NPM-PT (n = 39) and WHO-EURO (n = 43) in 50% and 55% of brands, respectively.

Figure 2 represents the compliance rate for the nutrient content of RTECs types with the criteria defined in the three nutrient profile models.

a



b

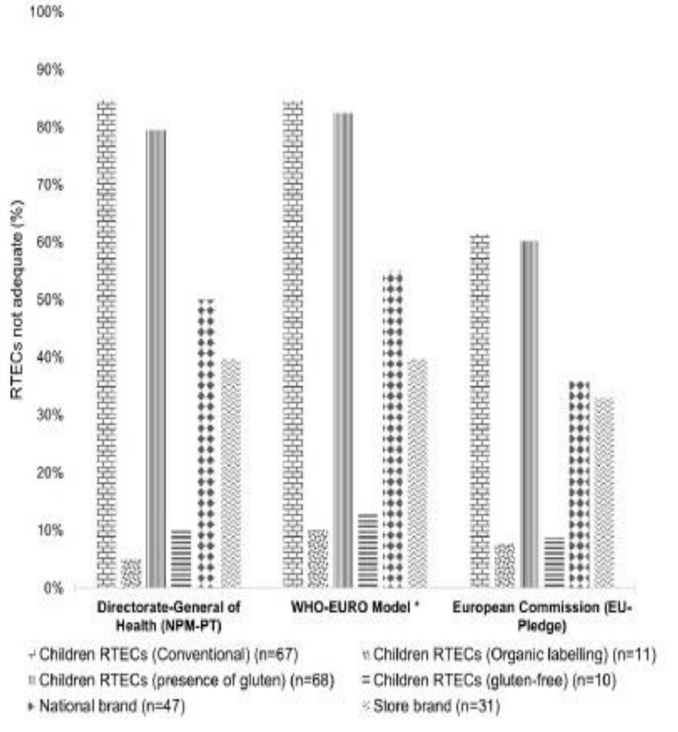


Figure 1. (**a**) Percentage of RTECs not adequate to be promoted by each nutrient profile model and (**b**) by nutrition claim (gluten), type of brand, and conventional/organic labelling. (*) For the WHO-EURO model application, the recommended minimum criterion fiber content of 6 g/100 g of product was included in evaluating the different RTECs.

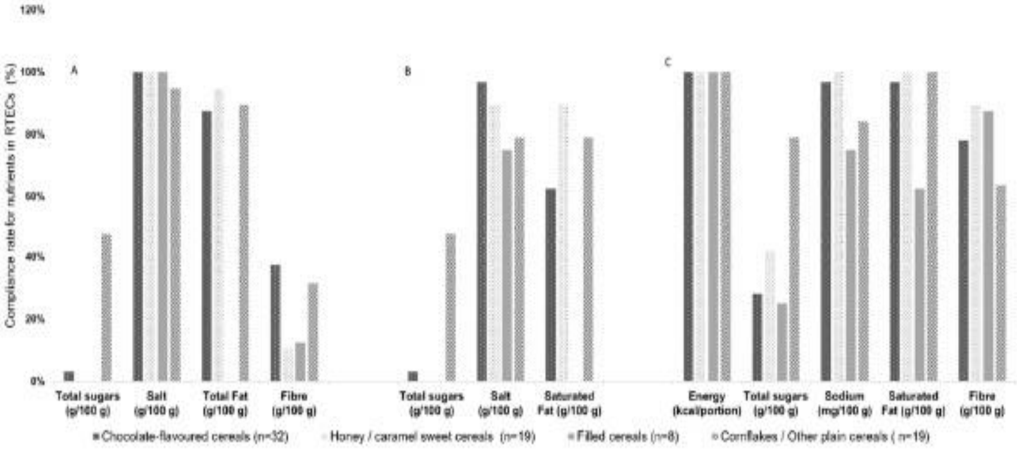


Figure 2. Percentage of agreement between RTECs' nutrient content and the criteria set by the nutrient profile models: (**A**) the WHO-EURO model, (**B**) the Directorate-General of Health model (NPM-PT), and (**C**) the European Commission (EU-Pledge) model.

For total sugars, the WHO-EURO and NPM-PT models have the most restrictive criterion (<15 g/100 g), and consequently, none of the samples of filled cereals (n = 8) and honey/sweet caramel cereals (n = 19) complied with those models. Cornflakes/other plain cereals (n = 19) revealed a compliance rate of 47%. For the EU-Pledge model, the criterion is less restrictive for total sugars (<27 g/100 g) and the compliance rate ranged from 25% for filled cereals to 79% for cornflakes/other single cereals.

For sodium and salt, between 75% and 100% of the cereal types met the criterion for the three models under analysis.

The saturated fatty acids criterion has the most restrictive criterion in the NPM-PT model and the filled cereals type did not comply with the established criterion (≤1.5 g/100 g).

The recommended minimum fiber content of 6 g/100 g, is optional for the WHO-EURO model, and the chocolate-flavored cereals presented the highest percentage of products in this category (38%). For the EU-Pledge model, the minimum fiber content allowed is 3 g/100 g, with the honey/caramel cereals representing the highest percentage of products in this category (90%).

For energy criterion ≤210 kcal/portion (30 g), all types of RTECs complied with the criterion of the EU-Pledge model.

Analyzing the three different models, Table 3 indicates that substantial pairwise agreement was found between the WHO-EURO and the NPM-PT models. A fair agreement between the EU-Pledge and WHO-EURO models was identified. The NPM-PT model showed slight agreement with the EU-Pledge model.

Table 3. Pairwise k values calculated for the three models considered.

	WHO-EURO	NPM-PT
NPM-PT	0.642 ***	-
EU-Pledge	0.217 **	0.114 *

*, slight; ** fair; *** substantial agreement

These results allowed us to use the NPM-PT model as a reference for the reformulation of RTECs identified as not adequate, and two scenarios were considered—the current (not considering reformulation) and the alternative (considering reformulation to accomplish the nutrient profile requirements) scenarios. Table 4 summarizes the main results obtained regarding the estimated intake of the considered nutrients through the consumption of RTECs by the Portuguese children population, considering reformulation or no reformulation.

Table 4. Estimated intake of total sugar, salt, saturated fatty acids (SFA), and dietary fiber through the consumption of RTECs by the Portuguese children population, considering reformulation (estimates considering the children consumption).

	without Reformulation	with Reformulation [a]
	Total Sugar (g/day)	
Mean	17.5 ± 0.7 **	10.0 ± 0.4 **
Median	15.8	9.0
Minimum	0.2	0.2
Maximum	83.2	48.0
	Salt (g/day)	
Mean	0.444 ± 0.019	0.439 ± 0.019
Median	0.408	0.408
Minimum	0.002	0.002
Maximum	2.720	2.720
	SFA (g/day)	
Mean	0.654 ± 0.032	0.597 ± 0.027
Median	0.495	0.458
Minimum	0.018	0.018
Maximum	2.94	2.64
	Fiber (g/day)	
Mean	1.83 ± 0.09 **	2.46 ± 0.1 **
Median	1.38	1.98
Minimum	0.09	0.13
Maximum	8.59	9.60

** $p < 0.001$ for the statistical comparison of RTECs intake, without and with reformulation; [a] Reformulation scenario performed according to the NPM-PT (for total sugar, salt, and SFA) and EU-Pledge (for fiber).

Analyzing the results of the estimations, with and without reformulation, total sugar and fiber are the nutrients where statistically significant differences were observed i.e., the decrease (in the case of total sugar) and increase (in the case of fiber) after reformulation are statistically significant when compared to the current scenario (without reformulation). Salt and SFA did not show statistically significant differences, which was already expected considering their usual contents in these types of products.

4. Discussion

Breakfast cereals are mentioned by several international surveys as having a high variability in their nutritional composition, in particular concerning sugar and salt content [40]. Simultaneously, robust results showed that consumption of RTECs, especially of fiber-rich or whole-grain RTECs, are implicated with several beneficial nutritional and health outcomes. Nevertheless, high total sugar intakes associated with frequent consumption of RTECs are a cause for concern [4].

Data from the present study do not (intentionally) include whole grains and 'hot' cereals, since this study focused on RTECs with non-whole grain cereals (refined cereal flours), where nutritional quality can be improved through product reformulation. This research aims to support industrial companies, nutrition professionals, and policymakers to identify actions associated with the implementation of reformulation strategies for the development of healthier food products to be promoted to children.

This study was one of the first in Portugal that addressed the nutritional composition and the adequacy of the RTECs for children available in the Portuguese supermarket, according to three nutrient profile models designed to restrict food marketing and advertising to children, including the model recently developed for Portugal.

According to the results obtained in the present study, the levels of total sugar in children's RTECs are considerably higher, and 87% of RTECs did not comply with the sugar criterion (<15 g/100 g). Our findings are consistent with a previous study performed in Portugal, showing that 85% of children's RTECs were non-compliant with the sugar criterion and 26% of children's RTECs had more sugar than non-children's (adult's) RTECs [3].

The results of our study suggest that choosing organic children's RTECs will result in a lower intake of total sugars, highlighted by our data, which are in line with the data from Germer et al.'s study [23]. A study published in 2018 focused on gluten-free products aimed at children and reported that gluten-free products contain lower amounts of sodium, total fat, saturated fatty acids, and sugar content, similar to the values of comparable products with gluten [41]. However, according to the present study, the total sugar content was lower and the total protein level was higher, when comparing gluten-free products with gluten counterparts.

Focusing on the type of brand, the higher values for total sugars observed in the in-store brand are in line with the results of the Ikonen et al. study. These authors concluded that despite being "tastier" and consequently presenting a higher consumer demand, these products are nutritionally poorer than other types of cereals [42]. The median fat (3.1 g/100 g) and saturated fatty acids contents observed in our study (1.1 g/100 g) were higher than the results indicated by Tong et al.'s study (1.1 g/100 g and 0.4 g/100 g, respectively) [43]. This discrepancy could be justified by the fact that, in the present study, filled cereals were considered, contrary to the Tong et al.'s study.

The sodium content of children's RTECs found was 230 mg/100 g. Similar results were also reported by Tong et al., revealing a median content of 254 mg/100 g in children's cereals [43]. Chepulis et al., in a cross-sectional analysis, described a median sodium content level of 240 mg/100 g in the UK for the children's breakfast cereal with promotional characters [9].

Our data revealed, on average, that children's breakfast cereals contained 4.9 g of fiber per 100 g. About 78% of ready-to-eat cereals are considered a "source of fiber" (≥3.0 g), but only 27% of ready-to-eat cereals are considered "high in fiber" (≥6.0 g) [28]. Assuming the child consumption of 30 g of breakfast cereals serving, they would ingest 1.5 g of fiber, which represents on average between 9% to 15% of the adequate intake. According to EFSA monitoring studies [35], the adequate intake of total fiber varies between 10 and 16 g/day for children between 3 to 10 years old. The consumption of RTECs represents an important source for dietary fiber intake from a single food category [44]. Fayet-Moore et al. reported that children who consume cereals at breakfast are more likely to meet their recommended intakes of B vitamins (niacin, thiamine, folate), calcium, iron, and fiber [45]. According to van den Boom et al., the consumption of RTECs is associated with a better nutritional profile in the diet of Spanish children, adolescents, and young adults. The breakfast has better quality in terms of food choices as well as energy and nutrient content [46].

Several studies suggest that children with diets consisting of higher amounts of fiber-rich foods generally consume less energy from total fat and saturated fatty acids and more dietary fiber in children's diets might be associated with a lower risk of childhood obesity [32,47].

Comparing the different nutrient profile models used in the present study, we verified that the WHO-EURO is the most restrictive nutrient profile model followed by the NPM-PT. The EU-Pledge is the most tolerant regarding the restrictions to the marketing of foods for children. This was already described in different contexts [38,48].

Bonsmann et al. [48] observed that, from 2691 food products sold in the EU, 48% (EU-Pledge) and 68% (WHO-EURO) do not comply with the EU-Pledge and WHO-EURO nutrient profile criteria, respectively. Maschkowski et al. [24] also observed a lower compliance rate, with only 4–36% of German products meeting the criteria of the different nutrient profiles for cereals marketed to children.

Labonte et al.'s research revealed great variations in the degree of accuracy and agreement between nutrient profile (NP) models with applications in restricting the marketing of low nutritional quality food and beverages for children [49].

Recognizing the obtained results for the compliance of the RTECs available in Portugal with the nutrient profile models, the reformulation of RTECs and the associated impact of this reformulation on health constitutes an important aspect to be properly characterized.

The results from the Muth et al. study showed that reformulating a few categories of foods and beverages to reach the levels of products meeting an existing standard could improve dietary intake, particularly for saturated fatty acids, sugars, and fiber [50].

Trying to explore the potential for the reformulation of the RTECs identified as not adequate, the estimated intake of the nutrients considered in the NPM-PT model, as well as fiber, were estimated. Analyzing the results of the simulations with and without reformulation, we observed a reduction of the total sugar intake from 17 g/day to 10 g/day, representing a reduction of 43% for the total sugar intake from RTECs. Combet et al., who tested the capacity of a multi-nutrient profiling system for product reformulation, found average reductions between 19% and 38% [51].

Food reformulation can be a challenge, especially as nutrients such as sodium, fat, and sugar often play a role in the technological and sensorial functions in these products. Sugar, for example, is used for taste or texture, for preservation, and as a bulking agent, and salt is a preservative that prevents spoilage [52,53].

In Portugal, food products' reformulation was established under co-regulation agreements with the food industry in the framework of the Integrated Strategy for the Promotion of Healthy Eating (EIPAS) [54]. The "Food Industry Co-Regulation Agreement" covers the reformulation of several food products high in salt, sugar, and trans fatty acids, as well as the main dietary sources of these nutrients, for the Portuguese population. The principles of the reformulation include reducing salt content between 12% and 30% and sugar content between 7% and 10% by 2021. The current agreement covers the reformulation of breakfast cereals establishing a reduction target of 10% for salt (sodium) and sugar contents. This will be achieved by setting progressive reduction targets for each food and drink category [55].

Food reformulation strategies based on setting targets for progressive reduction or increase of key nutrients are crucial to avoid consumers switching to another product or changing the amount they consume when, for example, the product's levels of added sugar or salt are changed. The taste and texture of foods after reformulation will also influence consumption at a population level [56–58].

Considering the WHO recommendations for the intake of free sugars per day (<5% Energy) [36], children of 3 to 10 years old should have an upper daily limit of free sugars of 14–23 g [35], respectively. In this study, if we assign 100% of total sugars as added sugar for RTECs [59], and consider that the breakfast meal represents 20% of the energy of children's daily reference values and nutrient intake, the reformulation scenario showed the RTECs representing 44–73% of the daily reference value for free sugars through the consumption of RTECs. The reformulation scenario contributes to a considerable reduction in total daily sugar intake from RTEC, although these still represent a higher contribution to the daily free sugars intake, in particular for young children.

For most lipid components, no reference values are proposed by EFSA [35]. In this case, we decided to follow the nutrient-based standards for planning nutritionally balanced menus developed by Public Health England, which recommend not more than 11% of energy as a reference value for saturated fatty acids [37]. For a 1500 kcal diet, this would be 18 g SFA per day. The reformulation scenario showed that RTECs contributed to 3.3% of the total SFA intake, reflecting a non-significant result to the contribution to SFA intake and diet quality.

On the other hand, for salt intake, children of 3 to 10 years old should have an upper daily limit of salt of 2.75–4.25 g [35], respectively. Our study revealed that salt intake through breakfast cereals consumption ranged between 0.444 g/day for the scenario without reformulation (current formulation of breakfast cereals) to 0.439 g/day for the scenario with reformulation, which represents a reduction of 1.1% in daily salt intake. These results showed that cereals have been produced with lower levels of salt across all of the different cereal categories considered, and this represents a non-significant contribution to salt intake and diet quality of the RTECs. Pombo-Rodrigues et al.'s study also described similar results concerning the sodium or salt levels in RTECs [60].

According to EFSA, the adequate intake for fiber is 10–16 g/day for children between 3 to 10 years old [35]. Considering the reformulation of RTECs, we observed an average increase of 34% in the daily dietary fiber intake. IAN-AF revealed that the mean intake of fiber was 14 g per day for children under 10 years. The present results support the inclusion of dietary fiber in the NPM-PT model, contributing to the improvement of its intake and complying with the recommendations for fiber dietary recommendation intake.

Comparing two typical Portuguese children's breakfast options of RTEC children consumers (250 mL of milk + 30 g portion of RTECs reformulated + 50 g portion of bread) and non-RTEC children consumers (250 mL of milk + 50 g portion of bread) at breakfast, the RTEC consumers have a nutrient intake on average of 23.5 g total sugars, 1.4 g salt, 3.1 g saturated fat, and 4.6 g fiber, representing total sugars as 6.0% of the total energy intake (TEI), salt between 33% and 51%; fiber between 33% and 46%, and saturated fat at 1.9% of the TEI of the daily nutrient intake in children. For non-RTEC children consumers, the breakfast provides a nutrient intake on average of 13.5 g total sugars, 0.97 g salt, 2.4 g SFA, and 2.2 g fiber, representing total sugars with 3.4% of the TEI, salt between 23% and 35%; fiber between 16% and 22%, and saturated fat with 1.4% of the TEI of the daily nutrient intake in children [3,35,37,61]. Compared with non-cereal breakfast consumers, breakfast cereal consumers had higher intakes of dietary fiber and total sugars. This finding is consistent with Fayet-Moore et al.'s study [45].

These results can provide the food industry with an overall picture of RTECs' nutrient daily intake contribution to modify the products to be healthier and more beneficial.

This is the first study applying a national policymaking tool, the NPM-PT model, to classify RTECs as suitable/unsuitable for marketing to children. In this study we assessed the potential of nutrient profiling models to guide food reformulation, contributing to changing the food environment and improving children's nutritional intake. In order to reach its full potential, reformulation should be implemented across the food sector.

Further studies are needed to suppress some drawbacks of this study including the following:

- For some categories of cereals (e.g., gluten-free and organic children's RTECs) the number of samples considered was low (<15); however, the sample reflected the products available in the market.
- The presented results constitute a snapshot of the RTECs available on the market in a particular period.
- The reformulation scenario is a theoretical study; therefore, we did not assess the sensory properties of RTECs after reformulation, and we assumed that children will consume the same amount of reformulated RTECs. Future research should address the issues raised here, including sensory analysis and determining the children's acceptability of these new products.
- This research reflected only RTECs, and upcoming research focusing on other food groups, e.g., fruit-based snacks, bread and bakery products, convenience foods, and yogurts, will allow for a more accurate nutritional profile to be defined for food products marketed to children.
- Access to data on added sugars would help to identify the exact amount of sugar consumed that was added to food during its production.
- Easier access to composition data of high-quality branded food is also needed.

Finally, future research should explore the impact of reformulation of target nutrients on health outcomes and quality of life measures i.e., quality-adjusted life years (QALYs) and disability-adjusted life years (DALYs).

5. Conclusions

Although nutrient profiling does not address all aspects of nutrition, diet, or health, it is a helpful tool to use in conjunction with interventions aimed at improving diets. It can also be used in implementing the recommendations on the marketing of foods to children.

From our study, 87% of RTECs had a sugar content >15 g/100 g, responsible for the highest percentage of non-compliance in the evaluation by the various nutrient profile models.

Considering the used models, NPM-PT provides very similar results to the WHO nutrient profile model in terms of its purpose, enabling a good level of agreement.

As demonstrated in the current study, the process of reformulation of RTECs, namely, to reduce salt and sugar contents, is recommend and should not compromise their global nutritional profile. It is important to define feasible reduction targets without having to replace them with other ingredients, such as sugar by sweeteners. Additionally, it is necessary to define a gradual reduction to achieve the adaptation by the consumer to products with a lower amount of salt and sugar.

To summarize, this study provides the food industry with a general picture of children RTECs' nutritional profiles, mainly focusing on reducing sugars and salt and increasing fiber, offering healthier products.

Author Contributions: M.S.: conceptualization and study design, data collection, data analysis, and writing. F.M.: data collection, data analysis, and feedback on the paper. A.I.R.: data analysis and feedback on the paper. I.C.: data analysis and feedback on the paper. D.T.: data analysis and feedback on the paper I.L.: data analysis and feedback on the paper. R.A.: conceptualization, methodology, data analysis, and writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: The authors appreciate the financial support of AHFES project (EAPA_1071_2018AHFES). This project was co-funded by the European Regional Development Fund through the Atlantic Area Program. Ricardo Assunção thanks FCT/MCTES for the financial support to CESAM (UIDP/50017/2020+UIDB/50017/2020) through national funds, and the FCT Individual CEEC 2018 Assistant Researcher Grant CEECIND/01570/2018. The IAN-AF 2015–2016 was supported by funding received from the EEA Grants Program, Public Health Initiatives (PT06-000088SI3).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: This manuscript was developed under the scope of WHO Collaborating Center on Nutrition and Childhood Obesity—National Institute of Health Ricardo Jorge.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Characteristics of the three nutrient profile models considered in this study.

Models	Purpose	Food Categories	Type of Model	Classification Criteria	Breakfast Cereal Category		
					Nutrients to Limit	Nutrients to Encourage	Nutritional Criteria
Directorate-General of Health (NPM-PT) model [21]	Defining better options in the context of marketing food and beverage to children ≥36 months and <16 years.	20	Threshold	Food category specific	Total sugars, salt, and saturated fatty acids	none	Total sugars: ≤ 15 g/100 g [(1),(2)] Salt: ≤1.0 g/100 g [(3)] Saturated fatty acids: ≤1.5 g/100 g [(4)]
WHO-EURO model [19]	Defining better options in the context of marketing food and beverage to children ≥36 months and <16 years.	17	Threshold	Food category specific	Total sugars, salt, and total fat	Fiber [(5)]	Total sugars: ≤15 g/100 g [(1),(2)] Salt: ≤1.6 g/100 g Total fat: ≤10 g/100 g Fiber: >6 g/100 g [(5)]
European Commission (EU-Pledge) model [20]	Defining better options in the context of advertising food and beverage to European children under the age of 12 years old on TV, print, and the internet.	9	Threshold	Food category specific	Energy, total sugars, sodium, and saturated fatty acids	Fiber	Energy: ≤210 kcal/portion (30 g) [(6)] Total sugars: ≤27 g/100 g [(7)] Sodium: ≤450 mg/100 g Saturated fatty acids: ≤5 g/100 g Fiber: ≥3 g/100 g

[(1)] The WHO-EURO and the NPM-PT models consider the same criterion for total sugars (<15 g/100 g), representing approximately 25% of the reference intake per 100 g needed to be identified as "high sugar content" product [21]. [(2)] Total sugars refers to the total sugar content of the food product, which may be composed of: intrinsic sugars incorporated within the structure of intact fruit and vegetables; sugars from milk (lactose and galactose); and all additional monosaccharides and disaccharides added to foods by the manufacturer, cook, or consumer, plus sugars naturally present in honey, syrups, and fruit juices [19]. [(3)] For the salt content, the criterion of 1 g (instead of 1.6 g) was established, as this was the target set in the agreement with the food industry and distribution for the reformulation of this food category [21]. [(4)] For the category breakfast cereals, considering the impossibility to set a value for the total fat content, the limit for the content of saturated fatty acids was added according to the value of the claim "low saturated fat"—1.5 g, as defined in Regulation (EC) No 1924/2006 [28]. [(5)] For this category, countries may choose to include a limit for the minimum fiber; the WHO proposes the minimum value of >6 g dietary fiber. [(6)] The reference unit for the energy is established per portion (kcal/portion). For breakfast cereals, the portion ranges from 30 g to 45 g, although in our study, only the results for 30 g were considered. [(7)] For total sugars, the considered criterion was 27 g/100 g, a value that corresponds to <11% of the children's reference value (based on 85 g sugar/day).

