SNACKIFICATION:

Understanding healthiness and naturalness in snacking products

Michelle Klerks

Propositions

1. Anything can be a snack.
   (this thesis)

2. Healthy, natural, but tasty snacks are key to meet consumer and public health demands.
   (this thesis)

3. Human intelligence will always be required in addition to artificial intelligence.

4. Requiring researchers to peer-review a manuscript of others first before submitting their own manuscript accelerates the academic publishing process.

5. Social media is an unreal version of reality.

6. Evidence-based parenting education prior to childbirth is essential for future parents to prevent them from deception by misinformation.

Propositions belonging to the thesis, entitled:
Snackification: Understanding healthiness and naturalness in snacking products

Michelle Klerks
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Michelle Klerks

Thesis committee

Promotor
Prof. Dr V. Fogliano
Professor of Food Quality and Design
Wageningen University & Research

Co-promotors
Dr L.M. Sánchez-Siles
Director, R&D Baby and Toddler Food & Group Knowledge Management
Hero Group, Alcantarilla, Spain

Dr R. Verkerk
Associate Professor, Food Quality and Design
Wageningen University & Research

Other members
Prof. Dr E.H. Zandstra, Wageningen University & Research
Dr J.H.M. Dijk, Wageningen University & Research
Dr E.M. Brouwer-Brolsma, Wageningen University & Research
Prof. Dr M. Siegrist, ETH Zürich, Switzerland

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Thesis

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CHAPTER 1

General Introduction

1.1 Introduction

To date, a consistent definition of "snacks" and "snacking" is still absent. Yet, these terms are frequently used in literature in relation to their impact on people's diets, health, or consumption trends. Some people consider packaged indulgent food items as snacks, such as chips or chocolate, while others also consider fruit or dairy products as snacks. Irrespectively of its definition or what comes into people's mind when hearing the term "snack", it is apparent that our traditional eating behaviour is shifting from three substantial meals in a day to the frequent consumption of smaller amounts of food (Chaplin & Smith, 2011). This new way of eating is also known as "Snackification", which has been considered a trend that is here to stay (Mellentin, 2021).

As the prevalence of overweight and obesity is increasing worldwide and climate is changing (Swinburn et al., 2019), consumers' awareness and concerns about their own and the planet's health are widespread. Their concerns result in a demand for healthy, natural, and sustainable foods, also when it comes to snacks (Arenas-Jal et al., 2019). Corroborating with these consumer demands, the snack market moved away from mainly traditional indulgent snacks to a more nutritive and innovative offer. In fact, snack products are an excellent and relatively accessible way to implement additional benefits through people's diets, for example, by including functional ingredients or increasing protein content (Mellentin, 2021). Nonetheless, taste is – besides convenience and costs – consistently reported as one of the most important attributes of food choice (Daly et al., 2022).

To meet consumer demands, manufacturers are driven to (re)formulate their snacks towards healthier and more natural products while maintaining an appealing taste. Accordingly, to get a better understanding of which approach manufacturers should take, the research in this thesis investigated the healthiness and naturalness in snacking products, compared different snack categories and snacks for different target populations (babies, children, and adults) accordingly, and evaluated consumer acceptance of healthier and more natural reformulated snacks. Background information on the Snackification trend, food healthiness and naturalness, and the opportunities and challenges of new product development and reformulation is provided in the following sections of the first Chapter.

1.2 The rise of Snackification

1.2.1 Definitions of snacks and snacking

The noun “snack” appears to have been borrowed in the fourteenth century from the Middle Dutch “snacken”, which means “to bite” or “to snap”, referring to the sound of the snapping together of teeth. Later, in the mid-eighteenth century the meaning was narrowed down to “small portion of food eaten” upon which a century later the verb “snack” was created (Ayto, 2012). At first, this definition might seem clear, however, upon a second reading the definition is quite ambiguous. How small is “small”? What is meant by “food”? Indeed, snacks and snacking are difficult to define and to study, as these concepts depend on a combination of many external factors such as the moment, purpose, type of food, duration, context, among others (Hess et al., 2016). The term “snack” is dynamic, and does not have a fixed definition (Johnson & Anderson, 2010). Current definitions applied in studies as well as those perceived by consumers differ in nature and may include different dimensions such as the moment, type, and duration. To illustrate, various definitions used in literature and perceived by consumers are presented in **Table 1.1** and **Table 1.2**, respectively.

It can be concluded from these overviews, which are merely a glimpse from literature, that many definitions are employed. For example, a common definition in literature is “All foods, excluding beverages, healthy and unhealthy, consumed in between regular meals”. However, one could argue why drinks are left out of the definition. The inconsistent definitions of snacks and snacking used in existing literature affect data collection and consequently restrict the extent to which findings across studies can be generalized and pose therefore a challenge in science.

Regardless of the various definitions of snacks and snacking that exist, the primary focus of this thesis is on commercial snack products that are produced by the industry. In particular, the snack products of focus include snack bars (cereal and chocolate bars), biscuits, and baby yoghurt pouches.

1.2.2 Consumer mega-trends, macro-trends, trends, and fads

As Snackification is central to this thesis, a general understanding of the different types of trends is essential. In general, trends could be divided in different types: mega-trends, macro-trends, trends, and fads (Boschetto Doorly, 2020). Mega-trends are transformative phenomena that have the power to shape our societies at global level, usually over a period of decades. They can be seen as the backbone of our community. Current key mega-trends are, for example, the rapid urbanisation, climate change, and technological breakthroughs. Macro-trends are long lasting trends with a slow period of acceptance, but with a big impact on