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6. Nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score* and consistency with nutritional recommendations

Chapter 6 consists of a manuscript based on the application of NP models, in the area of food labelling that aimed to assess the nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score* algorithm and to investigate the consistency with the food-based dietary guidelines. The manuscript was submitted to the *Journal of Food Composition and Analysis* on 10 November 2021 and is currently under review.

Manuscript 3

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Title: "Nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score* and consistency with nutritional recommendations" (Manuscript number JFCA-D-21-01823).

6.1 Abstract

In the last few years, public health authorities have shown interest in introducing front-of-pack labelling (FOPL) as one of the main policies to combat diet-related non-communicable diseases (NCDs). *Nutri-Score* is a FOPL that can discriminate the nutritional quality of foods, obtaining a score mostly in line with nutritional recommendations.

This study aimed to assess the nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score* and to investigate the consistency with the food-based dietary guidelines.

The applicability of *Nutri-score* was assessed by applying it to 165 food products and beverages that were considered under the PT-total dietary study (PT-TDS).

At least three categories of the *Nutri-Score* were observed for 75% (n=124) of food products and for similar food products a minimum of two categories were identified. The food classification according to the *Nutri-Score* was consistent with the nutritional recommendations. Food groups in which consumption is encouraged were more favourably classified than those in which consumption should be limited (i.e., Vegetables and Pastries were classified as A (93.0%) and E (57.1%), respectively).

Appropriate food labelling with a system such as *Nutri-Score* can be relevant to health-promoting purchasing choices, improving diet quality and consequently public health.

Keywords: Front-of-package labelling (FOPL); Food-based dietary guidelines; *Nutri-Score*; Portugal

Highlights

- *Nutri-Score* helps consumers to rank foods by nutritional quality.
- Distribution within the *Nutri-Score* categories showed a good performance within main food groups.
- Three categories at least were observed for 75% (n=124) of food products under analysis.
- Food classification was consistent with the Portuguese food-based dietary guidelines.

6.2 Introduction

Dietary risk factors are leading contributors to the global burden of disease, responsible for an estimated 11 million deaths from non-communicable diseases (NCDs) (22% of all adult deaths) and 15% of disability life years (DALYs) lost in 2017, with cardiovascular diseases, diabetes and cancer, leading contributors to dietary-related deaths (GBD 2017 Diet Collaborators, 2019).

In order to tackle the growing burden of nutrition-related NCDs, public health authorities have developed strategies and have introduced policies focused on nutrition, which is one of the key modifiable determinants of chronic disease development (World Health Organization, 2013).

In recent years, there has been an increasing interest by public authorities in the implementation of front-of-package nutrition labelling (FOPL) as one of the key policies to fight NCDs (World Health Organization, 2017). FOPL empowers consumers to make informed, healthy and sustainable food choices.

The European Commission in its new ''Farm to Fork' strategy", launched in May 2020, proposes the development of a mandatory harmonised FOPL system by the end of 2022 (European Union, 2020). Additionally, in the European region, FOPL is also recommended by the World Health Organization (WHO) European Food and Nutrition Action Plan 2015-2020, reflecting the importance to support consumers' choices, promoting in some cases the reformulation of products, and thereby promoting healthier diets (World Health Organization (WHO), 2015).

In this context, in the last five years, several countries have been developing new types of FOPL schemes (Kelly and Jewell, 2018) including nutrient-specific schemes, providing more or less detailed nutritional information on specific nutrients, and 'summary indicator' schemes that rather provide a synthetic appreciation of the product's overall nutritional quality/healthfulness (Kanter et al., 2018; Savoie et al., 2013; World Health Organization, 2020).

Some FOPL currently in use in and outside Europe are Keyhole, Choices logo, Reference Intakes, NutrInform Battery, United Kingdon Multiple Traffic Lights (UK MTL), *Nutri-score*, Health Star Rating and Warning signs.

The Keyhole logo and the Choices logo are forms of expression of nutrition information that consists in attributing a 'positive logo' (also referred to as 'health logo' or 'endorsement logo') to foods with favourable nutrient profiles compared to same-category alternatives (Choices International Foundation, 2016; Larsson et al., 1999).

The Reference Intakes label, developed by members of the European food and drink industry is in use throughout Europe, provides numerical information on the amount of energy and the nutrients present in a portion of a food and how much this represents as a percentage of the daily reference intake ("Food and Drink Federation. GDAs explained.," 2014). The NutrInform Battery is a voluntary front-of-package scheme based on the Reference Intakes label with an added battery symbol indicating the amounts of energy and nutrients in a single serving as a percentage of the daily intake. The scheme is not yet present on the European Union market ("Made in Italy: Notificato alla Commissione Ue il Sistema di Etichettatura 'NutrInform Battery,'" n.d.).

The UK MTL scheme is a colour-coded nutrient-based scheme developed by the UK Food Standards Agency (FSA). This system hybridises the Reference Intakes scheme information with traffic-light colours. A Portuguese retailer also uses this scheme (Food Standards Agency, 2007).

A different approach to FOPL consists in attributing an overall rating for a product's nutritional quality/healthfulness. An overall rating can be expressed by various means. For example, the *Nutri-Score*, a scheme developed under the aegis of the French Ministry of Health and implemented in France in 2017 (Chantal, J., & Hercberg, 2017), then in Belgium, Spain, Germany, the Netherlands, Switzerland and Luxembourg between 2018 and 2020 (European Commission, 2020). Is an algorithm based on nutritional criteria, validated scientifically, which categorizes food products into 5 categories (expressed by a colour and a letter). Each colour is associated with a letter from A (dark green) to E (dark orange) to make the labelling more accessible and understandable to consumers (Chantal, J., & Hercberg, 2017; Julia et al., 2014). Nutri - Score is based on a modified version of the British Food Standards Agency's Nutrient Profiling System (FSAm-NPS), which was originally developed for the UK media regulator to regulate television advertising aimed at children (Rayner et al., 2009).

The Health Star Rating (HSR) is a monochrome type of graded rating system used in Australia and New Zealand. HSR is a voluntary front-of-pack labelling system that rates the overall nutritional profile of packaged food and assigns it a rating from ½ a star to 5 stars. It provides a quick and easy standard way to compare similar packaged foods, and the more stars, the healthier the choice (Australian Government Department of Health, 2018).

Some countries outside Europe require front-of-package warning signs for foods containing high amounts of energy or nutrients for limit, such as saturated fat, sugars, or salt. Nutrient-specific warning signs are mandatory labels that do not express the overall nutritional value of a food or repeat the numerical information from the nutrition declaration. Warning labels work by helping consumers identify unhealthy products and discouraging them from consuming these products (S Storcksdieck genannt Bonsmann, G Marandola, E Ciriolo, R van Bavel, 2020).

In Portugal, despite no single/unique FOPL has been yet officially adopted, several FOPL models are being used in food packages that are commercialized by different operators in the food industry (Feteira-Santos et al., 2021). The current situation would be difficult for the consumers to understand and consequently negatively affect the probability to select the healthiest product. According to the WHO report on FOPL, 40% of Portuguese consumers did not understand the nutritional information on food labels, and for consumers with a low level of education, this percentage was around 60% (Gomes et al., 2017).

Recently, an Health Impact Assessment on nutrition labelling conducted in Portugal, appraised the impact of the adoption of a single FOPL, and which FOPL would be the most appropriate to promote healthy food choices and mitigate inequalities. The results of this study showed that although traffic light nutrition labelling appears to be the model that best enables Portuguese consumers to make healthy food choices, the results obtained for the other FOPL models (e.g. *Nutri-Score*, Guideline daily amounts, Health StarRating) suggest that all of them have the potential to contribute to healthier food choices (Graça et al. 2019; Graça et al., 2020).

Various studies have shown that the algorithm underlying *Nutri-Score* can discriminate the nutritional quality of foods, obtaining a score mostly in line with nutritional recommendations (Dréano-Trécant et al., 2020; Julia et al., 2015). Furthermore, *Nutri-Score*, when compared to other nutrition labelling models, was found to be the most effective in terms of encouraging consumers to make healthier food choices and simultaneously helping to assess the nutritional quality of products (Egnell et al., 2019; Hercberg et al., 2021).

Several European countries are considering the implementation of the *Nutri-Score*, however, some concerns have been expressed especially for the validation, which was mainly conducted in the French context, and consequently, the algorithm may not reflect the food-based dietary guidelines from other countries (Julia et al., 2015; van Tongeren and Jansen, 2020).

In this context, the main aims of this study were 1) to investigate the nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score*, and 2) to investigate the consistency of these foods with the Portuguese food-based dietary guidelines, as a contribution to the validation of this FOPL in the Portuguese context.

6.3 Materials and Methods

6.3.1. Food selection

The applicability of *Nutri-Score* was assessed by applying it to different groups and subgroups of food products that were included under the PT-total dietary study (PT-TDS).

The European Food Safety Authority and the WHO consider total dietary studies (TDS) as an important public health tool for the assessment of dietary exposure to contaminants and beneficial substances (nutrients) through food (European Food Safety Authority, Food and Agriculture Organization of the United Nations, 2011). The TDS approach is recognized as a cost-effective method of assessing dietary exposure, including for nutrients, especially if preparation (culinary treatments) are taken. (European Food Safety Authority, Food and Agriculture Organization of the United Nations, 2011; Vin et al., 2014). Through the combination of food intake data with analytical data from food products collected following the methodologies of the TDS, it was possible to evaluate the nutrient intake of a population (Dofkova et al., 2016).

The study considered the selection, collection and analysis of representative foods from the Portuguese diet, grouping the prepared foods into representative food groups and processing the foods as for consumption, taking into consideration the PT-TDS data.

The selection of foods was based on food consumption data from the Portuguese Population’s Food Habits and Lifestyles study conducted by the Portuguese Society of Food and Nutrition Sciences. The design of one 24-h recall was used and data were collected for 3529 individuals from all regions of the country, including the islands, both sexes and ages 18–93 years (Poínhos et al., 2009). A food list was established based on the foods as consumed, that contributed to at least 90% of the total consumption.

Each food product is a composite sample, which is prepared by pooling the same amount of 12 prepared subsamples, reflecting its importance regarding consumption. Thus, the results for each product subgroup were obtained from representative composite samples. Seasonality was also considered for the food groups vegetables, fruits, starchy roots and fish.

After the selection of foods, a PT-TDS food list with 169 TDS food products coded with the respective FoodEx2 codes and names was established, based on the weight of food as consumed (Dofkova et al., 2016; Vasco et al., 2021). It is also important to remark that food products were selected to generate a representative collection from the most frequently consumed foods in Portugal. The 'Additives, flavours, baking and processing aids' and 'Food products for young population' were not included as the consumption was very low by the adult and elderly populations. Also, Products for non-standard diets, food imitates and food supplements or fortifying agents (n=2) and Alcoholic beverages (n=2), were excluded as they were out of the scope of *Nutri-Score* (Julia et al., 2014; Partearroyo et al., 2019). Overall, a total of 165 food products and beverages were considered under this study.

6.3.2. Food Classification and Composition Data

Nutritional analyses of the 165 food products were carried out in compliance with the ISO/IEC 17025 standard (ISO, 2017) and according to the methods of analysis (AOAC (Association of Official Analytical Chemists), 2000; EN, 2017) described in Table 1.

Table 1 List of analytical methods used for nutritional composition analysis of PT-TDS food products.

Component	Method	Reference
Protein (total nitrogen × 6.25)	Kjeldahl	AOAC method 991.20
Total fat	Acid hydrolysis with extraction	AOAC method 948.15
Fatty acids (includes saturates, mono-unsaturates, polyunsaturates)	Gas chromatography-flame ionization detection (GC-FID)	AOAC method 996.06.
Total dietary fibre	Enzymatic–gravimetric	AOAC method 985.29
Total sugars (includes monosaccharides and disaccharides)	Munson–Walker	AOAC method 950.50; AOAC method 906.03; AOAC method, 945.2
Sodium (Na) (covert to salt = sodium × 2.5)	Inductively coupled plasma optical emission spectrometer (ICP-OES)	EN 16943:2017

The results obtained through the laboratory nutritional analysis were compiled in a database that integrates the following elements: Food Classification and Food Composition.

6.3.2.1. Food Classification

Under the present study, foods were categorized into 16 food groups (level 1): "Grains and grain-based products"; "Vegetables and vegetable products"; "Starchy roots or tubers and products thereof, sugar plants"; "Legumes, nuts and oilseeds"; "Fruits and fruits products"; "Meat and meat products"; "Fish, seafood, amphibians, reptiles and invertebrates"; "Milk and dairy products"; "Eggs and egg products"; "Sugar, confectionery and water-based sweet desserts"; "Animal and vegetable fats and oils"; "Fruit and vegetable juices and nectars"; "Water and water-based beverages"; "Coffee, cocoa, tea and infusions"; "Composite dishes" and "Seasoning, sauces and condiments". Each food group was split into 77 lower-level subgroups (FoodEx2 system of classification level 3).

6.3.2.2. Food Composition data

The analyses were performed according to established analytical method criteria in terms of precision and accuracy, limit of quantification (LoQ), selectivity, and an effective internal and external quality control programme, including appropriate use of Certified Reference Materials (CRMs) and participation in appropriate Proficiency Test schemes (PTs) launched by accredited PTs providers such as FAPAS.

For each food product analysed the following data was computed in the database: total energy (kJ), total protein (g), total carbohydrates (g), total sugars (g), total fat (g), saturated fatty acids (g), total dietary fibre (g) and sodium (mg).

6.3.3. FSAm-NPS score computation

Nutri-Score is based on a modified version of the British Food Standards Agency's Nutrient Profiling System (FSAm-NPS). The original FSAm-NPS was developed in the UK by the Office of Communication (Ofcom) to categorize foods and drinks as 'healthier' and 'less healthy' to regulate television food advertising to children (Rayner et al., 2009).

The FSAm-NPS score included adaptations to the established cut-offs to allow for more than two categories reflecting nutritional quality. In line with the French National Nutrition and Health Program and the French High Council for Public Health, other modifications included the scoring criteria for cheese, added fats and beverages (Santé Publique France, 2021).

The *Nutri-Score* FOPL scheme was applied, assigning points based on the nutritional composition per 100 g or 100 ml of the product (beverages). Positive points were attributed to the amounts in elements that should be limited, including energy (kJ), total sugars (g), SFA (g), and sodium (mg) (0 to 10 positive points for each). Negative points were attributed to the amount of elements that should be promoted, including protein (g) and dietary fibre (g), percentage of fruits, vegetables, legumes, nuts (FVLN %), walnut, rapeseed and olive oils) (0 to 5 negative points for each). The FVLN % was estimated for each product, according to the methodology described by Vergeer et al (Vergeer et al., 2020). The total score of the product was calculated by subtracting the “positive” (nutrients to limit) points from the “negative” (nutrients to encourage) points. Thus, the final FSAm-NPS score for each food/beverage was based on a scale that could range from - 15 (most healthy) level, to +40 (least healthy) (Chantal, J., & Hercberg, 2017).

All the calculations were performed with the Microsoft Office® software.

6.3.4 Consistency of *Nutri-Score* with national dietary guidelines

In the context of FOPL harmonization in Europe, this study intended to investigate the nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score* and consistency with nutritional recommendations. Food groups whose consumption is encouraged by recommendations should be classified primarily as of higher nutritional quality by *Nutri-Score* ('A' or 'B'), whereas groups whose consumption has to be limited should be classified primarily as lower nutritional quality ('D' or 'E').

The consistency of food classification using *Nutri-Score* with the Portuguese food-based dietary guidelines was assessed by comparing the distribution of foods in the different *Nutri-Score* categories, with the recommended consumption frequency of the group (FAO, 2019). The Portuguese dietary guidelines established by the Food wheel for Food groups and other important categories are described in Supplemental Methods 1.

6.3.5 Statistical analyses

Statistical analysis was performed using the Statistical Package for Social Sciences software (IBM SPSS Statistics, Version 26.0, IBM corp., Chicago, IL, USA).

Double-entry tables were analysed to study the frequencies of the categorisation obtained by the *Nutri-Score* of the groups and subgroups. The ability of the system to discriminate the different nutrient profiles of foods and beverages was assessed by the number of available colours in each food group and for similar food products in the same subgroups as a discriminant performance indicator. When three or more colours were available in a food group, the performance of *Nutri-Score* was considered good, as described in previous studies (Dréano-Trécant et al., 2020; Julia et al., 2015; Szabo de Edelenyi et al., 2019). For similar food products in the same subgroups, the presence of two colours was considered a satisfactory discriminant performance.

6.4. Results and Discussion

Overall, a final food list including 165 food products and beverages was used, 21 grain and grain-based products; 42 fresh or processed Vegetables and vegetable products, Starchy roots or tubers, Legumes, nuts, oilseeds and spices and Fruits and fruits products; 41 Meat and meat products, eggs and fish, seafood, amphibians, reptiles and invertebrates; 35 composite dishes; 6 milk and dairy products; 2 fats or oils; 5 seasoning, sauces and condiments; 4 Sugar, confectionery and water-based sweet desserts and powder cocoa and derivatives and 9 beverages (Fruit and vegetable juices and nectars, Water and water-based beverages, Coffee, cocoa, tea and infusions).

Food products from the food group Coffee, Cocoa, Tea and Infusions were assessed as beverages for coffee, tea and infusions and as general food for powder cocoa and derivatives.

Each food product is a composite sample, which is prepared by pooling the same amount of 12 prepared subsamples. Thus, the results for each product subgroup were obtained from representative composite samples.

The distribution of the different *Nutri-Score* categories among each main food group is shown in Tables 2 and 3. The variability in the FSAm-NPS scores with each food group and beverages was illustrated via boxplots of the distribution (Figures 1 and 2).

Table 2 Distribution (n, %) of the different *Nutri-Score* categories among each main food group (beverages are not included).

Food group (FoodEx2 level 1)	**A (Min- -1))**	**B (0-2)**	**C (3-10)**	**D (11-18)**	**E (19-Max)**	**N**	**Score (median) P25; P75**
Grains and grain-based products	**2 (9.5%)**	**2 (9.5%)**	**3 (14.3%)**	**12 (57.1%)**	**2 (9.5%)**	**21**	**14.0 (5.50;15.5)**
Vegetables and vegetable products	**19 (100%)**	**0(0%)**	**0(0%)**	**0(0%)**	**0(0%)**	**19**	**-6.00 (-8.00;-5.00)**
Starchy roots or tubers and products thereof, sugar plants	**1 (100%)**	**0(0%)**	**0(0%)**	**0(0%)**	**0(0%)**	**1**	**-6.00***
Legumes, nuts, oilseeds and spices	**6 (75.0%)**	**0(0%)**	**2 (25.0%)**	**0(0%)**	**0(0%)**	**8**	**-9.00 (-11.0;2.00)**
Fruits and fruits products	**11 (79.0%)**	**2 (14.0%)**	**1 (7.1%)**	**0(0%)**	**0(0%)**	**14**	**-4.00 (-4.00;-1.25)**
Meat and meat products	**0(0%)**	**3 (27.3 %)**	**3 (27.3%)**	**5 (45.4%)**	**0(0%)**	**11**	**5.00 (2.00;12.0)**

Fish, seafood, amphibians, reptiles and invertebrates	**5 (17.2%)**	**12 (41.4%)**	**9 (31.1%)**	**3 (10.3%)**	**0(0%)**	**29**	**2.00 (0.00;4.00)**
Milk and dairy products	**2 (33.3%)**	**0(0%)**	**3 (50.0%)**	**1 (16.6%)**	**0(0%)**	**6**	**1.00 (-1.25;8.50)**
Eggs and egg products	**1(100%)**	**0(0%)**	**0(0%)**	**0(0%)**	**0(0%)**	**1**	**-1.00***
Sugar, confectionery and water-based sweet desserts	**0(0%)**	**1(33.3%)**	**0(0%)**	**1(33.3%)**	**1(33.3%)**	**3**	**14.0 (7.50;18.0)**
Animal and vegetable fats and oils	**0(0%)**	**0(0%)**	**1(50.0%)**	**0(0%)**	**1(50.0%)**	**2**	**16.0 (7.00;25.0)**
Coffee, cocoa, tea and infusions	**0(0%)**	**1 (100%)**	**0(0%)**	**0(0%)**	**0(0%)**	**1**	**0.00***
Composite dishes	**12 (34.3%)**	**18 (51.4%)**	**5 (14.3%)**	**0(0%)**	**0(0%)**	**35**	**0.00 (-2.00;2.00)**
Seasoning, sauces and condiments	**0(0%)**	**1 (20.0%)**	**1 (20.0%)**	**3 (60.0%)**	**0(0%)**	**5**	**11.0 (3.5;12.5)**
Total	**59 (37.8%)**	**40 (25.6%)**	**28 (17.9%)**	**25 (16.0%)**	**4 (2.6%)**	**156**	**-**

* For product groups with one composite sample, the result of the score is present as the mean value of the replicate analyses; N is the total number of *Nutri-Score* classes among the Food group

Table 3 Distribution (n, %) of the different *Nutri-Score* categories among beverages

Food group (FoodEx2 level 1)	**A (Water)**	**B (Min-1)**	**C (2-5)**	**D (6-9)**	**E (10-Max)**	**N**	**Score (median) P25;P75**
Fruit and vegetable juices and nectars	**0(0%)**	**0(0%)**	**0(0%)**	**0(0%)**	**2 (100%)**	**2**	**13.0 (12.0;14.0)**
Water and water-based beverages	**1 (25.0%)**	**0(0%)**	**0(0%)**	**1 (25.0%)**	**2 (50.0%)**	**4**	**8.50 (-1.50;11.0)**
Coffee, cocoa, tea and infusions	**0(0%)**	**3 (100%)**	**0(0%)**	**0(0%)**	**0(0%)**	**3**	**1.00 (1.00;1.00)**
Total	**1 (11.1%)**	**3 (33.3%)**	**0 (0%)**	**1 (11.1%)**	**4 (44.4%)**	**9**	**-**

N is the total number of *Nutri-Score* classes among the Food group

The distribution of *Nutri-Score* among the foods analysed (beverages excluded) revealed, 37.8% (n=59) of the foods were classified in category A, 25.6% (n=40) of the foods that were classified in category B, 17.9% (n=28) of the foods were classified in category C, 16.0% (n=25) of the foods were classified in the category D and 2.6% (n=4) of the foods were classified in the category E.

A total of 93.0% of products from fruits and fruit products, 100% Vegetables and vegetable products, 100% Starchy roots or tubers and 75.0% of Legumes, nuts and oilseeds were classified as dark green (A) or green (B).

Among the Grains and grain-based products, only 19.0% were classified as dark green (A) or green (B) while 66.6% of the products were classified as orange (D) or dark orange (E).

The food group "Meat and meat products" was mainly classified between green (B) and orange (D). For the food fish, seafood, amphibians, reptiles and invertebrates, a total of 58.6% of products were categorized between dark green (A) or green (B).

The composite dishes showed a distribution of *Nutri-Score* between dark green (A) and yellow (C).

For the sugar, confectionery and water-based sweet desserts, 66.6% of the products were classified as orange (D) or dark orange (E). The milk and dairy products showed an 83.3% distribution of *Nutri-Score* between dark green (A) and yellow (C).

In the food group Animal and vegetable fats and oils, olive oil obtained the classification yellow (Category C). The FSA scoring algorithm was optimised to better take into account the content of saturated fatty acids, which is more consistent with the evidence obtained from several epidemiological and experimental studies that thoroughly support the beneficial health effects of olive oil (Gómez-Donoso et al., 2021; Guasch-Ferré et al., 2020, 2014; Ministère des solidarités et de la santé, 2017).

The variability in the FSAm-NPS scores was the widest for grain and grain products; meat and meat products; sugar, confectionery and water-based sweet desserts and seasoning, sauces and condiments (Figure1).

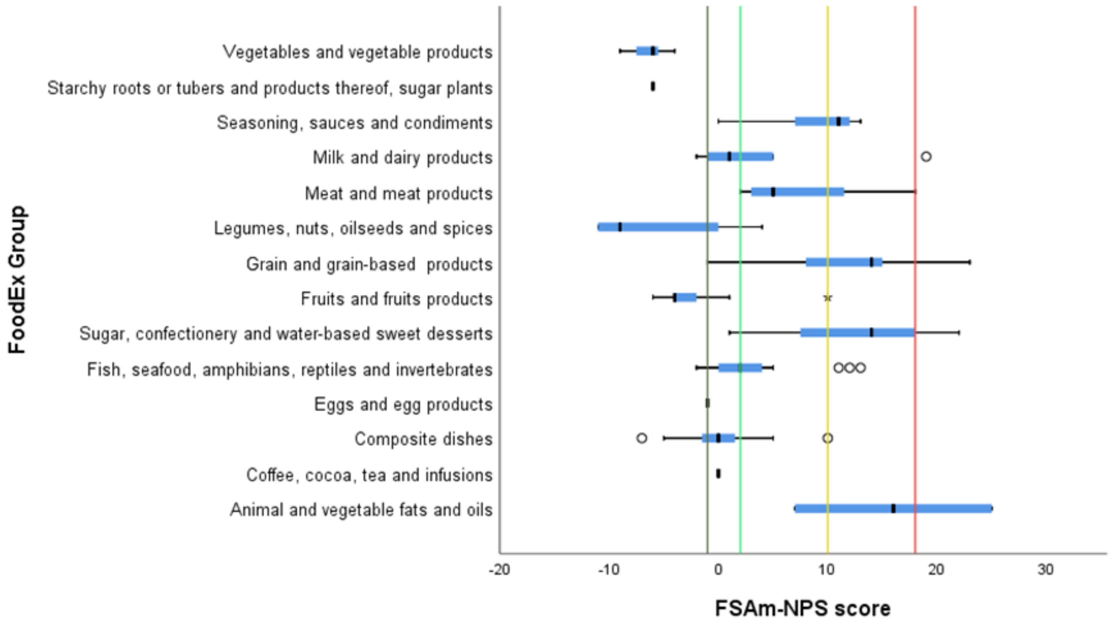

Figure 1. Boxplot of the FSAm-NPS score across the categories of the food products (exclude beverages). The boundary of the box nearest to the right indicates the 25th percentile, the line within the box marks the median, and the boundary of the box furthest from the right indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the lower limit (25th percentile -1.5 (interquartile range)) and the upper limit (75th percentile + 1.5 (interquartile range)). The circles are individual outlier points.

For beverages categories, water was classified as healthier (A) and coffee, tea and herbal infusion were categorized as green (B). Fruit juices, fruit nectars and soft drinks were categorized as orange (D) or dark orange (E) (Table 3).

Table 4 Distribution of the food products analysed across the different *Nutri-Score* categories considered in the study.

Food group and Product group (FoodEx2 level 1 and level 3)	***Nutri-Score* Categories**				
Grains and grain-based products	**A**	**B**	**C**	**D**	**E**
Shortcrust pastry	-	-	-	Fruit; milk and chocolate pies	-
Leavened bread and similar	Corn bread	Bread	-	-	-
Yeast leavened pastry	-	-	Milk bread	-	Croissants
Cakes	-	-	Leavened cakes	Muffins; Cream puffs; Chocolate and other diverse cakes	-
Biscuits and crackers	-	-	-	Salt crackers; Biscuits and crackers	Chocolate Biscuits
Breakfast cereals	-	-	Cereals and Chocolate cereals	-	-
Pasta and similar products	Pasta	-		-	-
Cereal grains and cereal-like grains	-	Rice	-	Popcorns	-
Vegetables and vegetable products	**A**	**B**	**C**	**D**	**E**
Solanacea	Tomato[(*)] Pepper[(*)]	-	-	-	-
Turnips and similar	Turnip greens [(*)]	-	-	-	-
Sweet corn and similar	Corn	-	-	-	-
Cucurbits fruiting vegetables	Melon[(*)] Cantaloupe[(*)]; Watermelon [(*)]	-	-	-	-
Broccoli sprouts	Sprouts [(*)]	-	-	-	-
Beans (with pods) and similar	String beans [(*)]	-	-	-	-
Asparagus and similar	Asparagus	-	-	-	-
Head brassica	Portuguese cabbage; Brussels sprouts; white cabbage	-	-	-	-
Cauliflowers and similar	Cauliflower [(*)]	-	-	-	-
Fungi	Mushroom	-	-	-	-
Carrots and similar	Carrot [(*)]	-	-	-	-

Onions and similar	Onion (*)	-	-	-	-
Broccoli and similar	Broccoli (*)	-	-	-	-
Lettuces and salad plants	Lettuce (*)	-	-	-	-
Starchy roots or tubers and products thereof, sugar plants	**A**	**B**	**C**	**D**	**E**
Potatoes and similar	Boiled potato(*)	-	-	-	-
Legumes, nuts, oilseeds and spices	**A**	**B**	**C**	**D**	**E**
Pulses (dried legume seeds)	Bean; Chickpea; Black-eyed beans	-	-	-	-
Legumes fresh seeds	Broad beans; Peas; Lupines	-	-	-	-
Oilseeds	-	-	Peanuts	-	-
Oil fruits	-	-	Olives	-	-
Fruits and fruits products	**A**	**B**	**C**	**D**	**E**
Berries and small fruits:	Grapes* Strawberries	-	-	-	-
Miscellaneous fruits *	Fruits salad	-	-	-	-
Miscellaneous fruits with inedible peel, small	Kiwi	-	-	-	-
Canned or jarred fruits	Canned fruits	-	-	-	-
Stones fruits	Peach	-	-	-	-
Jams of fruits and vegetable spreads and similar	-	-	Marmalade	-	-
Pomme fruits *	Apple*; Pear	-	-	-	-
Citrus fruits *	Orange	-	-	-	-
Dried fruits		Dry fig*; Raisins	-	-	-
Miscellaneous fruits with inedible peel, large:	Pineapple; Banana		-	-	-
Meat and meat products	**A**	**B**	**C**	**D**	**E**
Mammals	-	Bovine fresh meat; Rabbit fresh meat	Calf fresh meat; Swine fresh meat	Sheep fresh meat	-
Generic poultry	-	Chicken fresh meat	Turkey fresh meat	-	-
Cooked cured (or seasoned) meat	-	-	-	Ham	-

Raw cured (or seasoned) meat	-	-	-	Smoked ham and Bacon	-
Preserved or partly preserved sausages	-	-	-	Frankfurter type sausages; Charcuteries	-
Fish, seafood, amphibians, reptiles and invertebrates	**A**	**B**	**C**	**D**	**E**
Marine fish	Ling; Conger European; Other pelagic marine fishes (*Physycis physics*, Forkbeard, rosefish, redfish); Other marine fish (Wrasse, *Trisopterus luscus*, Red porgy, Red seabream,)	Flounder; Sea bream; Hake; Gilthead bream; Mackerel; Horse mackerel; Fresh tuna;	Seabass; Swordfish; Snapper; Cod, atlantic (Fresh cod)	European Sardine (*)	-
Diadromous fish	-	-	Salmon	-	-
Freshwater fish	Nile perch		Catfish	-	-
Squids, cuttlefishes, octopuses	-	Octopus, common	Squid, common	-	-
Mussels	-	Mussels	-	-	-
Bivalves (Clams, cockles, arkshells)	-	-	-	Bivalve molluscs (*Donax variabilis*, Clam)	-
Crustaceans	-	Marine Shrimps or prawns cooked	-	-	-
Terrestrial invertebrates	-	-	-	Snails	-
Processed or preserved fish:	-	Canned sardine; Cod, dried	Fish fingers, breaded; Canned tuna;	-	-
Milk and dairy products	**A**	**B**	**C**	**D**	**E**
Milk	Milk (partly skimmed milk, skim milk)	-	Flavoured milks	-	-
Fermented milk products:	Fermented probiotic milk-like drinks	-	Yoghurts (natural, flavoured, fruit and cereals)	-	-
Firm-ripened cheese	-	-		Flemish cheese	-
Dairy desserts	-	-	Dairy desserts	-	-
Eggs and egg products	**A**	**B**	**C**	**D**	**E**
Whole eggs	Eggs (cooked)	-	-	-	-
Sugar, confectionery and water-based sweet desserts	**A**	**B**	**C**	**D**	**E**
Sugars				Common sugar	

Chocolate and chocolate products					Chocolate dessert
Water-based desserts spoonable	-	Gelatine	-	-	-
Animal and vegetable fats and oils	**A**	**B**	**C**	**D**	**E**
Vegetable fats and oils, edible	-	-	Olive oil	-	-
	-	-		-	Butter (with salt)
Fruit and vegetable juices and nectars	**A**	**B**	**C**	**D**	**E**
	-	-	-	-	Fruit juices
	-	-	-	-	Fruit nectars
Water and water-based beverages	**A**	**B**	**C**	**D**	**E**
Soft drinks:	-	-	-	Soft drink with tea extracts	Soft drink with fruit juice; Cola soft drinks
Bottled water:	Natural mineral water	-	-	-	-
Coffee, cocoa, tea and infusions	**A**	**B**	**C**	**D**	**E**
	-	Powder cocoa and derivatives	-	-	-
	-	Coffee and coffee with milk)	-	-	-
	-	Tea beverages	-	-	-
	-	Herbal and other non-tea infusions	-	-	-
Composite dishes	**A**	**B**	**C**	**D**	**E**
Soups (dry mixture uncooked): diverse vegetables, legumes, chicken, fish or seafood soups	Legume's soup (Legume beans soup)	Tomato soup; Vegetable's soup (Mixed vegetable soup, with puree or pieces); Cabbage soup (Mixed vegetables soup); Chicken soup (Meat soup, with pieces)	Seafood cream and fish soup	-	-
Prepared mixed egg/meat/fish/vegetable salad dishes: Russian salad; salad with legumes and fish	Salad with legumes and fish	Russian salad	-	-	-

Mixed vegetable salad: salad of lettuce and tomato	Salad of lettuce and tomato	-	-	-	-
Dishes excluding pasta or rice dishes, sandwiches and pizza	Chickpea, pasta and various meats; Smashed potato; Beans, meat, and vegetables meal; Fish pie; Tripe (Beans and meat meal); Diverse dishes with meat (Meat-based dishes Bolognese); Stews; Brás and Gomes de Sá style cod (Fish and potatoes meal)	Omelet; Meat pie; Portuguese stew (Beans, meat, and vegetables meal); Meatballs; Bread and breadcrumbs dish; Cod with cream and boiled cod with potatoes, chickpeas and an olive-oil	Sandwich with fillet steak, ham and smoked sausage covered with cheese and a spicy sauce; Hamburger's	-	-
Sandwiches; pizza and other stuffed bread-like cereal products	Meat and vegetables quiches	-	-	Pizzas; Snacks (Finger food)	-
Pasta and rice (or other cereal)-based dishes	-	Seafood rice; Vegetables rice; Poultry rice (Rice and meat meal); Fish rice; Valencian rice (Rice based dishes cooked); Meat and vegetarian lasagne	-	-	-
Sushi with fish and seaweed	-	Sushi with fish and seaweed	-	-	-
Seasoning, sauces and condiments	**A**	**B**	**C**	**D**	**E**
Stock cubes or granulate (bouillon base)	-	-	Meat broths	-	-
	-	Vinegar	-	-	-
Savoury sauces	-	-	-	Ketchup; Mayonnaise; Various sauces	-

(*) Seasonal sample (sampling was conducted in the 4 seasons to account for seasonal variation)

The variability in the FSAm-NPS scores was much narrowed for beverages, with the category water and water-based beverages having the widest range of variability due to soft drinks with tea extracts and soft drinks with fruit juice (Figure 2).

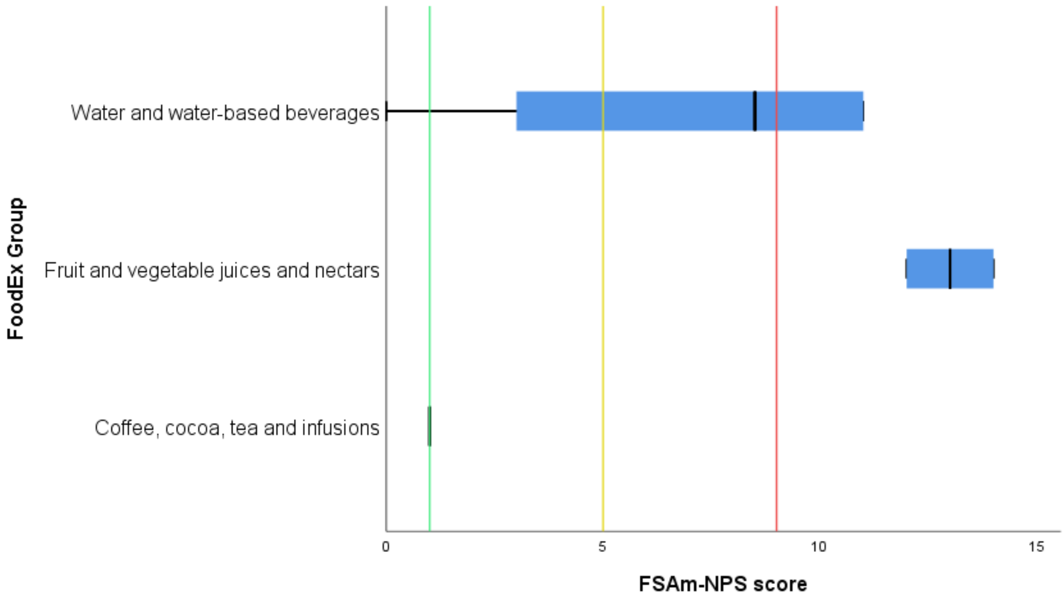

Figure 2. Boxplot of the FSAm-NPS score across the categories of beverages. The boundary of the box nearest to the right indicates the 25th percentile, the line within the box marks the median, and the boundary of the box furthest from the right indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the lower limit (25th percentile -1.5 (interquartile range)) and the upper limit (75th percentile + 1.5 (interquartile range)).

The overall distribution of the food products analysed across the different *Nutri-Score* categories among each main food group is shown in Table 4. In the 16 food groups under study, at least three categories of the *Nutri-Score* were observed for 75.0% (n=124) of food products under analysis.

In the group's Vegetables and vegetable products and Fruits and fruits products, 97.0% (n=32) of the products were represented by the categories dark green (A) or green (B).

The food group Grains and grain-based products include foods such as bread, cornbread and breakfast cereals. It also includes foods such as spaghetti and other pasta, as well as grain-based products, such as fine bakery (Biscuits, cakes, Shortcrust pastry). The fine bakery represents 54.0% (n=12) of the dark orange (E) category.

The food groups Legumes, nuts and oilseeds and Eggs and egg products, 75.0% (n=6) and 100% (n=1) of the products were represented by the category dark green (A), respectively.

For the food groups Meat and meat products and Fish, seafood, amphibians, reptiles and invertebrates, the highest number of products was classified as light orange (category D) and yellow (category C), respectively.

For similar food products in the same subgroups, at least two colours (two categories) were identified: the subgroup cakes (muffins; cream puffs; leavened, chocolate and other diverse cakes) is distributed between C and D category; the subgroup Marine fish (flounder; sardine; seabass; hake; fresh cod; ling; diverse marine fish) in distributed in four colours from 'Green' to 'Orange'; the subgroup Milk (milk; flavoured milk) is distributed between A and C category. Among Water and water-based beverages, all waters were in category A, while the soft drinks were classified in category C (25.0%) and E (50.0%).

The Grains and grain-based products and Fish, seafood, amphibians, reptiles and invertebrates food groups showed a wide distribution (4 or 5 *Nutri-Score* categories represented in the food subgroups), which highlighted the large variability in prepared products in terms of nutritional quality, for which the *Nutri-Score* is a very useful tool to identify healthier options.

The categories where *Nutri-Score* was not able to discriminate between products (only 1 or 2 categories) were homogeneous food groups (e.g., Legumes, nuts, oilseeds and spices; Fruits and fruits products) and food groups with a small number of products (e.g., Starchy roots or tubers and products thereof, sugar plants; Eggs and egg products).

In addition, the classification with the *Nutri-Score* allowed discrimination between manufactured and raw foods. For example the category "Grains and grain-based products" "Breakfast cereals" and "Cookies and crackers" which are considered highly processed foods were classified between categories C and E; pasta and rice were identified in categories A and B.

Assessing the consistency of food classification using the *Nutri-Score* with the Portuguese food-based dietary guidelines revealed that food groups whose consumption is encouraged on a daily basis were more favourably classified, i.e. Vegetables and vegetable products 100% were classified A, Legumes, nuts, oilseeds and spices 75.0% were classified A, Fruits and fruits products 93% were classified A and B, milk and milk products 33.3% were classified A and Fish, seafood, amphibians, reptiles and invertebrates, 58.6% were classified A. Foods for which consumption should be limited were classified as D, 45.4% of processed and red meats and 57.1% of pastries or classified as E, 100% of Fruit and vegetable juices and nectars. These results are illustrated in figure 3. To illustrate these results pie-charts with the distribution of the *Nutri-Score* within five food categories) are shown in Figure 3.

Figure 3. Pie-charts with the distribution of the *Nutri-Score* within seven food categories.

These results represent a key step in the discriminatory ability of *Nutri-Score* as a nutrient profiling system to classify foods adequately and following Portuguese food-based dietary guidelines (FAO, 2019).

The *Nutri-Score* was consistent with the National Programme for the Promotion of Healthy Eating Portugal (PNPAS) and with the Integrated Strategy for the Promotion of Healthy Eating (EIPAS), aiming to improve the nutritional status of the Portuguese population as well as to encourage healthier food consumption habits (Diário da República. 2.a série – N.° 249 – 29 de dezembro de 2017: Despacho n.° 11418/2017., 2017; Diário da República 2.a série – N.° 10 – 13 de janeiro de 2012: Despacho No 404/2012, 2012).

The PNPAS and EIPAS intend to promote cross-sectoral actions that encourage the consumption of foods of good nutritional quality; modify the supply of certain foods, particularly those with high sugar, high salt and high-fat content; to promote the consumption of food categories directly related to the prevention of chronic disease, namely fresh fruit and vegetables, across the population; to encourage actions of nutritional reformulation of food products through an articulated action with the food industry (Diário da República. 2.a série – N.° 249 – 29 de dezembro de 2017: Despacho n.° 11418/2017., 2017).

Among more favourable foods are foods with low salt content (i.e. as not containing more than 0.3 g of salt per 100 g or 100 mL) and food with low sugar content (i.e. as not containing more than 5 g of sugar per 100 g for solid foods or 2.5 g of sugar per 100 mL) (National Health Service England, 2019). The *Nutri-Score* classified these food products as A or B. Also, Fruits and fruits products, 79.0% and Vegetables and vegetable products 100 % were classified A.

In the present study, the distribution of foods within the *Nutri-Score* categories showed a good performance of the FOPL to discriminate the nutritional quality of products within main food groups and subgroups, and across relevant food groups.

Similar results were previously reported by Hafner and Pravst study, which observed *Nutri-Score* had a high ability to discriminate food products based on nutritional composition and was aligned with Slovenian nutritional recommendations. Products that are encouraged in the dietary recommendations (fruits, vegetables, cereals) were graded A or B, while less desirable categories, such as confectioneries and snack foods, were mostly graded D or E (Hafner and Pravst, 2021).

Gómez-Donoso et al., in their study also found that the classification of foods in accordance with the nutrient profiling system underlying the *Nutri-Score* was consistent with the Mediterranean and national dietary recommendations. The higher the FSAm-NPS Dietary Index (DI), the lower the adherence to the Spanish Mediterranean Dietary Index (Gómez-Donoso et al., 2021).

Our results are likewise consistent with other research using the European Food Information Resource (EUROFIR) nutritional composition databases. Dréano-Trécant et al. analysed the applicability of the *Nutri-Score* using data from generic food composition tables for eight European countries, which have highlighted a high discriminating ability for all food groups, with similar trends in the eight countries, and the food classification by *Nutri-Score* was generally consistent with public health nutritional recommendations. The majority of products containing mainly fruit and vegetables are classified in A or B, while the majority of sweet and salted snacking products, sauces and animal fats are classified in D or E.

Consistency was also confirmed within specific food groups, i.e. in Grain or grain products, pulses, pasta and rice are overall ranked higher than breakfast cereals; in milk and dairy products, milk and yoghurt are ranked lower than cheese. Composite dishes are widely distributed, highlighting the variability of products in this particular category. Finally, beverages, while most fruit juices are rated C, soft drinks are rated E and only water is A (Dréano-Trécant et al., 2020).

The present study showed that the *Nutri-Score* based on the FSAm-NPS profile had a good performance to discriminate the nutritional quality of products across and within food groups and product groups, with at least three classes of *Nutri-Score* represented. The discriminating ability of the *Nutri-Score* is particularly important to help consumers to rank food products by nutritional quality (Aguenaou et al., 2021; Egnell et al., 2020b, 2020a). Furthermore, the results of our specific study in the Portuguese context showed good consistency between the *Nutri-Score* classification concerning the national dietary recommendations, in line with previous studies that have been conducted (Hafner and Pravst, 2021; Julia et al., 2015; Szabo de Edelenyi et al., 2019).

According to Goiana-da-Silva et al, it is safe to assume that *Nutri-Score* would be an adequate FOP labelling system to be considered and endorsed by Portugal (Goiana-da-Silva et al., 2019).

Although the PT-TDS study was primarily designed to assess exposure to contaminant residues, we used this public health tool approach since it is possible to assess dietary exposure not only to contaminants but also to beneficial substances (nutrients) (Santé Publique France, 2021). We aimed to assess the discrimination capacity of the *Nutri-Score* and to assess the consistency of the *Nutri-Score* classification with the dietary guidelines as previously performed (Dréano-Trécant et al., 2020; Gómez-Donoso et al., 2021; Hafner and Pravst, 2021; Szabo de Edelenyi et al., 2019).

Future research before selecting a FOPL will be needed to investigate the consumer's ability to understand and use various schemes, as this ability is an essential step for a label to be effective in influencing food purchase and consumption.

Our study provides evidence of the relevant application of *Nutri-Score* and its adaptability to the Portuguese context.

6.5. Conclusions

There is currently a global public debate on the need to introduce simplified nutritional labelling on food, as part of a wider policy approach to improve human diets. FOPL is a public health measure that can represent significant advantages for literacy and population health. However, these tools will have a sub-optimal impact if they are not linked to policy changes that address the causes of poor diet quality in the social determinants of health.

In this study, the distribution of food products within the *Nutri-Score* categories showed a good performance of the FOPL to discriminate the nutritional quality of products within main food groups and across relevant product groups, with consistency with food-based dietary guidelines. The discriminating ability of the *Nutri-Score* is particularly important to help consumers to rank food products by nutritional quality.

As the graphical format of the *Nutri-Score* suggests the results of our study contribute to validate the choice of this FOPL model in the Portuguese context, contributing to promote healthier food choices for Portuguese consumers.

Appropriate food labelling with a system such as *Nutri-Score* can be relevant to health-promoting purchasing choices, improving diet quality and consequently public health.

Author agreement statement

The authors whose names are listed immediately below certify that the undersigned declare that the manuscript title "Nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score* and consistency with nutritional recommendations" is original, has not been published before and is not currently being considered for publication elsewhere. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We understand that the Corresponding Author is the sole contact for the Editorial process. He/she is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

Declaration of Competing Interest

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Acknowledgements

This work has been funded by the National Health Institute Doutor Ricardo Jorge, I.P., under the project 'Incentivo aos Estudos de Dieta Total' (Reference number 2016DAN1260). Elsa Vasco and M. Graça Dias previous work (unpublished) contributed to this study, and they were responsible for the sampling plan, collection and treatment of food products, which we thank.

This manuscript was developed under the scope of the WHO Collaborating Center on Nutrition and Childhood Obesity—National Health Institute Dr. Ricardo Jorge.

Ricardo Assunção thanks FCT/MCTES for the financial support to CESAM (UIDP/50017/2020 + UIDB/50017/2020), through national funds.

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6.7. Supplementary material

Table S1. Portuguese dietary guidelines were established by the Food wheel for Food groups and other important categories.

Food group	Frequency of Consumption	Weight of each Serving
Starchy Foods	4–11 servings/day	1 loaf of bread = 50 g; 1 thin slice of corn bread = 70 g; 1 and 1/2 potato (medium size = 125 g); 5 tablespoons of breakfast cereal = 35 g; 6 biscuits = 35 g; 2 tablespoons of uncooked rice/pasta = 35 g; 4 tablespoons of cooked rice/pasta = 110 g
Vegetables	3–5 servings/day	2 cups of raw vegetables = 180 g/day; 1 cup of cooked vegetables = 140 g/day
Legumes	1–2 servings/day	1 tablespoon of dried raw legumes (chickpeas, beans, lentils) = 25 g; 3 tablespoons of fresh raw legumes (peas, beans) = 80 g; 3 tablespoons of cooked/ fresh legumes = 80 g
Fruits	3–5 servings/day	1 piece of fruit; medium size = 160 g
Meat, Fish and Eggs	1.5–4.5 servings/day 1 egg/day	raw meat/fish = 30 g; cooked meat/fish = 25 g); 1 egg (medium size) = 55 g
Dairy products	2–3 servings/day	1 cup of milk = 250 mL; 1 liquid yogurt or 1 and 1/2 solid yogurt = 200 g; 2 thin slices of cheese = 40 g; 1/4 of fresh cheese (medium size) = 50 g; 1/2 curd (medium size) = 100 g
Animal and vegetable fats and oils	1–3 servings/day	1 tablespoon of olive oil/oil = 10 g; 1 teaspoon of lard = 10 g; 4 tablespoons of cream = 30 mL; 1 tablespoon of butter/margarine = 15 g
Water	1.5-2 L/day (at least 8 glasses of water/day)	1 glass = 200 ml
Salt	< 5g/day	-
Sugar and sugar products	The consumption of this type of food should be consumed preferably at the end of the meals, and its consumption should be eaten less often and in smaller amounts.	-

7. Commercial baby foods aimed at children up to 36 months: are they a matter of concern?

Chapter 7 consists of a study that aimed to assess the application of the NPM proposed by the WHO Regional Office for Europe to identify which CACFs are appropriate/inappropriate for promotion to IYC up to 36 months of age and what is the degree of processing, as defined by the NOVA classification system. This research intended to support policymakers in their efforts to implement and operationalize an NP model to restrict the inappropriate promotion of foods for IYC.

A summary of this work was submitted as a manuscript to the Journal *Foods*.

Manuscript 4

Article published in the Journal Foods

Santos, M.; Matias, F.;Loureiro, I.; Rito, A.I.; Castanheira, I.;Bento, A.; Assunção, R. Commercial Baby Foods Aimed at Children up to 36 Months: Are They a Matter of Concern? Foods 2022, 11, 1424. https://doi.org/10.3390/foods11101424

7.1. Abstract

Proper nutrition in infancy and early childhood is key to ensuring optimal child growth and development and better health outcomes later in life. The nutrient profile model proposed by WHO Regional Office for Europe aims to assess the nutritional quality and promotional/marketing aspects of commercial foods for infants and young children aged 6–36 months.

We used commercial data of nine food categories collected between March 2021 and July 2021, from eight supermarket chains in the Lisbon Metropolitan area (n = 191). We assessed the nutritional quality and promotion aspects according to the model specifications and the degree of processing, using the NOVA classification system.

In total, 34.0% of the products contained at least one sugar-contributing ingredient; 13.9% of products listed sugars and 15.0% listed fruit juices or concentrates as an ingredient. Claim 'No added sugar' was present in 69.6% of products; Only 35.1% of products comply with all the nutritional requirements of the model. Concerning processing classification, 61.8% of products were ultra-processed and about 57.0% were indicated for children <12 months. These findings reinforce the importance of implementing measures to ensure that commercial foods for infants are marketed appropriately and to promote foods with a lower degree of processing.

Highlights

- Nutrient Profile Model to assess commercial foods for infants from 6-36 months of age
- Several categories of commercial foods for infants from 6-36 months of age were high in total sugar content
- Sugar/fruit juice or concentrates was the most common sugar-contributing ingredient
- Over 50% of CACFs, were classified as ultra-processed and were indicated for children <12 months

Keywords: Nutrient profile model; Commercially available complementary foods; Sugars; Ultra-processed foods; Infants and young children;

7.2 Introduction

Good nutrition in infancy is vital for normal growth and development, helps the establishment of taste preferences and may have implications for health throughout life (Scaglioni et al., 2018). Food preferences begin to take shape during fetal development and continue to change throughout life, influenced by biological, social and environmental factors (Mennella, 2006). These preferences are key determinants of food choice, and therefore diet quality.

The promotion of exclusive breastfeeding for six months is the gold standard for infant feeding and a global public health recommendation (World Health Organization (WHO), 2002). From 6 months of age, infants should receive safe and nutritionally adequate complementary foods, solid, semi-solid and soft, while breastfeeding continues until 2 years of age or older (World Health Organization & United Nations Children's Fund (UNICEF)., 2003). However, the role of these products in appropriate complementary feeding has been widely debated, driven by concerns regarding their nutritional content and potentially problematic marketing strategies used to promote these products (Maslin and Venter, 2017).

In 2016, the WHO guidance on ending the inappropriate promotion of foods for infants and young children (IYC) was approved, to support countries to take action on this issue (World Health Organization (WHO), 2017, 2016). To implement this Guidance, a Nutrient Profile Model (NPM) for commercially available complementary foods (CACFs) for infants under the age of 36 months was developed to drive the decisions regarding the identification of foods that are inappropriate for promotion, particularly reducing the intake of free sugars and salt (WHO Regional Office for Europe, 2019a).

Currently the European Commission Directive 2006/125/EC does not have provisions on total sugar but sets out the amount of added sugar such as sucrose, fructose, syrups and honey allowed in processed cereal-based foods, however, it was not possible to determine the amount of these or the total added (or free) sugar in products as this is not included on the packaging information (European Commission, 2006).

Children's diets are generally characterised by low fruit and vegetable consumption and an excess of products high in sugar, saturated fat and sodium (UNICEF, 2019). In particular, sugar consumption among children has raised concern worldwide, as it exceeds the recommended.

The WHO recommends reducing the intake of free sugars to less than 10 % of total energy intake as a ‘strong recommendation’, along with a ‘conditional recommendation’ to further reduce free sugars to below 5 % (World Health Organization (WHO), 2015).

Published data shows that this recommendation is not met in most countries, for example in several European countries, total sugars ranged between 15 and 21% of energy intake in adults and between 16 and 26% in children (Azaïs-Braesco et al., 2017). Added sugars contributed 7 to 11% of total energy intake in adults and represented a higher proportion of children’s energy intake (11 to 17%) (Azaïs-Braesco et al., 2017). In Portugal, the National Food, Nutrition and Physical Activity Survey reported that IYC (<5 years) had the highest energy contribution from total sugars (28%) (Marinho et al., 2020). In addition, evidence is growing that some CACFs for infants (also referred to as baby foods) contain considerable high amounts of sugar (Da Rocha et al., 2021; Garcia et al., 2016; Grammatikaki et al., 2021; Hutchinson et al., 2020; McCann et al., 2021).

The introduction of complementary food in the first two years of life represents a window of opportunity for infants to establish long-term healthy dietary patterns (Spaniol et al., 2021), however recent studies have found that ultra-processed (UP) foods make up an increasing proportion of children's diets. About 30% of daily energy intake is from UP foods in the Belgian population, and young children consume the largest proportion of their daily energy intake from UP foods (Vandevijvere et al., 2019). Other studies, such as those from the US and Canada also found that UP foods represent more than 50% of the daily energy intake (Moubarac et al., 2017; Neri et al., 2019).

Despite the fact that food processing plays a critical role in achieving food and nutrition security (Augustin et al., 2016), UP foods are usually high in added sugar, trans-fat, sodium, and refined starch and low in fiber, protein, vitamins, and minerals (Moubarac et al., 2017). The consumption of UP foods during childhood has also been linked to obesity and cardiometabolic risk factors in children and adults (Askari et al., 2020; Costa et al., 2018) as well as an increased risk of cardiovascular disease, stroke and overall higher mortality risk among adults (Schnabel et al., 2019; Srour et al., 2019).

According to Sadler et al. literature review, there are a great number of food classification systems based on food processing. Most of the classification systems are proposed by expressing concerns about the food transition to industrially-made products and an associated increase in chronic disease (Sadler et al., 2021).

Monteiro et al. developed the NOVA classification system that has been extensively applied in studies of food availability, diet quality, and health outcomes, particularly obesity (Monteiro et al., 2017). This system classifies foods and food products into four categories according to the degree of processing, including unprocessed and minimally processed foods (e.g. fresh fruit and vegetables), processed culinary ingredients (e.g. sugar and honey), processed foods (e.g. fruits in sirup and vegetables in brine) and UP foods (e.g. pizza and instant noodles) (Monteiro et al., 2019).

Several studies have evaluated the consumption of UP foods in paediatric populations (Khandpur et al., 2020; Spaniol et al., 2021), however, there is still limited research on the evaluation of CACFs marketed for IYC under 36 months, according to the NOVA classification system (De Araújo et al., 2021; Grammatikaki et al., 2021; McCann et al., 2021).

The present study aims to assess the nutritional quality and promotion (labelling requirements, visual information on labels and type of statements) of products marketed for IYC under 36 months available on the Portuguese market, taking the following aspects into account:

1) compliance with the expected nutritional profile suitable for children, according to the criteria of the Nutrient Profile Model (NPM), developed by the WHO Regional Office for Europe, for commercially available complementary foods for infants and young children under 36 months;

2) degree of processing, as defined by the NOVA classification.

7.3. Materials and Methods

7.3.1. Data collection

This study used a cross-sectional design and a convenience sample of 191 products targeted to infants under 36 months of age (CACFs), collected between March 2021 and July 2021, from eight supermarket chains in the Lisbon Metropolitan area, which holds almost 80% of the market share in Portugal. Following the method of a previously published study (Hutchinson et al., 2020), nutritional and packaging information and information about the ingredient list from the products, in-store or the supermarkets' websites were collected and photographed.

A Microsoft Excel template was created for recording the different variables studied, including information on basic information (brand name, product name, product category), packaging information (recommended age, serving size, nutrition-related messages, composition claims and health claims), nutritional content (total energy (kJ/kcal), protein (g), carbohydrates (g), total sugars (g), fat (g), saturated fatty acids (g), and sodium (mg)) and visual information (e.g. cartoons, pictures of infants/young children). All the nutritional values have been expressed per 100 g product.

7.3.2. Products categorization

CACFs were categorised based on the proposed NPM classification developed by the WHO Regional Office for Europe, (WHO Regional Office for Europe, 2019a) and presented in Figure 1.

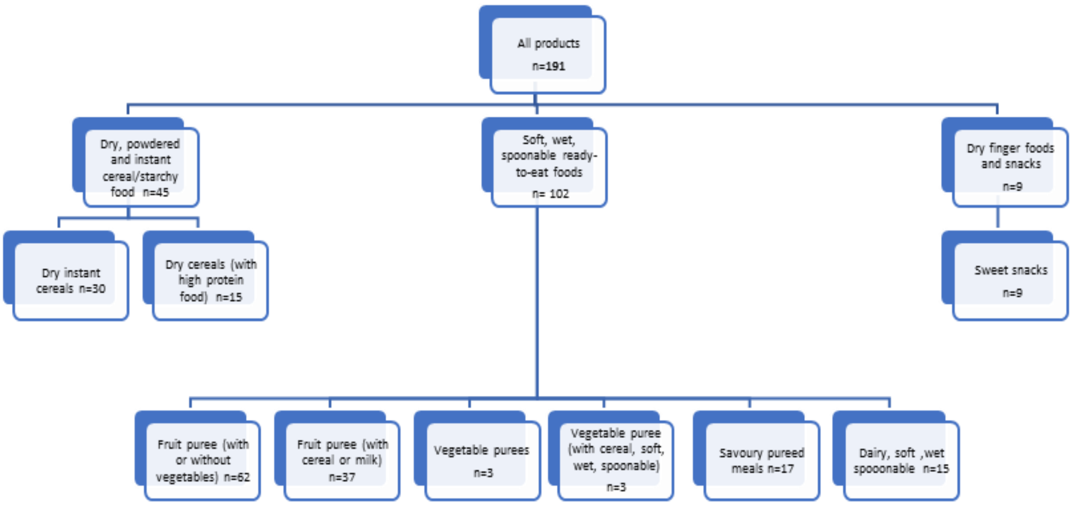


Figure 1. Sampling and Product categorization according to the WHO Regional Office for Europe (WHO Regional Office for Europe, 2019a).

All the CACFs were also classified according to their processing level, as minimally processed (MP), processed or UP based on the NOVA classification system (Monteiro et al., 2019) using the photographs of the ingredients list, Foods whose ingredients list only presented unprocessed foods such as fruit and vegetables were classified as minimally processed. Products with culinary ingredients such as salt, sugar and fats were classified as processed, while when the ingredient list contained additives, whose function was to enhance flavour, colour or texture, such as flavourings, colourants and emulsifiers, the food product was classified as UP. Our analysis was based solely on the listed ingredients, however for the classification of UP products the use of industrial techniques such as extrusion, hydrogenation and carbohydrate modifications, such as maltodextrin, was also taken into account (Da Rocha et al., 2021; Grammatikaki et al., 2021). Information on the coded variables, product category and definitions are provided in Supplementary material (Tables S1 and S2).

7.3.3. Nutritional composition and labelling requirements evaluation

Nutrient composition, labelling requirements and promotional restrictions were evaluated according to the proposed criteria of NPM for CACFs to identify products appropriate for promotion for IYC up to 36 months (WHO Regional Office for Europe, 2019a), as detailed in Supplementary material (Table S3).

Results for energy, protein, total sugars, total fat, saturated fat and sodium are presented on a g (or mg) per 100 g. The energy density results are shown on a kcal per 100 g basis. In addition, the nutrient values in g per 100 kcal were calculated, to enable valid comparisons between dry products that have to be reconstituted with water or milk before consumption and ready-to-eat products.

The presence of added sugars was identified from the back-of-pack ingredient list. For the present study, added sugar was classed as fruit juice whether whole, concentrated or powdered (except lime, lemon or equivalent citrus juice used in small amounts as a preservative); sugar; sucrose; dextrose; fructose; maltose; any syrup; honey; barley malt/malted barley/malt extract; molasses; and artificial or natural zero/low-calorie sweeteners, in line with the WHO definition of free sugar (World Health Organization (WHO), 2015). This definition extends the European Food Safety Authority (EFSA) definition of added sugars (EFSA Panel on Dietetic Products; Nutrition and Allergies., 2010) by additionally including fruit juice (and derivatives) and honey.

7.3.4. Classification of CACFs into target age groups

CACFs were classified into four groups, based on the minimum recommended age specified on the food label. Group 1- foods recommended for infants from 4 or older, Group 2 (6 months or older), Group 3 (8 months or older) and Group 4 (12 months or older).

7.3.5. Data Analysis

Data were analyzed by using the Statistical Package for Social Sciences software and included frequency distribution, descriptive statistics, and correlation (IBM SPSS Statistics, Version 28.0, IBM corp., Chicago, IL, USA) ("IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp," n.d.).

Descriptive statistics were used to report the proportion of CACFs in each food category, food processing (NOVA classification), age and claims messages.

Tests for normality on the nutritional values of foods were performed with the Kolmogorov-Smirnov test and confirmed that data were not normally distributed; therefore, non-parametric testing was undertaken.

The categorical variables were presented as relative and absolute frequencies. Median, standard deviation (SD), P_{25}, P_{50} values for nutritional information were calculated from the labels. Pearson's chi-square test ($\chi2$ test) was used to evaluate the associations between two variables (for example, between the food categories, nutrition/composition claims). Kruskal–Wallis non-parametric test with multiple pairwise comparisons was performed to test for differences in levels of nutrients between food categories and food processing (NOVA classification). The Bonferroni correction was applied. A result was considered statistically significant if the p-value was less than 0.05 and highly statistically significant for an observed p-value of less than 0.01. Results are shown in tables and box plot diagrams.

7.4. Results and Discussion

7.4.1. General Characteristics

Table 1 provides information on the number of products by categories for data collected, respectively.

Of the 191 CACFs identified in this study, a total of 137 (71.7%) were classified as Soft, wet spoonable ready-to-eat foods, 45 (23.6%) were classified as Dry, powdered and instant cereal/starchy food and 9 (4.7%) were classified as Dry finger foods and snacks. The most abundant categories of CACFs were Fruit purée (with or without vegetables) (n=62, 32.5%), Fruit purée with cereal or milk (n=37, 19.4%) and Dry instant cereals (n=30, 15.7%).

The majority (n = 177, 92.7%) of all CACFs were recommended for children less than 12 months of age [Groups 1–3]. As shown in Table 1, 12.6% of CACFs were meant to be consumed by Group 1 [4 to <6 months] children, 61.3% for group 2 [6 to <8 months] children, 18.8% for group 3 [8 to <12 months] children and 7.3% for Group 4 [≥ 12 months] children.

Table 1 Distribution of CACFs according to food category, processing level (NOVA), and age group.

Characteristic	Sub-category or classification	Number (n)	Percentage (%)
Product/Food category:	Dry, powdered and instant cereal/starchy food		
	Dry instant cereals	30	15.7
	Dry cereals (with an added high protein food - powder milk or whey)	15	7.9
	Soft, wet, spoonable ready-to-eat foods		
	Fruit purée (with or without vegetables)	62	32.5
	Fruit purée with cereal or milk	37	19.4
	Vegetable purées	3	1.6
	Vegetables purée with cereal, soft, wet spoonable	3	1.6
	Savoury puréed meals	17	8.9
	Dairy, soft, wet spoonable;	15	7.9
	Dry finger foods and snacks		
	Sweet snacks	9	4.7
Processing level (NOVA)	Minimally processed	70	36.6
	Processed	3	1.6
	Ultra-processed	118	61.8
Age group (months)	Group 1 (4 to <6)	24	12.6
	Group 2 (6 to <8)	117	61.3
	Group 3 (8 to <12)	36	18.8
	Group 4 (≥ 12)	14	7.3

7.4.2. Nutrient composition

A description of the nutrient composition of the CACFs is provided in Table 2.

Table 2. Median (25th–75th percentile) nutrition information per 100 g for commercially available complementary foods by food category.

	Dry, powdered and instant cereal/starchy food		Soft, wet, spoonable ready-to-eat foods						Dry finger foods and snacks	
	Dry instant cereals	Dry cereals (with high protein food)	Fruit purée (with or without vegetables);	Fruit purée with cereal or milk	Vegetable purée	Vegetables with cereal, soft, wet spoonable	Savoury puréed meals	Dairy, soft, wet spoonable	Sweet snacks	*p**
Energy (kJ)	1651 (1617-1696)	1739 (398-1781)	243 (220-274)	271 (244-305)	105 (81.0-†)	223 (195-†)	254 (236-296)	339 (276-383)	1810 (1787-1903)	<0.001
SD	57	624	41	49	47	38	39	50	60	
Protein (g)	10.0 (7.9—12.0)	13.6 (2.9-16.5)	0.4 (0.3-0.7)	0.7 (0.4-1.0)	0.8 (0.3-†)	1.3 (0.7-†)	2.7 (2.4-2.9)	3.0 (2.7-3.1)	8.7 (6.7-9.7)	<0.001
SD	3.8	5.8	0.2	0.7	0.3	0.8	0.4	0.5	2.8	
Total fat (g)	2.3 (1.8-4.6)	9.5 (3.0-11.0)	0.2 (0.1-0.2)	0.3 (0.2-1.0)	0.3 (0.2-†)	1.1 (1.0-†)	1.8 (1.7-2.2)	2.8 (2.3-3.2)	10.0 (8.6-13.5)	<0.001
SD	2.8	3.9	0.2	1.4	0.7	0.7	0.4	0.6	2.4	
Saturated fatty acids (g)	0.5 (0.3-1.5)	1.8 (1.3-2.5)	0.0 (0.0-0.6)	0.0 (0.0-0.3)	0.0 (0.0-†)	0.1 (0.0-†)	0.4 (0.3-0.6)	1.5 (1.3-2.0)	1.3 (1.3-3.3)	<0.001
SD	1.2	1.3	0.2	0.7	0.2	0.4	0.2	0.4	1.9	
Carbohydrate (g)	76.7 (75.0-82.0)	63.0 (14.0-66.4)	12.9 (11.3-14.1)	13.0 (12.0-15.0)	4.1 (3.5-†)	8.0 (8.0-†)	7.60 (6.6-9.3)	11.5 (8.8-12.2)	76.0 (75.0-76.0)	<0.001
SD	7.3	24.8	2.3	1.9	1.2	0.3	1.6	2.3	1.9	
Total sugars (g)	20.0 (1.5-26.2)	27.2(8.0-31.1)	11.0 (9.1-12.1)	10.7 (9.6-12.0)	1.5 (1.3-†)	2.9 (2.0-†)	1.3 (1.2-2.4)	7.2 (5.0-8.1)	12.0 (2.8-24.0)	<0.001
SD	12.7	10.7	2.2	1.7	0.5	0.7	0.9	2.0	11.0	
Sodium (mg)	16.0 (4.0-45.0)	80.0 (36.0-108)	4.00 (2.0-16.0)	4.00 (0.0-16.5)	28.0 (25.2-†)	16.0 (12.0-†)	32.0 (20.0-78.0)	36.0 (30.0-52.0)	32.0 (8.0-80.0)	<0.001
SD	54.0	49.9	14.4	11.6	17.0	8.3	40.0	14.7	68.9	

SD- standard deviation;* p-value obtained with Kruskal-Wallis test for independent samples with multiple pairwise comparisons (food categories);† Not calculated

Assessment of the nutrition information per 100 g for Dry, powdered and instant cereal/starchy food and Dry finger foods and snacks showed significantly higher values for energy, protein, carbohydrate and total sugar ($p < 0.001$), while Dry instant cereals, Fruit purée (with or without vegetables), Fruit purée with cereal or milk and Vegetables with cereal, soft, wet spoonable presented significantly lower values for sodium ($p < 0.001$). The lower medium energy content was found in vegetable purée (105 kJ/100 g) and vegetables with cereals or milk products (223 kJ/100 g) and the highest content was found in Sweet snacks (1810 kJ/100 g). Dry cereals (with an added high protein food - powder milk or whey), Dairy, soft, wet spoonable and Sweet snacks showed the highest median Saturated fatty acids content (Table 1). Similarly, Gómez Martin et al., identified complementary food, vegetable, legumes and past purée with lower energy content. Grammatikaki et al. found on average the highest content for energy in Baby biscuits and rusks (Sweet snacks) (Gómez-Martín et al., 2019; Grammatikaki et al., 2021).

Analysing the energy density (kcal/100 g) by food category, Figure 2A shows that some soft, wet, spoonable products such as the case of vegetable purée and vegetables with cereals or milk products provide a lower energy density, less than 60 kcal/100 g, the minimum energy density proposed by the NPM of WHO Regional Office for Europe for CACFs (WHO Regional Office for Europe, 2019a).

Low energy density can be a problem because the small stomachs of babies and young children limit to relatively small amounts of consumption at mealtimes. On the other hand, some products in the Sweet snacks category have a very high energy density, increasing the risk of excessive energy intake and unfavourable gain in body mass (Azzopardi et al., 2020).

As the European Commission Directive 2006/125/EC does not contain any provisions regarding energy density, all products effectively comply with this directive (European Commission, 2006).

Concerning dry products, the WHO Codex CAC/GL 8-1991 guidelines for formulated complementary foods suggest that energy densities should be at least 4 kcal/g (400 kcal/100 g) on a dry-weight basis (FAO.WHO., 2017). The median energy density for Dry cereals (with an added high protein food - powder milk or whey) is in accordance with the Codex recommendation, for this food category (FAO.WHO., 2017).

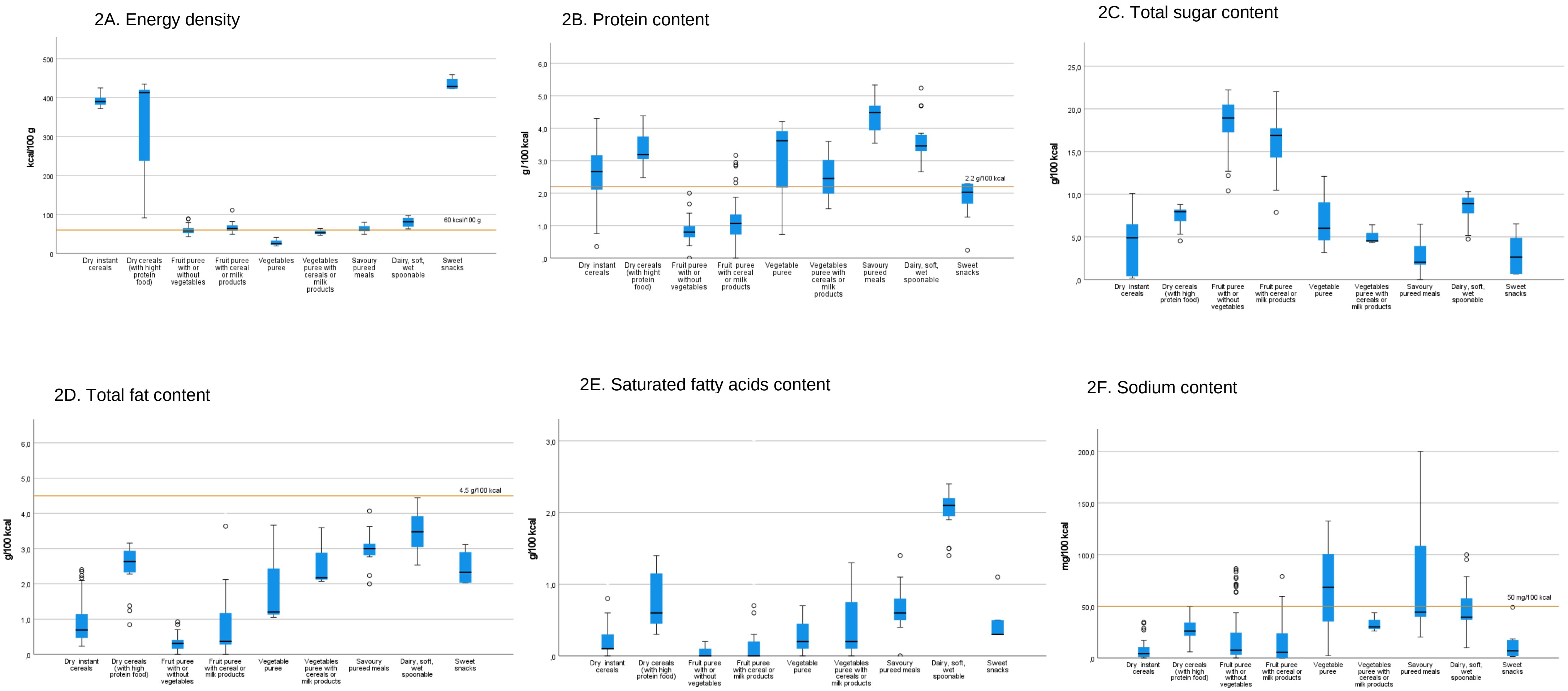


Figure 2. **(A)** Energy density of food products. The horizontal yellow line at 60kcal/100g indicates the minimum energy density proposed by the NPM of the WHO Regional Office for Europe, for the several CACFs categories **(B)** Protein content of food products. The line at 2.2 g/100 kcal indicates a lower limit proposed by the NPM of the WHO Regional Office for Europe, for several CACFs categories **(C)** Total sugar content of food products; **(D)** Total fat content of food products; The yellow line at 4.5 g/100 kcal indicates an upper limit for total fat proposed by the NPM of the WHO Regional Office for Europe, for some CACFs categories **(E)** Saturated fatty acids content of food products; **(F)** Sodium content of food products. The yellow line at 50 mg/100kcal indicates the upper limit for sodium proposed by the NPM of the WHO Regional Office for Europe, for some CACFs categories.

Regarding protein content (Figure 2B), our study shows that most products contain more than the proposed lower limit of total protein (2.2 g/100 kcal), proposed by the NPM of the WHO Regional Office for Europe, for several CACFs categories. The highest protein contents in Dry instant cereals and Dry cereals (with an added high protein food - powder milk or whey), 10.0 g/100 g and 13.6 g/100 g, respectively, are in line with Grammatikaki et al. study, that reports baby cereals with the highest protein content (10.5 g/100 g) (Grammatikaki et al., 2021).

According to our data, the Fruit purée (with or without vegetables) and Fruit purée with cereal or milk presented higher content of carbohydrates than the Vegetable purée, Vegetables purée with cereal, soft, wet spoonable and Savoury puréed meals, these findings are in line with those by Garcia et al study (Garcia et al., 2016).

Analysis of the total sugar content revealed that the maximum total sugar content ranged from 0 g/100 kcal to 22.0 g/100 kcal (Figure 2C). The highest content of total sugars was observed for Dry cereals (with an added high protein food - powder milk or whey), Dry instant cereals and Sweet snacks (27.2, 20.0 and 17.2 g per 100 g of product, respectively). Analysis of the average energy contribution from total sugars showed that foods contained between 8.1% (Spoonable meals) to 75.7% Fruit purée (with or without vegetables). Similarly, Hutchinson et al. found added sugars present in a high percentage of Fruit purée, with the mean for each country being between 72%-79% (Hutchinson et al., 2020).

For all the Fruit purée with or without vegetables (n=62), Fruit with cereal or milk products (n=37) and half of the Dry instant cereals with high protein (n=8), more than 30% of calories come from total sugar, and around 30% (n=5) of the Savoury puréed meals have more than 15% of calories from sugars (Figure 3A). In these cases, when the total energy from sugars exceeds the specified thresholds (15% total energy; 30% total energy), CACFs would have to carry a front-of-pack flag with total sugar content (WHO Regional Office for Europe, 2019a).

Concerning the energy contribution from total sugar (Figure 3A), the products tend to have a relatively high total sugar content, with all the Fruit purée with or without vegetables (n=62) and Fruit with cereal or milk products (n=37) having more than 30% of calories come from sugars. For the Sweet snacks category, 44% (n=4) of the products have more than 15% of energy from sugars, according to the proposed WHO criteria, these products should not be marketed as suitable for IYC (WHO Regional Office for Europe, 2019a). These results could be considered high taking into account the WHO recommendations to limit free sugar intake to 5% or 10% of their overall energy intake and the EFSA Average Requirements for energy from IYC (EFSA Panel on Dietetic Products; Nutrition and Allergies., 2013; World Health Organization (WHO), 2015).

These results are of great concern because dietary preferences are established at a very young age and persist over time. Research showed that food preferences formed in infancy shape later food preferences (Scaglioni et al., 2018). Chronic exposure to foods with added and free sugars is linked with the increase of developing dental caries and metabolic diseases in childhood and later life (Fidler Mis et al., 2017; Vos et al., 2017).

In Portugal, the National Food, Nutrition and Physical Activity Survey reported that IYC (<5 years) had the highest energy contribution from total sugars (28 E%). The main food sources contributing to added and free sugars intake were for IYC (<5 years) milk, fruit, infant formula and yoghurts and in children from 5 years mostly processed foods, such as sweets, yoghurts, breakfast cereals, cakes and soft drinks (Marinho et al., 2020).

For total fat, a considerable degree of variation in terms of the total fat content of foods in different categories was verified (Figure 2D). The total fat content of fruit purée was minimal. The highest percentage of energy from total fat was observed in the Dairy, soft, wet spoonable category (Figure 3B).

The NPM proposed by the WHO Regional Office for Europe established maximum levels for total fat, ranging from 4.5 g/100 kcal to 6 g/100 kcal which is roughly equal to less than 40%-60% energy from total fat, depending on the product category, (WHO Regional Office for Europe, 2019a). All the CACFs, considered in the present study were within the recommended maximum levels for total fat and also under the current provisions of the European Commission directive for fat (European Commission, 2006).

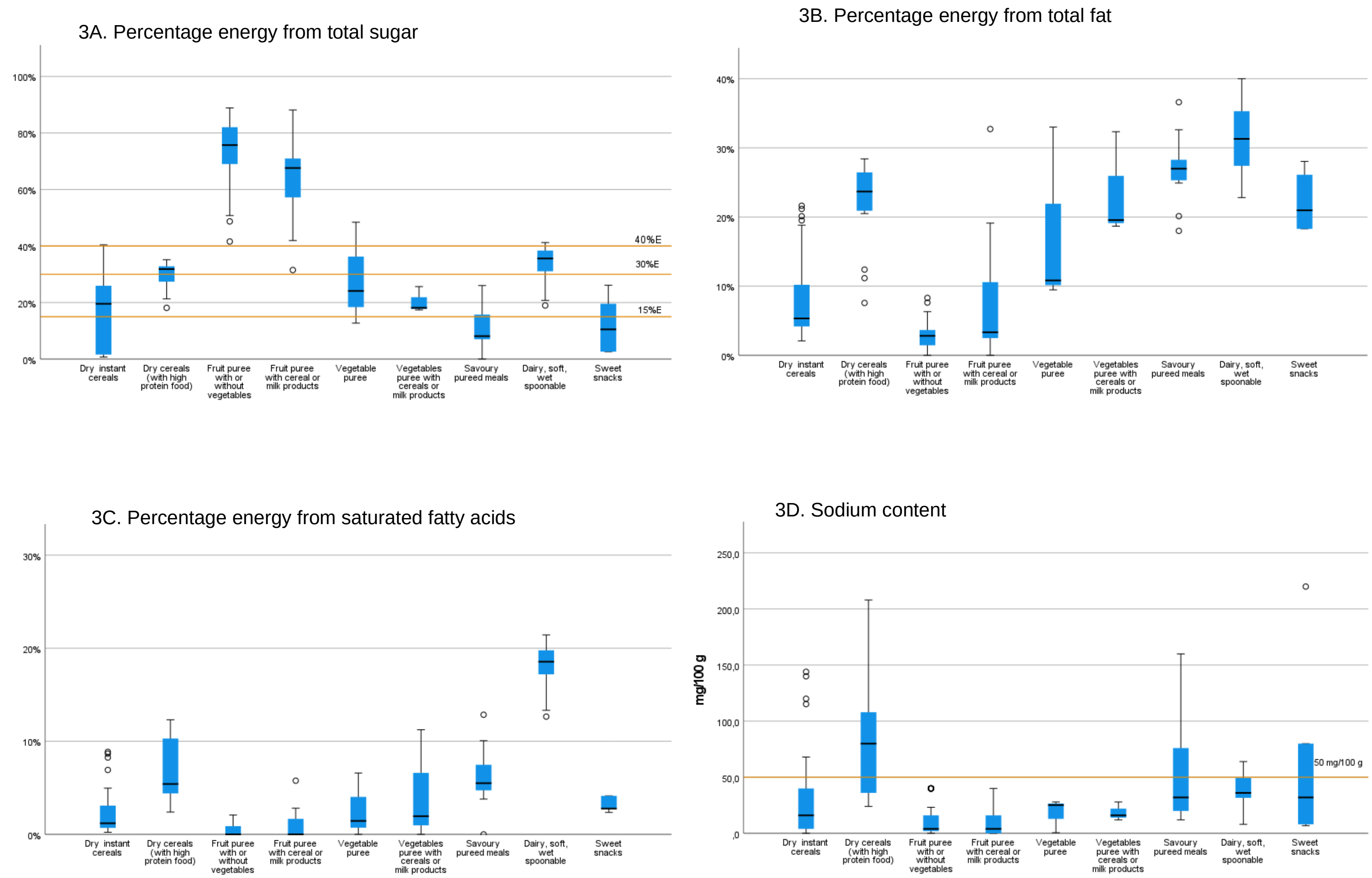


Figure 3. **(A)** Percentage of energy from total sugar of food products; The yellow lines at 15%, 30% and 40% indicate the proposed percentage of calories from total sugar to carry a front of pack flag on the label by the NPM of the WHO Regional Office for Europe, for several CACFs categories. **(B)** Percentage energy from total fat of food products; **(C)** Percentage energy from total saturated fatty acids of food products; **(D)** Sodium content (mg/100 g) of food products. The yellow line at 50 mg/100g in Figure 3D indicates the upper limit for sodium proposed by the NPM of the WHO Regional Office for Europe, for some CACFs categories.

For saturated fatty acids in foods for IYC no specific limits are proposed in current European Union legislation, Codex standards or the nutrient criteria proposed by the NPM for CACFs from WHO Regional Office for Europe (European Commission, 2006; FAO.WHO., 2017; WHO Regional Office for Europe, 2019a).

The highest medium content of saturated fat per 100 kcal was observed in the category Dairy, soft, wet spoonable (2.1 g /100 kcal) (Figure 2E). The average saturated fatty acids content for most of the products was less than or equal to 10% energy from saturated fat (Figure 4C). For children over the age of two years and adults, WHO recommends less than 10% energy from saturated fat, and for Dairy, soft, wet spoonable has been found to contain relatively high levels of energy from saturated fatty acids (19%) (World Health Organization (WHO), 2018).

For sodium content, the NPM for CACFs proposed by the WHO Regional Office for Europe includes maximum limits for sodium, 50 mg/100 kcal (and 50 mg/100 g) or 100 mg/100 kcal (and 100 mg/100 g), when a product contains cheese.

According to the recommendations of health organisations and experts, salt should be avoided during the first two years of life and limited thereafter because of the health risks and as a form of promoting healthier eating habits (Fewtrell et al., 2017; World Health Organization (WHO), 2012). For the adult population, WHO and EFSA recommend that the maximum sodium intake of 2 g per day (equivalent to 5 g per day of salt) be applied. For children, this threshold should be adjusted downwards due to the lower energy intakes. Some sodium is naturally present in foods and the study was unable to identify if and when salt had been added (EFSA Panel on Dietetic Products; Nutrition and Allergies., 2019; World Health Organization (WHO), 2012).

Considering the maximum limit proposed by the NPM for sodium 50 mg/100 g, we observed some products in the categories, Savoury puréed meals, Dairy, soft, wet spoonable and Sweet snacks exceeding the proposed limit (Figure 2F) and would require reformulation to reduce the sodium levels. Our results converging results described by Maalouf et al. and Padarath et al. which had found only a few of the CACFs present an excess of sodium content or contain an added salt (Maalouf et al., 2017; Padarath et al., 2020).

The limit of the European Commission Directive for sodium is 200 mg/100 g or 200 mg/100 kcal, or 100 mg/100 g or 100 mg/100 kcal for cereal products, and in our study, a small number of products exceeded the sodium thresholds (European Commission, 2006).

7.4.3. Compliance with the NPM criteria

7.4.3.1 Compositional criteria

The number of CACFs considered and the percentage of products meeting the nutritional requirements of the NPM proposed by the WHO Regional Office for Europe is represented in Figure 4.

From the 191 CACFs studied, only 35.1% (n=67) of the products complied with all the nutritional requirements of the NPM proposed by the WHO Regional Office for Europe for CACFs, as reported in Figure 4. Pace et al found similar results in their pilot study conducted in Malta to assess the nutritional characteristics of CACFs according to the NPM proposed by the WHO Regional Office for Europe, where only 36% of the 243 food products tested met the nutritional requirements used by this model (Pace et al., 2020).

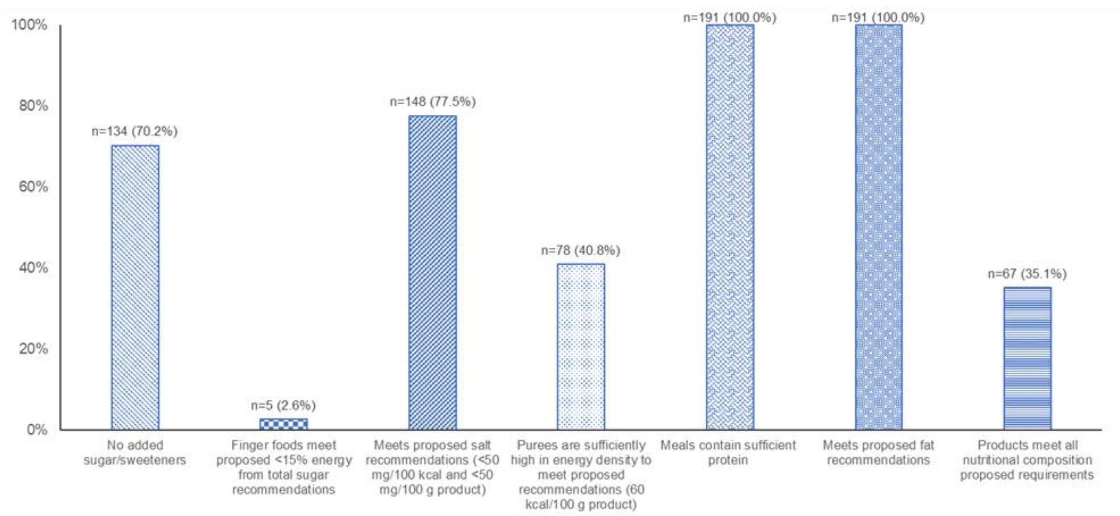


Figure 4. Percentage of CACFs products complying with NPM compositional criteria proposed by the WHO Regional Office for Europe (WHO Regional Office for Europe, 2019a).

7.4.3.2. Labelling requirements

Table 3 provides information on the claim type and visual information (n, %) collected from the CACFs under study.

Table 3 Distribution of claim type and visual information.

Characteristic	Sub-category or classification	Number (n)	Percentage (%)
Nutrition/Composition Claim	Yes	185	96.9
	No	6	3.1
Health Claim	Yes	17	9.0
	No	174	91.0
Claim type	Composition claim		
	No added preservatives	57	29.8
	Gluten-free	64	33.5
	Organic food	47	24.6
	Egg-free	15	7.9
	Dairy-free	18	9.4
	Nutrition claim		
	No added sugar	133	69.6
	No added salt	52	27.2
	Contains vitamin C	26	13.6
	Contains iron	19	9.9
	Contains Calcium	27	14.1
	Contains vitamin E	3	1,6
	Contains multiple vitamins	16	8.4
	Contains multiple minerals	13	6.8
	Contains dietary fiber	8	4.2
	Health claim		
	Nutritionally balanced /provides good nutrition to children	15	7.9
	Cognitive ability	2	1.0
Visual Information (cartons, pictures)	Yes	74	39.0
	No	117	61.0

7.4.3.3. Claims

Most of the CACFs carried a composition/nutrition claim (96.9%), with health claims present on 9.0% of products (Table 3). On the other hand, 69.6% (n=133) of the total products under study had a statement 'No added sugar' claim, with, 'Fruit purée with or without vegetables' (n=62) and 'Fruit with cereal or milk products (n=37), the most represented categories.

No added salt claim was found on 27.2% (n=52), with 'Vegetables purée' (n=3), 'Savoury puréed meals' (n=12) and 'Vegetables with cereals or milk products (n=2), the most represented categories. Health claims were present in 8.9% (n=17) most of which were 'Dairy, soft, wet spoonable' (n=10) (Table 3).

Regarding the presence of claims, the NPM for CACFs proposed by WHO Regional Office for Europe states that no claims (compositional, health or marketing) shall be permitted on packs or related marketing materials (WHO Regional Office for Europe, 2019a). Also, Codex guidelines state that foods for IYC must not carry nutrition or health claims (unless particular claims are specifically approved by regulatory authorities) (CODEX Alimentarius, 1997). The reason for this is that claims can idealize the products, mislead consumers, and/or undermine breastfeeding or complementary feeding with family and local foods (World Health Organization (WHO), 2017).

7.4.3.4. Visual information on labels

A few visual aspects of product labels that related to inappropriate promotion were found, 39.0% (n=74) of the products carried cartoon images (Table 3). These results are in line with the WHO study, which reported a substantial proportion of products carried cartoon images on the packaging, ranging from 16% in Israel to 53% in Bulgaria (WHO Regional Office for Europe, 2019b).

7.4.3.5. Ingredients

In total, 34.0% of the products (n= 65) contained at least one sugar-contributing ingredient. Added sugars (determined by the ingredient list) in the form of sugars, fruit juice or concentrates were found in 13.9% (n=27) and 15.0% (n= 29), respectively (Figure 5A, B). Additionally, it was found that 17.3% (n=23) of these products contained sugar (n=2) or concentrated fruit juice (n=21) in the ingredient list had the claim ‘No added sugar’ (Table 4 and Figure 5A, B). Although this is in line with the European Commission directive and EFSA definition of added sugars (fruit juice is not included in the definition), these sweet fruit-based ingredients will contribute to the total and free sugar content of these foods (European Commission, 2006; European Food Safety Authority (EFSA), 2010; Hutchinson et al., 2020).

Our results are in line with those by Grammatikaki et al. that reported 38.5% of the products contained at least one sugar-contributing ingredient (added sugars, free sugars, Fruit and Vegetable purée or Fruit and Vegetable powders) (Grammatikaki et al., 2021). Similarly, Padarath et al. found that 34.0% of CACFs available for purchase contained free sugars in the form of sugars, maltodextrin, fruit juice, fruit juice concentrates and glucose (Padarath et al., 2020).

Table 4. Description of CACFs according to the presence of claims and presence of sugar-contributing ingredients.

		Dry, powdered and instant cereal/starchy food		Soft, wet, spoonable ready-to-eat foods						Dry finger foods and snacks
		Dry instant cereals (n=30)	Dry cereals (with high protein food) (n=15)	Fruit purée (with or without vegetables) (n=62)	Fruit purée with cereal or milk (n=37)	Vegetable purée (n=3)	Vegetables purée with cereal, soft, wet spoonable (n=3)	Savoury puréed meals (n=17)	Dairy, soft, wet spoonable (n=15)	Sweet snacks (n=9)
Composition Claim	No added preservatives [a)]	6.7%	6.7%	45.2%	19.9%	0,0%	0.0%	70.6%	46.7%	0.0%
	Gluten-free [b)]	20.0%	20.0%	46.8%	27.0%	100.0%	33.3%	23.5%	46.7%	11.1%
	Organic food [a)]	3.3%	0.0%	27.4%	43.2%	0.0%	100.0%	29.4%	26.7%	11.1%
Nutrition Claim	No added sugar[a)]	53.3%	33.3%	95.2%	91.9%	0.0%	0.0%	29.4%	66.7%	44.4%
	No added salt [a]	43.3%	33.3%	16.1%	8.1%	100.0%	66.7%	70.6%	6.7%	33.3%
Health Claim	Nutritionally balanced /provides good nutrition to children	0.0%	6.7%	0.0%	8.1%	0.0%	0.0%	0.0%	66.7%	11.1%
Ingredients (added sugars)	Sugar [a)]	30.0%	33.0%	4.8%	0.0%	0.0%	0.0%	0.0%	33.0%	55.6%
	Fruit juice concentrated [c)]	6.7%	20.0%	17.7%	29.7%	0.0%	0.0%	0.0%	13.3%	0.0%
	Other added sugars [d), e), f)]	16.6%	0.0%	0.0%	8.1%	0.0%	0.0%	0.0%	0.0%	11.1%

χ^2 test, a) ($p<0.001$); b) (p=0,014); c) ($p=0.079$); d) ($p>0.05$), for sirup, dextrose, sucrose, malt extract), e) ($p=0.038$, for honey); f) (p= Not calculated because variables is a constant, for malted barley extract, molasses, maltose, fructose, glucose, trehalose, galactose)

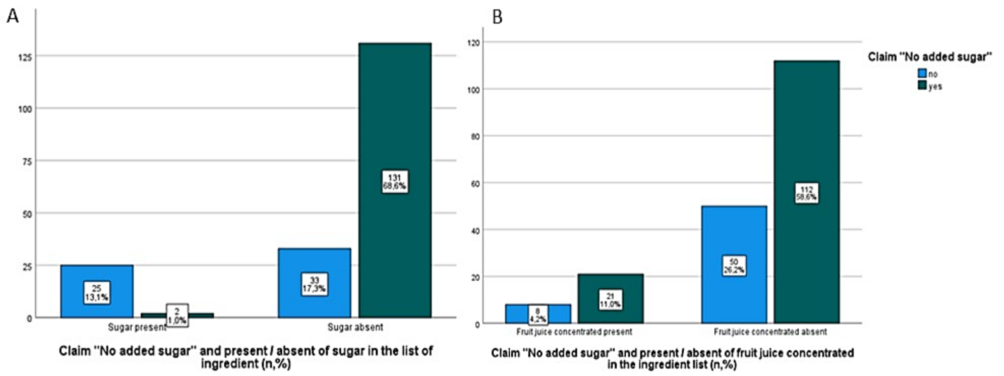


Figure 5. **(A)** Commercially available complementary foods with/without claim “No added sugar” and present/absent sugar in the ingredient list (n,%); **(B)** Commercially available complementary foods with/without claim “No added sugar” and present/absent fruit juice concentrated in the ingredient list (n, %).

7.4.4 Processing level

Our results show that 61.8 % (n=118) of the CACFs were UP and 36.6% (n=70) were MP and when comparing the nutritional composition between NOVA groups, UP were higher in energy density, proteins, total fat, saturated fatty acids and carbohydrates than the processed and minimally processed foods (Table 5). Comparable results were found in the study of Araujo et al, in which 33.6% were MP foods, 10.2 % were processed and 56.1% were UP foods (De Araújo et al., 2021).

Overall, the median energy density of the UPFs was 383 kJ (91.0 kcal), being 3.3 % of total energy from proteins, 16.5 % from carbohydrates and 2.5 % from lipids. Per 100g, total sugars were significantly lower (p= <0.001) when compared with MP foods, as well as between processed and MP foods. There were significant differences between medians for energy (kcal, kJ) and all the nutrient content (p<0.001), between each of the NOVA groups (Table 5).

Per 100 g, total sugar was significantly lower and sodium was significantly higher in UP foods when compared with MP foods, as well as between processed and MP foods respectively. McCann et al. also find the same unexpected results, for the content of total sugars and sodium in UP foods when compared to processed and MP foods (McCann et al., 2021).

As MP foods group consists of 'Fruit purée with or without vegetables' 88.6% (n= 62) and 'Fruit purée with cereals or milk' 24.6% (n=8), which have in common the use of certain ingredients may explain the higher sugar results observed. The sodium result in the processed food group can be attributed to the group being composed of Vegetable purée (n=3) which has a higher sodium content compared to Fruit purée. Da Rocha et al. found in their study that 79% of the Baby foods were UP foods. The difference observed compared with our results (61.8 %, n=118) might be explained by the fact their study included breast milk substitutes and follow-up formulas (n=31, 33%) and our analysis, included the food category 'Fruit purée with cereals or milk' which had 15.8% (n=29) of foods classified as UP, due to the presence of additives in the ingredient list or the manufactured process (Da Rocha et al., 2021).

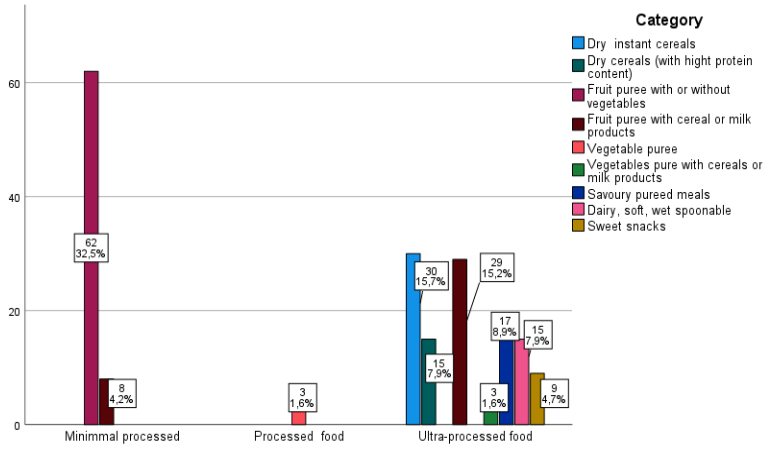
Table 5 Median (25th–75th percentile) nutrition information per 100 g across processing classification (NOVA).

	Minimally processed	Processed	Ultra-processed	*p**
Energy (kJ)	245 (222-272) [a,c]	105 (81.0-†) [a,]	383 (276-1681) [b]	<0.001
SD	39	47	708	
Energy (kcal)	58.0 (52.5-64.5) [a,c]	24.9 (19.0-†) [a]	91.0 (66.0-397.3) [b]	<0.001
SD	9.0	11.3	167.4	
Protein (g)	0.4 (0.3-0.7) [a]	0.8 (0.3-†) [a,c]	3.0 (1.9-10.0) [b,c]	<0.001
SD	0.2	0.3	5.0	
Total fat (g)	0.2 (0.1-0.2) [a]	0.3 (0.2-†) [a,c]	2.3 (1.1-4.0) [b,c]	<0.001
SD	0.2	0.7	3.6	
Saturated fatty acids (g)	0.0 (0.0-0.0) [a]	0.0 (0.0-†) [a,c]	0.7(2.9-1.8) [b,c]	<0.001
SD	0.2	0.2	1.2	
Carbohydrate (g)	12.9 (11.4-14.0) [b]	4.1 (3.5-†) [a]	15.0 (11.2-75.0) [c]	<0.001
SD	2.2	1.2	32.0	
Total sugars (g)	11.0 (9.5-12.1) [b,c]	1.5 (1.3-†) [a]	9.0 (2.9-19.0) [a,c]	0.040
SD	2.1	0.5	10.4	
Sodium (mg)	4.0 (0.4-12.0) [a]	25.2 (0.56-†) [a,c]	24.6 (8.0-52.0) [b,c]	<0.001
SD	14.0	15.0	46.0	

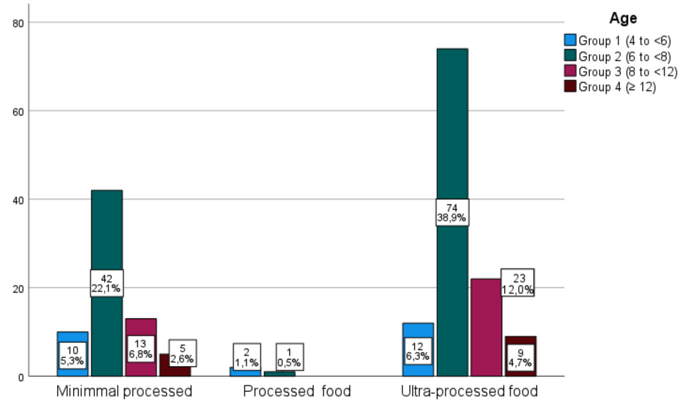
* p-value obtained with Kruskal-Wallis test for independent samples with multiple pairwise comparisons (processing classification). For each processing level, different lowercase letters in the same row indicate significant differences among processing (Kruskal–Wallis non-parametric one-way ANOVA for independent samples with multiple pairwise comparisons), † Not calculated; SD - Standard Deviation

Concerning processing classification and the food category, the highest proportion of minimally processed foods was observed for 'Fruit purée with or without vegetables' 88,6% (n= 62). 'Dry instant cereals' 25.4% (n=30), 'Fruit purée with cereal or milk' 24.6% (n=29) and 'Savoury puréed meals' 14.4% (n=17) represent the highest proportion of UP foods, respectively (Figure 6A).

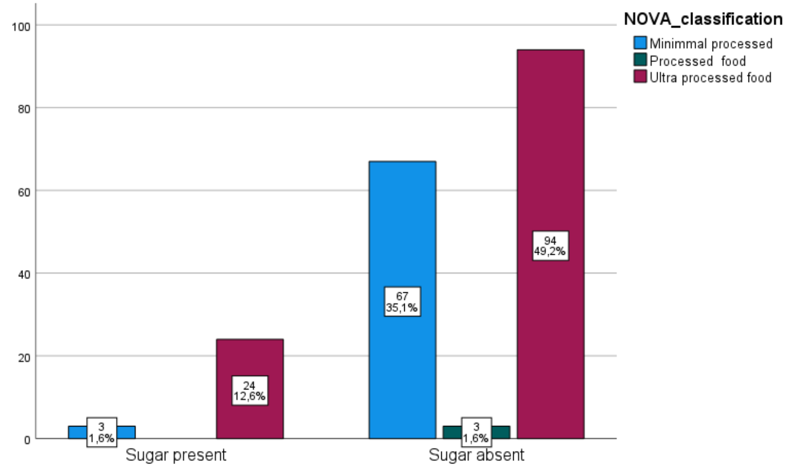
6A. Processing classification (NOVA) by food category



6B. Processing classification (NOVA) by targeted age groups



6C. Processing classification (NOVA) and sugar added present/absent



6D. Processing classification (NOVA) and fruit juice concentrated present/absent

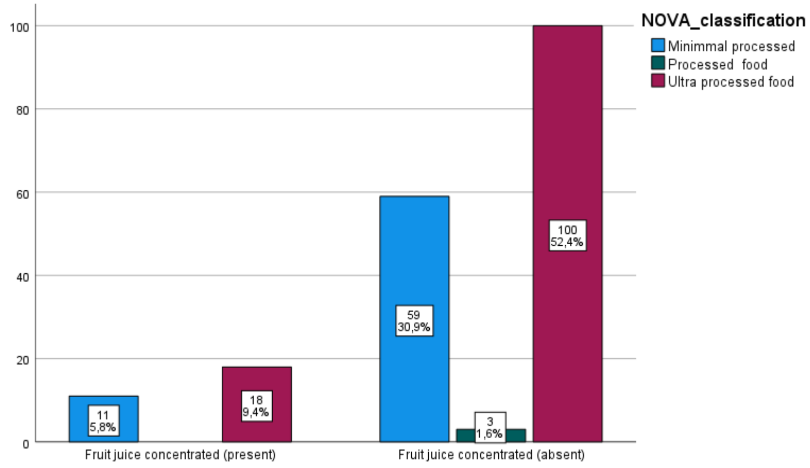


Figure 6. (A) Processing classification (NOVA) by food category (n, %); (B) Processing classification (NOVA) by targeted age groups (n, %); (C) Processing classification (NOVA) and Added sugars (Sugar) (present/absent) in the ingredient list (n, %); (D) Processing classification (NOVA) and Added sugars (Fruit juice concentrated) (present/absent) in the ingredient list (n, %).

Regarding the recommended age for consumption, our study revealed an early introduction of UP foods with 57.0% (n=109) of the analysed products indicated for children under 12 months (groups 1 to 3) (Figure 6B).

Considering the first 1000 days as a critical period for preventing childhood obesity, the adoption of dietary patterns high in foods with sugars as added ingredients or high in UP foods, already from an early age, can have consequences for child health and be a major contributor to the growth of childhood obesity and chronic diseases in later life (Birch and Doub, 2014; Lanigan, 2018; Spaniol et al., 2021). In its call to action, the European Childhood Obesity Group warned about the negative effects of children consuming large amounts of UPFs and called for restrictions (Khandpur et al., 2020).

The review conducted by Elisabeth et al. has found that a high intake of UP foods is associated with a range of adverse health outcomes, and non-communicable diseases, disorders and conditions, thus supporting the potential to significantly influence the global burden of disease. Among children and adolescents, the consumption of UP foods is associated with cardio-metabolic risks and asthma (Elizabeth et al., 2020).

Several studies have shown that children and adolescents are the main consumers of UP foods with caloric intake from UP foods ranging from 67% in the USA in 2018 in children aged 2-19 years (Wang et al., 2021) to 45.5% in France by the analysis of data from the INCA3 2014- 2015 study (children aged 1-10 years) (Fardet et al., 2021). In Brazil, the proportion of total UPF energy consumption was reported as 42.0% ± 8.7 at ages 3–4 years and 47.8% ± 8.9 at ages 6–8 years (Costa et al., 2019).

The contribution of processed and UP foods in children is also mentioned as a factor that can decrease the quality of children's diets, considering that many foods have unhealthy nutritional profiles, with higher amounts of nutrients of concern such as sugar, trans fat, and sodium, compared to unprocessed or minimally processed foods (Araújo et al., 2019). This reveals the need for more effective regulatory measures, including guidance for the infant and young child food industry on the manufacture of foods using lower levels of processing (Araújo et al., 2019; Khandpur et al., 2020).

In the current study, UP foods that contained at least one sugar-contributing ingredient (23.5%, n=45), sugar was identified in 53.3% (n=24), and fruit juice or concentrates were found in 40.0% (n=18). On the other hand, MP foods that contained at least one sugar-contributing ingredient (6.2%, n=12), fruit juice or concentrates were found in 91.7% (n=11) of MP foods (Figure 6C-D). Our results are consistent with the Grammatikaki et al. study which found in 60% of MP foods contained free sugars mainly fruit juices or fruit juice concentrates (Grammatikaki et al., 2021).

In the future, as part of the nutritional reformulation of food products with excessive content of fat, salt, sugar or energy, the present analysis may be repeated to monitor the nutrient profiles of CACFs targeted to IYC under 3 years of age in Portugal.

Strengths and limitations could be identified. An important strength of this study lies in providing valuable insight into CACFs at the national level and reinforces that action is needed to establish marketing and product guidelines and inform policymakers to align with health priorities important to IYC. Furthermore, this study also classifies CACFs against the NOVA classification, providing another perspective on this product category and could contribute to the limited research available in this area. Furthermore, our results also constitute an important challenge for policymakers to consider the reduction of sugar content in CACFs via health taxes, reformulation programmes, and food marketing restrictions (WHO Regional Office for Europe, 2020). In addition, it is advisable the development of stringent regulations for CACFs labelling to aid caregivers in making healthier choices. Labels should clearly be marked with the contribution of added and intrinsic sugars, (WHO Regional Office for Europe, 2019a).

Due to the inherent limitations with the labelling of CACFs assessment, as sugars naturally occurring in milk and fruit are not currently differentiated from added sugars on labels, it was not possible to obtain information on the contribution of added sugars to total calories or total carbohydrates.

7.5 Conclusion

This study provides an overview of the nutrient profile, promotion aspects of product packaging, use of nutrition and health claims and level of processing of CACFs, and contributes knowledge to the implementation of the WHO’s guidance on these foods.

Our results showed that the sugar content of several categories of CACF is higher than recommended and in contradiction with the guidelines to restrict sugar intake in infants and young children. Furthermore, our study suggests that an early introduction of UP foods in the IYC diet is probable, with more than 50% of products destined for children under 12 months being classified as UP.

Adequate nutrition during infancy and early childhood is essential to ensure the growth, health and development of children to their full potential. The results of this study reinforce firstly the importance of implementing the WHO guidelines on the assessment of commercially available foods for IYC as a strategy to improve complementary feeding practices, and secondly the importance of assessing the food processing characteristics of processed foods and beverages targeted to IYC under 3 years of age, to assist parents and health professionals with the correct information when choosing complementary and infant foods as an opportunity to prevent NCDs.

These findings endorse the importance of innovative interventions in the field of consumer education to decrease UP foods consumption while promoting the consumption of natural and MP foods.

This study also provides evidence to operationalize the implementation at the national level of NPM proposed by WHO to guide decisions about which foods are inappropriate for promotion for IYC under 36 months of age and to policymakers to update regulation and guide product reformulation concerning the sugar content of CACFs.

The data framed by WHO recommendations have essential applications in nutrition research, dietary counselling, and public health practice. The WHO recommendations are crucial to understand concerns detected in multicentre studies at the international or national-level and identify sub-populations at risk due to typical dietary patterns or increased physiological needs.

Abbreviations:

CACFs - Commercially Available Complementary Foods

IYC - Infants and Young Children

NPM - Nutrient Profile Model

UP – Ultra-processed

WHO – World Health Organization

Author agreement statement

The authors whose names are listed immediately below certify that the undersigned declare that the manuscript title “Commercial baby foods aimed at children up to 36 months: are they a matter of concern?” is original, has not been published before and is not currently being considered for publication elsewhere. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We understand that the Corresponding Author is the sole contact for the Editorial process. He/she is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

Declaration of Competing Interest

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Acknowledgements

This manuscript was developed under the scope of the WHO Collaborating Center on Nutrition and Childhood Obesity—National Health Institute Dr. Ricardo Jorge.

Ricardo Assunção thanks FCT/MCTES for the financial support to CESAM (UIDP/50017/2020 + UIDB/50017/2020), through national funds.

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7.7. Supplementary material

This appendix provides information on the coded variables that were subject to analysis (Table S1), on the definition and examples of foods included under food categories (Table S2) and provides details on the proposed nutrient and labelling and promotion specifications to be met by the nutrient profile model for commercially available complementary foods for infants and young children up to 36 months old (Table S3).

Table S1 Information on the coded variables that were subject to analysis.

Coded Variables	**Description**
Basic information	Brand name, product name, food type, ingredients, recommend age, serving size
Product category [a)]	Products were classified according to the NPM proposed by WHO Regional Office for Europe: 1. Dry, powdered and instant cereal/starchy food: **(1a**) Dry instant cereals, **(1b)** Dry cereals (with an added high protein food - powder milk or whey); 2. Soft, wet, spoonable ready-to-eat foods **(2a)** Fruit purée (with or without vegetables); **(2b)** Vegetable purée; **(2c)** Fruit purée with cereal or Milk; **(2d)** Vegetables with cereal, soft, wet spoonable; **(2f- 2g)** Savoury puréed meals; **(2i)** Dairy, soft, wet spoonable; 4, Dry finger foods and snacks **(4b)** Sweet snacks.
Nutritional information	Nutritional content (total energy (kJ/kcal), protein (g), carbohydrates (g), total sugars (g), fat (g), saturated fatty acids (g), and sodium (mg). All the nutritional analysis was per 100g product.
Details on the presence of added sugars	For these analyses, added sugars were classified as fruit juice whether whole, concentrated or powdered; sugar; sucrose; dextrose; fructose; maltose; any syrup; honey; barley malt/malted barley/malt extract; molasses; and artificial or natural zero/low-calorie sweeteners.
Composition, nutrition and health claims	**Composition claim**: No added preservatives, organic food, egg-free, dairy-claims-free, gluten-free. **Nutrition claim**: Contains calcium, contains iron, contains vitamin C, contains dietary fiber, contains multiple vitamins, no added sugar, no added salt, contains vitamin E, contains multiple minerals. **Health claims**: Provides good nutrition to children, nutritionally balanced, cognitive ability.
Visual Information	Presence of cartoons, pictures of infants/young children, pictures of mothers, pictures of bottles/teats.

[a)] Product categories and definitions are provided in Table S2.

Table S2 – Definition and examples of foods included under food categories, according to the proposed NPM for commercially available complementary foods for infants and young children up to 36 months old.

	Food category	Definition and examples
1	**Dry, powdered and instant cereal/starchy food**	
1a	Dry or instant cereals/starch with or without naturally sweet foods	Dry rice, cereal, pulverized rusks or starchy root (at least 25% cereal and/or starch root content) with or without naturally sweet foods (e.g. dry fruit).To be prepared for consumption with milk or other appropriate nutritious liquid (e.g. formula). Includes dry instant-type porridges and dry breakfast cereals (e.g. puffed rice or cereal hoops), if marketed as suitable for infants and young children. Excludes wet ready-to-eat cereals
1b	Dry or instant cereals/starch **with** an added high-protein food	Dry rice, cereal, pulverized rusks or starchy root (at least 25% cereal and/or starchy root content) with an added high-protein food (e.g. milk or whey powder) to be prepared for consumption with water or other appropriate protein-free liquid
2	**Soft, wet, spoonable ready-to-eat foods**	
2a	Fruit purée with or without vegetables	≥ 95% single or mixed fruit (or mixed with vegetables). Includes fruit-only smoothie purée/drinks and any spoonable fruit-only or fruit-and-vegetable purée
2b	Vegetable purée	≥ 95% single or mixed vegetables or legumes. Excludes products containing any fruit
2c	Fruit with cereal or milk products	Largest ingredient is single or total fruit, plus cereals or dairy. Includes foods such as smoothies with > 5% dairy or cereal, high-fruit breakfast foods (e.g. fruit-based breakfast rice/ porridge) and desserts (e.g. apple crumble or fruit-based baby rice). Excludes fruit/vegetable-based purées with < 5% cereal or dairy, which are categorized as 2a or 2b
2d	Vegetables with cereals or milk products	Puréed or semi-puréed vegetables/legumes with > 5% cooked weight in cereal (e.g. pasta, rice, barley), or a pseudocereal (e.g. quinoa, chia, buckwheat). Includes savoury-type meals with cereals (e.g. pasta with tomato and courgette) or pseudocereal (e.g. butternut squash, carrot and quinoa) or with milk products (e.g. cauliflower cheese/macaroni cheese). Includes vegetable-based foods containing cheese, where cheese is not mentioned in the product name
2e	Meal with cheese mentioned in the name	A puréed or semi-puréed meal containing vegetables, other carbohydrates and cheese (e.g. cheesy pasta with tomato and vegetables).
2f	Meal with fish mentioned first (as food) in name of the product	A puréed or semi-puréed meal containing vegetables, other carbohydrates and fish. Fish is mentioned as the first food in the product name (e.g. “Tasty fish pie” or “Salmon and pea risotto”).
2g	Meal with meat or poultry or other traditional sources of protein mentioned first (as food) in name of the product	A puréed or semi-puréed meal containing vegetables, other carbohydrates and meat, poultry or other traditional sources of protein, where the source of protein is mentioned as the first food in the product name (e.g. “Hearty beef hotpot” or “Chicken and potato pie”).

2h	Meals with meat, poultry, fish, offal or other traditional sources of protein (but not named as the first food in the product name)	A puréed or semi-puréed meal containing vegetables, other carbohydrates and traditional source of protein, where the meat/protein is not listed as the first food in the product name (e.g. "Hearty shepherd's pie", "Cottage pie" or "Carrot, potato and lamb hotpot").
2i	Dairy with or without fruit or other naturally sweet foods	Foods with dairy as the largest main ingredient by weight (i.e. greater than the sum of total fruit or total grain ingredients) such as yoghurt, fromage frais, custard, porridge or rice pudding, made with or without other naturally sweet foods such as fresh fruit, fruit juice or dried fruit (excluding honey and other added sugars).
2j	Only meat or poultry in name of the product	Puréed or semi-puréed poultry, where poultry is the only food listed in the product name and constitutes the single largest ingredient (except water).
2k	Only fish or other traditional sources of protein in name of the product	Puréed or semi-puréed fish or other traditional sources of protein, where this is the only food listed in the product name and constitutes the single largest ingredient (except water).
3	**Meals with chunky pieces**	
3a	Meat, fish or other traditional sources of protein-based tray or pot meal	Non-puréed soft meals containing chunky pieces of vegetables, legumes or other carbohydrates and meat, fish or other traditional sources of protein (often sold in trays)
3b	Vegetable-based tray or pot meal	Non-puréed soft meals containing chunky pieces of vegetables, legumes or other carbohydrates (often sold in trays)
4b	Sweet snacks and finger foods	Any sweet baked, fried, dried or dehydrated food intended to be eaten between meals with ≥ 15% energy from total sugar (≥ 2.5 g/100 kcal) is classed as a sweet snack or finger food. Any starchy food, fruit-based or vegetable-based product where the sugar content is < 15% of total energy may be classed as a savoury snack (category 4d). Includes foods such as sweet pastries; croissants; cookies/biscuits; sponge cakes; wafers; fruit pies; sweet buns; chocolate-covered biscuits; cake mixes and batters; cereal or energy bars (i.e. cereal/granola or muesli bars); and crisps/puff products made from fruit, vegetables or starchy foods (which may be coated in fat/oil).
4c	Rusks and teething biscuits	Light, crumbly or twice-baked dry sweet biscuit or bread to be chewed for teething or softened with liquid.
4d	Savoury snacks and finger foods	Foods consisting of ≥ 95% single or mixed grains, rice, potato, nuts, seeds, fruits or vegetables, including popcorn and maize corn with total sugar content < 15% energy from total sugar (< 2.5 g/100 kcal). Any product with ≥ 15% energy from total sugar is classed as a sweet snack (category 4b). Includes foods such as savoury biscuits and pretzels, baked chips/crisps (e.g. potato, grain or other starchy food, etc.), rice cakes coated in powdered fruit or vegetables, cereal bars and rusks made without added sugars.
4e	Fruit (fresh or dry whole fruit or pieces)	Includes fresh whole or peeled fruit (e.g. apple) and dried fruit (e.g. dry slices of plain apple, freeze-dried strawberries, raisins, dry apricots, prunes). Excludes fruit pieces coated in sugar or oils/fats (e.g. banana chips, sweetened cranberries or yoghurt raisins)

5	**Juices and other non-formula drinks**	
5a	Single or mixed fruit juices	Drinks made using anything other than ≥ 95% whole fruit (or fruit and vegetables) including fruit/vegetable cell walls (i.e. not ≥ 95% blended fresh fruit (or fruit and vegetable) pulp (which are classified in category 2a)). Includes drinks made using concentrated or strained/sieved fruit (e.g. apple juice, orange juice). Excludes smoothies/purées which are ≥ 95% whole fruit (or fruit and vegetables) (see category 2a).
5b	Single or mixed vegetable juices	Drinks made using “modified” vegetable pulp (i.e. not ≥ 95% blended fresh vegetables). Includes drinks made using concentrated or strained/sieved vegetables. Excludes vegetable purées made using ≥ 95% vegetables (see category 2b).
5c	Other non-milk-based drinks	Includes ready-made from cordials, energy drinks, ices, cola, lemonade, orangeade, other soft drinks, and mineral and/or flavoured waters (including aerated) with added sugars or sweetener.

Adapted from the Nutrient Profile Model proposed by the WHO-Regional Office for Europe (WHO Regional Office for Europe, 2019a).

Table S3 Proposed Nutrient and Labelling and Promotion specifications for Nutrient Profile Model for commercially available complementary foods for infants and young children up to 36 months old.

Product group	Code	Sub-category description	Content and labelling specifications									
			Energy density (kcal/100g)	Sodium (mg/100 Kcal)	Total sugar (%/ Energy)	Protein (g/100kcal)	Total fat (g/100kcal)	Fruit content (% weight)	Protein (% total weight)	Age indicated (months)[1]	Sugar flag	Labelling and promotion specifications
Dry foods: dry, powdered, and instant cereal starchy foods	1a	Dry or instant cereals/starch with or without naturally sweet foods	≥60	< 50	a)	<5.5g	≤4.5g; b)	≤10% dry weight		6-36	≥30%	No claims Product name/ingredient clarity No added sodium in the liquid used to reconstitute the product Ingredients list should state the amount of dried and powdered fruit (%)
	1b	Dry or instant cereals/starch **with** an added high-protein food										
Soft, wet, spoonable ready-to-eat foods	2a; 2c	Fruit purée with or without vegetables, cereals or milk	≥60	<50 and < 50mg/100g	a)		≤ 4.5g; b)			6-36 (6-12 for purée)	≥30%	No claims Product name/ingredient clarity Statement about no sucking from spouts if in a pouch Ingredients list should state the amount of added water (%), total fruit (%), total cereal (%) by weight of the total product
	2b	Vegetable purée		50 and < 50mg/100g	a)		≤ 4.5g; b)			6-36 (6-12 for purée)	≥30%	No claims Product name/ingredient clarity Statement about no sucking from spouts if in a pouch Ingredients list should state the amount of added water (%)
	2d	Vegetables with cereals or milk products	≥60	<50 and < 50mg/100g	a)		≤ 4.5g; b)			6-36 (6-12 for purée)	≥20%	No claims Product name/ingredient clarity Statement about no sucking from spouts if in a pouch Ingredients list should state the amount of added water (%)
	2e	Meal with cheese mentioned in the name	≥60	<100 and < 100mg/100g	a)	≥3g total or ≥2.2 dairy protein	≤ 6.0g; b)	≤5% (max. 2% dry)		6-36 (6-12 for purée)	≥15%	No claims Product name/ingredient clarity Statement about no sucking from spouts if in pouch Ingredients list should state the a mount of added water (%), total fruit (%), total cereal (%) by weight of the total product
	2f, 2g	Meal with fish, meat or poultry (named as the first food in product name (Savoury Pureed meals)	≥60	<50 and < 50mg/100g (or <100 and <100mg/100g if name cheese)	a)	≥4g total & ≥2.2 dairy protein	≤ 6.0g; b)	≤5% (max. 2% dry)	≥ 10% total protein ≥25% total named protein	6-36 (6-12 for purée)	≥15%	No claims Product name/ingredient clarity Statement about no sucking from spouts if in a pouch Ingredients list should state the amount of added water (%), total fruit

												(%), total cereal (%) by weight of the total product
	2h	Meals with meat, poultry, fish, (not named as the first food in product name)	≥60	<50 and < 50mg/100g (or <100 and <100mg/100g if name cheese)	a)	≥3g total & ≥2.2 dairy protein	≤ 6.0g; b)	≤5% (max. 2% dry)	≥ 8% total protein ≥25% total named protein	6-36 (6-12 for purée)	≥15%	No claims Product name/ingredient clarity Statement about no sucking from spouts if in a pouch Ingredients list should state the amount of added water (%), total fruit (%), total cereal (%) by weight of the total product
	2i	Dairy with or without fruit or other naturally sweet foods	≥60	<50 and < 50mg/100g	a)	≥2.2 dairy protein	≤4.5g; b)	≤5% (max. 2% dry)		6-36	≥40%	No claims Product name/ingredient clarity Statement about no sucking from spouts if in a pouch Ingredients list should state the amount of added water (%), total fruit (%), total cereal (%) by weight of the total product
	2j, 2k	Puree with only meat, poultry, fish or cheese in name of the product		<50 and < 50mg/100g (or <100 and <100mg/100g if name cheese)	a)	≥7g total & ≥2.2 dairy protein	≤ 6.0g; b)	≤5% (max. 2% dry)	≥30% total named protein	6-36 (6-12 for purée)	≥15%	No claims Product name/ingredient clarity Statement about no sucking from spouts if in a pouch Ingredients list should state the amount of added water (%), total fruit (%), total cereal (%) by weight of the total product Should state that these products are not intended as a complete meal and should be served with vegetables and starchy carbohydrates
Meals with chunky pieces,	3a	Meat, fish or cheese-based meal with chunky pieces		<50 and < 50mg/100g (or <100 and <100mg/100g if name cheese)	a)	≥3g total, ≥2.2g	≤4.5g or ≤6g if protein source first food	≤5% (max. 2% dry)	≥ 8% total protein or ≥ 10% if name first food ≥25% total named protein	6-36	≥15%	No claims Product name/ingredient clarity Ingredients list should state the amount of added water (%), total fruit (%), total cereal (%) by weight of the total product
	3b	Vegetable-based meal with chunky pieces		<50 and < 50mg/100g (or <100 and <100mg/100g if name cheese)	a)	≥3g		≤5% (max. 2% dry)		6-36	≥15%	No claims Product name/ingredient clarity Ingredients list should state the amount of added water (%), total fruit (%), total cereal (%) by weight of the total product
Dry finger foods and snacks	4a	Sweet confectionery, sweet spreads and fruit chews	-	-	-	-	-	-	-	-	-	"Not suitable for infants and young children under 36 months" should be added to foods aimed at older children
	4e	Fruit (fresh or dry whole fruit or pieces)	≤50 Kcal per	<50 and < 50mg/100g	a)		No added fats			6-36	≥30%	No claims Product name/ingredient clarity

			portion				≤4.5g; b)					
	4b,4c,4d	Other snacks and finger foods (included sweet and savoury snacks and finger foods)	≤50 Kcal per portion	<50 and < 50mg/100g	<15%; a)		≤4.5g			6-36		If ≥15% total energy "Not suitable for infants and young children under 36 months" should be added to foods aimed at older children". Ingredients list should state the amount of total fruit (%) by weight of the total product
Juices and other drinks	5a, 5b	Single or mixed fruit juices, vegetable juices, or other non-formula drinks	-	-	-	-	-	-	-	-	-	"Not suitable for infants and young children under 36 months" should be added to foods aimed at older children"
	5c	Cow's milk and milk alternatives, with added sugar or sweetening agent	-	-	-	-	-	-	-	-	-	"Not suitable for infants and young children under 36 months" should be added to foods aimed at older children"

a) No added sugar or sweetening agent; b) No industrially produced trans fatty acids.

Adapted from the Nutrient Profile Model proposed by the WHO-Regional Office for Europe (WHO Regional Office for Europe, 2019a).

8. Discussion

This chapter summarises the key results from this research and their implications for public health policy and practice. The primary limitations of the research are identified, and directions for future research are highlighted.

In this thesis, the overall aims were to investigate the application of NP models in the national context, regarding the domains of food labelling, food composition/reformulation and food promotion, to reinforce the importance of these tools and enable policymakers with information that allows setting strategies that can contribute to healthy food environments.

These objectives were addressed through four studies: a literature review and three descriptive observational studies with a cross-sectional design. Chapters 4, 5, 6 and 7 include a contextualisation within the existing literature of the various studies undertaken, an interpretation of the findings, a section outlining the strengths and limitations of the studies and a discussion of implications for policy and future research.

8.1. Main findings

8.1.1. Nutrient profile models a useful tool to facilitate healthier food choices: A comprehensive review

The development of a NP model involves a process that should be systematic, clear and rational and can be based on different criteria and approaches, depending on its objectives. Given this, when designing a NP model, it is important to follow specific science-driven rules. In this study, the decision points taken into consideration in the development of a NP model were addressed. The guiding principles to implement NP models were considered including the main characteristics, advantages, disadvantages, and associated gaps of the considered NP models.

What was known

The term NP has been associated with several concepts arising from the need to regulate the choice of food products, and to allow consumers to make informed and healthier food choices. The use of NPM as a policy tool to improve public health nutrition and reduce the prevalence of non-communicable diseases has also been receiving increasing attention (168).

In this study, a literature review was undertaken to identify the documents which were relevant to the research questions, i.e. what is nutrient profiling? And what are the assumptions used during the development of nutrient profiling? What are the gaps and opportunities for research?

Nutrient profiling can be defined as 'The science of classifying or ranking foods according to their nutritional composition for reasons related to preventing disease and promoting health' (58) and is operationalised by NP models, algorithms intended to classify or score food products according to their nutritional composition and their impact on health (59).

This study found that assessment of the nutritional quality of food through NP models involves multiple decisions that concern the type of NPM, the selection of qualifying and disqualifying nutrients, the selection of reference standards, and the basis of calculation 100 kcal, 100 g, or serving (60,63).

Nutrient profiling has a wide range of applications including front-of-pack (FoP) food labelling, regulation of food marketing to children, regulation of health and nutrition claims and school food standards. Sodium, saturated fatty acids (SFA), and total sugars were the nutrients most frequently to limit; on the contrary, fibre was the nutrient to be more frequently encouraged (2,168).

What this study adds

This study provides an outline of the methodology and guiding principles to implement a NP model, including validation, limitations and potential applications.

Current NP models may not fully capture the health impact of foods, as they focus only on nutrients. A hybrid nutrient profiling approach that takes both nutrients and all desirable food groups and ingredients may provide an opportunity to avoid the criticisms of nutritional reductionism (169). The review conducted by Drewnoski et al reveals NP models that are both food and nutrient-based allow a broader approach where nutrient density is considered not only for individual foods but also for meals, menus and the total diet, reflecting the various ways in which individuals make food choices throughout the day and supporting them to build healthy eating patterns (169).

A holistic approach should be taken for the development and sustainable application of a NP model (170). This approach involves the scientific basis for the labelling of food products according to their environmental and nutritional impact, allowing consumers to make informed choices. The existence of valid data supporting the relationship between diet and health should be considered in the framework for its development (170).

The results of this review contribute to support policymakers and health authorities regarding the choice of an applicable model once the establishment of nutrition-related policies would benefit from the utilization of the NP models.

NP models can be used to decide which food should not be advertised to children, how foods should be reformulated to increase their healthiness, which foods should be made available in a school, which food should be subject to health claims, etc. For example, Chile used the same NP model to effectively restrict foods that have front-of-pack warning labels (FOP) from being sold or consumed in or near the school and to prohibit the marketing of foods with a FOP label (171). Australia and New Zealand use a NP model, the Food Standards Australia New Zealand Nutrient Profiling Scoring Criterion (FSANZ NPSC) to regulate the use of health claims since 2016 (172).

Portugal implemented mandatory regulations to restrictions on food advertising directed at those under 16 years of age (Law No. 30/ 2019 of 23 April). This law provides for a ban on the advertising of foods with high energy value and high sugar, saturated fatty acids, trans fatty acids and salt content (157). With the approval of this law, a NP model was defined to restrict food advertising to children. The NP model was developed by PNPAS and published in August 2019 through Order No. 7450-A/2019 (158,159). From this moment a valid tool became available to enable decision-making, from regulation to marketing/promotion or food reformulation.

The NP model is based on the WHO-EURO NP model with some adaptations to align the nutrient thresholds for some food categories with the European Union legislation. The model establishes nutritional criteria for various categories of foods, to restrict the promotion of foods and beverages with high energy, salt, sugar, saturated fatty acids and trans fatty acids to children under 16 years of age (159).

8.1.2 Breakfast cereals intended to children: opportunities for reformulation and potential impact on nutrient intake

In this study, the application of NP models in the domain of food composition/reformulation was addressed. The purpose of this work was to add evidence on the ability of the NPM-PT, to discriminate foods that can (or cannot) be promoted to children, by comparing with other models, as well as to test the capacity of the NPM-PT to guide a theoretical reformulation of RTECs marketed to children.

What was known

The application of NP models as tools to identify foods that can (or cannot) be marketed to children constitutes an emerging area of research in different countries (2,60).

RTECs have become a popular breakfast option claiming to provide important nutrients to children's diets, despite being a source of excess sugar and, therefore, a health concern (173). Thus, food reformulation is an important public health strategy that has long been seen as a promising public health strategy to tackle poor nutrition and obesity, and which could benefit from the inputs provided by NPM (63,108).

In this context, the following questions were addressed: (i) what is the compliance rate of the RTECs for children available in the Portuguese supermarket, considering three

NP models designed to restrict food marketing and advertising to children-the NPM-PT, WHO-EURO, and EU-Pledge; (ii) what is the potential for reformulation of the RTECs identified as not adequate; and (iii) what is the impact of RTECs reformulation on the nutritional quality of Portuguese children's diets.

According to the obtained results, the levels of total sugar in children's RTECs were considerably higher (174). Rito et al. also found that infant cereals had the highest total sugar content of all RTECs in Portugal (173).

Comparing the different NP models used in the present study, we verified that the WHO-EURO is the most restrictive NPM followed by the NPM-PT. The EU-Pledge is the most tolerant regarding the restrictions to the marketing of foods for children. This was already described in different contexts (175,176).

The scenarios of reformulation considered could reduce the RTECs average content of total sugars, SFA, and salt by 43%, 8.7%, and 1.1%, respectively, and dietary fiber intake could be increased by 34% (174). The results from the Muth et al. study showed that reformulating a few categories of foods and beverages to reach the levels of products meeting an existing standard could improve dietary intake, particularly for saturated fatty acids, sugars, and fiber (177).

What this study adds

This was the first study applying a national policymaking tool, the NPM-PT, to classify RTECs as suitable/unsuitable for promotion to children. This study has shown that the NPM-PT can be a useful tool to use in conjunction with interventions to improve children's diets such as comprehensive reformulation strategies.

Combet et al tested a category-specific nutrient profiling system developed for product reformulation and found that the system was suitable to identify reformulation priority areas, across several countries with contrasting eating habits and levels of industrialisation (109).

Food reformulation can be a challenge, especially as nutrients such as sodium, fat, and sugar often play a role in the technological and sensorial functions of these products. Sugar, for example, is used for taste or texture, for preservation, and as a bulking agent, and salt is a preservative that prevents spoilage (178,179).

It is important to define feasible reduction targets without having to replace them with other ingredients, such as sugar by sweeteners. Additionally, it is necessary to define a gradual reduction to achieve the adaptation by the consumer to products with a lower amount of salt and sugar (180,181).

In our study, we propose the inclusion of dietary fiber in the NPM-PT, as a nutrient to encourage' contributing to the improvement of its intake and complying with the recommendations for dietary fiber intake. The UK Ofcom model and the Health Star Rating system are examples that consider the contribution of nutrients or food components to encourage (182,183). However, this should be assessed with caution as the inclusion of nutrients/foods to be promoted makes the model more permissive, resulting in some foods that are not consistent with dietary guidelines being eligible for marketing to children (184).

Data from the present study are intended to assist and support the industry companies, nutrition professionals, and policymakers to identify new avenues of research and regulatory actions associated with the implementation of reformulation strategies for developing healthier food products to be promoted to children.

At the national level, this research serves as a call for policymakers to consider the NPM-PT as a tool to promote the reformulation of RTECs and other child-targeted foods available in the market.

8.1.3 Nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score* and consistency with nutritional recommendations

This study is based on the application of NP models, in the domain of food labelling, that aimed to assess the nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score* and to investigate the consistency with the food-based dietary guidelines.

What was known

In the last few years, public health authorities have shown interest in introducing FOPL as one of the main policies to counteract diet-related NCDs (14).

Several front-of-packs labelling systems (FOPLs) have become established around the world. The best-known systems include the British Traffic Lights, the Keyhole in

Scandinavian countries, the New Zealand and Australian Health Star Rating, the Chilean Warning Labels and the French *Nutri-Score* among many others (78).

Various studies have shown that the algorithm underlying *Nutri-Score* can discriminate the nutritional quality of foods, obtaining a score mostly in line with nutritional recommendations (185,186). Furthermore, *Nutri-Score*, when compared to other NP models, was found to be the most effective in terms of encouraging consumers to make healthier food choices and simultaneously helping to assess the nutritional quality of products (187,188).

Several European countries are considering the implementation of the *Nutri-Score*, however, some concerns have been expressed especially for the validation, which was mainly conducted in the French context, and consequently, the algorithm may not reflect the food-based dietary guidelines from other countries (88,186).

In this context, the main aims of this study were 1) to investigate the nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score*, and 2) to investigate the consistency of these foods with the Portuguese food-based dietary guidelines, as a contribution to the validation of this FOPL in the Portuguese context.

Our study showed the *Nutri-Score* based on the FSAm-NPS profile had a good performance to discriminate the nutritional quality of products across and within food groups and product groups, with at least three classes of *Nutri-Score* represented. The food classification according to the *Nutri-Score* was consistent with the nutritional recommendations.

Our results are in line with previous studies that examined the *Nutri-Score* discriminating ability and consistency with dietary recommendations. Szabo de Edelenyi et al. found the classification of foods according to the *Nutri-Score* was consistent with German Food-Based Dietary Guidelines i.e. foods whose consumption is recommended were more favourably classified than foods whose consumption should be limited (189). Hafner and Pravst in their study profiled 15.822 products available in the Slovenian and found *Nutri-Score* had a high ability to discriminate food products based on nutritional composition. Products that are generally encouraged in dietary recommendations had, in most cases, better *Nutri-Score* grades than less favourable products, which is also in line with the national nutrition policy programme (190).

What this study adds

There is currently a global public debate on the need to introduce simplified nutritional labelling on food, as part of a wider policy approach to improve human diets (39). FOPL is a public health measure that can represent significant advantages for literacy and populations' health (80). However, these tools will have a sub-optimal impact if they are not linked to policies changes that address the causes of poor diet quality in the social determinants of health (74).

The results of our study provide evidence to validate the choice of the FOPL *Nutri-score* model in the national context, contributing to a healthier food choice of Portuguese consumers. Appropriate food labelling with a system such as *Nutri-Score* can be relevant to health-promoting purchasing choices, improving diet quality and consequently public health. According to Goiana-da-Silva et al, it is safe to assume that *Nutri-Score* would be an adequate FOP labelling system to be considered and endorsed by Portugal (191).

8.1.4 Commercial baby foods aimed at children up to 36 months: are they a matter of concern?

This study assesses the nutritional quality and packaging characteristics of foods intended for IYC up to 36 months of age, available in the Portuguese retail food environment. It is focused on the application of a proposed NPM to identify foods that may be considered suitable to be marketed for IYC under 36 months, to ensure that permitted products are promoted appropriately and what is the degree of processing, as defined by the NOVA classification system.

What was known

Food preferences begin to take shape during fetal development and continue to change throughout life, influenced by biological, social and environmental factors (192). These preferences are key determinants of food choice, and therefore diet quality. Good nutrition in infancy is vital for normal growth and development, helps establish taste preferences and may have implications for health throughout life (193).

Adequate complementary foods, solid, semi-solid and soft, while breastfeeding continues until 2 years of age or older, represents a window of opportunity for infants to establish long-term healthy dietary patterns (121,132) However, the role of these products in an appropriate complementary feeding has been widely debated, driven by concerns regarding their nutritional content and potentially problematic marketing strategies used to promote these products (122).

In 2016, the WHO Guidance on Ending the Inappropriate Promotion of Foods for IYC was approved, to support countries to take action on this issue (161). To implement this Guidance, a NP model for CACFs for infants under the age of 36 months was developed to drive the decisions regarding the identification of foods that are inappropriate for promotion, in particular to reducing the intake of free sugars and salt (124).

Another relevant aspect is ultra-processed foods, which constitute an increasing proportion of children's diet as several researchers have found in recent studies (125–127). Consumption of UP foods during childhood has been linked to obesity and cardiometabolic risk factors in children and adults (128,129).

Concerning these issues, a study was carried out to address the following points: 1) What is the compliance of CACFs for IYC sold in the Portuguese marketplace according to the criteria of the NP model? 2) What is the degree of processing, as defined by the NOVA classification? 3) Are the findings adequate to provide a proposal for updated regulation and to promote the reformulation of foods for IYC?

The results of our study show that most categories of CACFs are high in sugar content. The use of added sugar/fruit juice or concentrates as an ingredient is widespread in CACFs. The percentage of products that did not meet all the nutritional requirements of the NP model was high and an early introduction of UP foods in the IYC diet is probable, due to the high number of products indicated for children <12 months classified as UP foods. Similar results were found in the studies conducted by Grammatikaki et al. that reported 38.5% of the products contained at least one sugar-contributing ingredient (added sugars, free sugars, Fruit and Vegetable purée or Fruit and Vegetable powders) (135) and Da Rocha et al. that found in their study 79%% of the baby foods were UP foods (194).

What this study adds

The sugar content of commercial baby foods across several CACFs categories is high and contrary to existing health guidelines to restrict sugar intake in IYC (116,195). The law needs to be reviewed and updated to support and guide the reformulation of these products. In addition, more effective regulatory measures are needed to guide the infant and toddler food industry on the manufacture of food using lower levels of processing.

This research provided a valuable insight into CACFs at the national level, reinforcing firstly the importance of implementing the WHO guidelines on the assessment of commercially available foods for IYC as a strategy to improve complementary feeding practices, and secondly the importance of assessing the food processing characteristics of processed foods and beverages targeted to IYC under 3 years of age.

Providing parents and health professionals with correct nutrition information on food labels, to assist in the choice of complementary and infant foods, will be an opportunity to prevent NCDs (161,196).

8.2. Limitations of the research

There are several limitations to the research, many of which have already been identified in the 'Discussion' section of each of the manuscripts. This section highlights the key limitations and notes ways in which these could be addressed in future research.

8.2.1 Nutrient profiling

Nutrient Profiling is a scientific method that assesses the nutritional quality of foods and beverages by categorising, ranking or classifying them according to their nutritional composition and their impact on health regarding disease prevention and health promotion (58).

NP models have provided the scientific rationale for numerous educational, labelling, regulating marketing and advertising to children and tax initiatives. NP models are the basis of multiple front-of-pack symbols and logos that communicate a given food's nutritional value to the consumer. NP models have also provided the necessary benchmarks for product reformulation by the food industry (2,197,198).

NP models, designed to help consumers identify nutrient-rich foods, make food purchasing decisions and improve diet quality by encouraging a healthy diet, have become an important public policy tool (2).

NP models have some limitations as cannot solve all problems with diet and health, such as the nutritional composition of an individual food does not determine the profile of the overall diet or dietary pattern; it also does not reflect other concerns that people have about food (e.g. ethical, religious and environmental concerns) (199).

NP models are primarily concerned with the nutrients and energy content of food, and rarely include substances that are not nutrients but may be considered alongside nutrients (e.g. phytochemicals), and do not cover other substances such as pathogens, contaminants and food additives that may affect the health of some, particularly vulnerable, people (199).

NP models cannot change consumers' eating habits (e.g. if the NP model is based on portion size and its use to regulate a serving), although the serving guidelines on the packaging and the presentation of the nutritional information per serving may help them to consume the recommended portion in agreement with national dietary guidelines (197). There is also not enough evidence to establish a link between NP models, healthy foods, healthy diets and general health (200).

Although the nutrient profile does not address all aspects of nutrition, diet and health, it is a useful tool that can help promote public health dietary goals by ensuring consistency with national guidelines to encourage a healthy diet and prevent obesity and NCDs (58,59).

8.2.2 Possible application of NP models

This thesis addresses the application of NP models in the national context, as a tool for food labelling, food composition/reformulation and food promotion. Concerning the application of NP models to restrict food marketing to children, one of the primary applications of NP models (2), this research did not consider the broadcast (television and radio), or to other media, such as digital social media platforms, apps or ‘advergames’ (an online game which in some way contains an advertisement), as well as restriction of food advertising in schools (33).

The digital environment is a rapidly evolving and changing area, providing new opportunities for advertisers to reach key audiences, including children and their carers, as well as new challenges for policymakers (142).

An increase in exposure to marketing in the often unregulated digital sphere has become an area of concern as the digital environment has changed significantly. Children's screen time has shifted from primarily broadcast media to phones, computers and tablets, where major media platforms are over-flooding cyberspace with advertising (142).

Also, this research did not consider the adoption of NP models for specific healthy diet policies, such as a healthy public food procurement and service policy for schools. School-aged children seldom meet recommended fruit and vegetable intake, frequently consume sugar-sweetened beverages, and often eat at fast-food outlets. Rapidly changing food environments, with increased availability of unhealthy food, are not conducive to promoting healthy diets (41).

NP models (e.g. WHO- NPM, NPM-PT), provide nutrient-based criteria for food categories that would be prohibited from marketing to children, and some countries are already adopting them for school foods. The NP model could be a starting point for developing nutrient-based criteria for healthy public food procurement and service policies.

8.2.3 Data Collection and Analysis

In this thesis, a standard approach to supermarket food monitoring in studies 2 and 4 was undertaken to collect the information presented on food labels, based on a convenience sample. Such an approach had several challenges: the studies were only conducted in selected shops; it involved a great human effort to collect the information presented on the photographed foods and the nutritional information on their packaging; a long period was needed to complete such studies: by the time data collection and analyses are completed, the situation in the food supply may already be different; the accuracy of the data is limited to the accuracy of the data provided on food labels.

This limitation can be overcome by making available branded food databases that can be used directly for assessments of the nutritional composition of food in the food supply (e.g. salt, sugar content), use of specific ingredients, for example, food additives, for nutrient profiling, and the assessment of marketing techniques on food labels. Such datasets are also valuable for other studies, for example, for nutrient intake assessments in dietary surveys. In an ideal situation, the composition of branded foods would be provided in an open-access format automatically by food manufacturers (201,202).

In data analysis, a limitation was identified regarding access to commercial food sales and purchase data, as access is restricted for a fee. This would have been an added value for the studies that were carried out as they are a complementary source of information to evaluating some food policy interventions, including tracking the nutritional quality of the food supply and assessing how individual food companies are responding to mandatory or voluntary targets for food reformulation (203).

In the third study, data were obtained from food samples collected for the PT-TDS study, whose main objective was to assess the exposure to contaminant residues and may not reflect the representativeness of the food samples consumed by the Portuguese population. However, we aimed to assess the discrimination capacity of the *Nutri-Score* and through PT-TDS it is possible to assess dietary exposure not only to contaminants but also to beneficial substances (nutrients) through food. In addition, there are some differences concerning the number of food items available in some food groups, however, the results were consistent with the literature.

Another limitation of the present study remains the somewhat arbitrary aspect of the measurements of the discriminating performance of the FOPL and the consistency with dietary guidelines. Nevertheless, in the absence of a consensual indicator to which to compare the performance of nutrient profiling, we used a similar methodology to previous studies (185,189).

8.3. Implications for public health practice and research

One of the objectives of public health nutrition policy is to shift the population towards healthier diets through changes in the food environment and, ultimately, in eating behaviour (204).

Overweight and obesity among children and adolescents is a matter of concern in many countries and represents a serious health and social challenge with immediate negative consequences for the children concerned. Children and adolescents who are overweight or obese are at a greater risk of poor health, and this effect persists into adulthood (137).

The environments in which we grow, play, live and work also have a significant impact on the development of our food preferences and choices and the overall nutritional quality of our diets. Therefore, tailored policies and interventions are needed to create healthier food environments, where Nutrient profiling could be used to transform food systems and support health-promoting food policies (33).

Nutrient profiling is a scientific method that evaluates the nutritional quality of foods and beverages, categorizing, classifying or ranking them according to their nutritional composition and their impact on health as regards disease prevention and health promotion. These categorisations can form an important part of policies aimed at improving public health nutrition and preventing diet-related chronic disease (60).

Using NP models it is possible to design measures to promote food and beverage reformulation, eliminate trans fatty acids and restrict the marketing of HFSS foods to children, as well as efforts to increase the availability and promotion of healthy foods (e.g. in school settings) and implement interpretive labelling for guidance on healthy food choices (2).

The development of a harmonised mandatory front-of-pack nutrition labelling will enhance transparency for the consumer, improve consumers' understanding of the nutritional value of foods when purchasing them and incentivise food producers to produce healthier foods. Appropriate food labelling based on a system that grades products within a product category, such as *Nutri-Score*, can be relevant to health-promoting purchasing choices, improving diet quality and consequently public health (205).

Another important issue is the inappropriate promotion of foods for IYC, because can interfere with breastfeeding, contribute to obesity and NCD, undermine the use of suitable home-prepared or local foods, and /or create a dependency on commercial products. Thus, the NP model proposed by the WHO Regional Office for Europe sets out nutrient composition standards, labelling requirements and promotion restrictions for foods marketed as suitable for IYC up to 36 months (124).

With the application of the proposed NP model at the national level, it was found evidence of widespread inappropriate promotion of commercial foods for IYC according to WHO criteria. These results are in line with other recent studies and confirm the trend that many commercial foods for IYC up to 36 months are high in sugar and/or have added sugar (133,135,147,149).

Our findings highlight the importance to consider the reduction of sugar content in commercial foods for IYC. This can be achieved by defining actions for reformulation of the nutritional composition of these food products, through an articulated action with the food industry. Also should be considered an improvement in the product labelling to allow distinguishing between added and intrinsic (natural) sugars; labels should clearly show the contribution of added and natural sugars, and preferably show this information on the front of the packaging. To further highlight products with high sugar content, consideration should be given to including a flag, icon or traffic light to highlight the energy percentage of sugars in the FOPL (124).

The above measures should be aligned and, in parallel, political investment in food literacy should be considered to promote healthy eating habits not only among children and young people but among the whole population, reinforcing good labelling, advertising and marketing practices of food products (13).

Food and nutrition literacy are relevant issues in achieving the sustainability of the food system and may play a vital role in improving individuals' eating quality (206).

The food environment is critical for ensuring access to sustainable healthy diets. It is important to implement consistent and coherent policies to make healthy sustainable foods easy, affordable and preferred choices.

Concerted actions from government, private sector, and civil society is needed so that food environments deliver equitable access to sustainable healthy diets (207).

9. Conclusions

This thesis has investigated the application of NP models, in the domains of food labelling, food composition/reformulation and food promotion. It demonstrated that there is substantial scope for using nutrient profiling as part of tailored policies and interventions to:

- ✓ **create healthier food environments**: improving the nutritional quality of foods available, using product reformulation; using easy-to-understand or interpretive and consumer-friendly labelling on the fronts of packages; adopting measures to reduce the impact on children of all forms of marketing of foods high in energy, saturated fat, trans-fatty acids, sugar or salt.

- ✓ **promote the gains of a healthy diet across the life course, especially for IYC**: implementing a strategy to monitor the nutritional composition, labelling requirements and promotion restrictions of CACFs foods available for IYC, to identify foods that may be considered suitable for marketing to IYC under 36 months and to ensure that permitted products are promoted appropriately.

From the results generated in all studies included in this dissertation the following conclusions can be drawn, linked to the previously formulated research objectives:

OR 1. Address a comprehensive review to clarify the importance of NP model as a tool to establish public health interventions concerning consumers' food choices.

This study found that assessment of the nutritional quality of food through NP model involves multiple decisions. Nutrient profiling has a wide range of applications including front-of-pack (FoP) food labelling, regulation of food marketing to children, regulation of health and nutrition claims and school food standards. Nutrient profiling was developed in response to a series of measures and agreements established between the food industry, policymakers, and public health legislators, to improve diet quality and increase healthy eating habits among the population. Nutrient profiling is considered a very valuable tool to support consumers in the choice of healthier food based on their nutrient composition.

OR 2. Identify the potential role of NP models in the reformulation of food products as a means for improving the nutritional quality of Portuguese children's diets.

The obtained results reveal levels of total sugar in children's RTECs were considerably higher. Comparing the different NP models used in the present study, we verified that the WHO-EURO is the most restrictive NP model followed by the NPM-PT. The EU-Pledge is the most tolerant regarding the restrictions to the marketing of foods for children. The RTECs reformulation, considering the nutrient thresholds defined by the NPM-PT, could reduce the intake of total sugars, SFA, and salt and improve the intake of dietary fiber.

This research serves as a call for policymakers to consider the NPM-PT as a tool to promote the reformulation of RTECs and other child-targeted foods available in the market. This research aimed to provide evidence for policymakers to consider the NP models as a tool to be implemented for the reformulation of food products targeted to children, and to develop healthier food products.

OR 3. Characterized the application of NP models in the domain of food labelling, to assess the nutritional quality of foods consumed by the Portuguese population according to the *Nutri-Score* and to investigate the consistency with the food-based dietary guidelines.

Our study showed the *Nutri-Score* based on the FSAm-NPS profile had a good performance to discriminate the nutritional quality of products across and within food groups and product groups.

The food classification according to the *Nutri-Score* was consistent with the nutritional recommendations. The results of our study provide evidence to assume that *Nutri-Score* would be an adequate FOP labelling system to be considered and endorsed by Portugal.

OR 4. Assess the application of a NP model proposed by the WHO Regional Office for Europe to identify which CACFs are appropriate/inappropriate for promotion to IYC up to 36 months of age and what is the degree of processing, as defined by the NOVA classification system.

This study provided an overview of the nutrient profile, promotion aspects of product packaging, use of nutrition and health claims and level of processing of CACFs, and contributes knowledge to the implementation of the WHO's guidance on these foods.

The study results showed that the total sugar content of several categories of CACF was higher than recommended and in contradiction with the guidelines to restrict sugar intake in infants and young children. Furthermore, our study revealed an early introduction of UP foods with more than 50% of products indicated for children under 12 months.

This work has reinforced firstly the importance of implementing the WHO guidelines on the assessment of commercially available foods for IYC as a strategy to improve complementary feeding practices, and secondly, the importance of assessing the food processing characteristics of processed foods and beverages targeted to IYC under 3 years of age. Furthermore, endorse the importance of innovative interventions in the field of consumer education to decrease UP foods consumption while promoting the consumption of natural and MP foods.

This study has contributed evidence to operationalize the implementation at the national level of the NP model proposed by WHO to guide decisions on the promotion and nutritional quality of commercially available foods for IYC and to policymakers to update regulation and guide product reformulation concerning the sugar content of CACFs.

The implementation of measures aimed at modifying food environments, based on the NP model, represents a key area of intervention, to support a healthy diet for children and contribute to the fulfilment of the fundamental right to healthy food and adequate nutrition, to which all children are entitled.

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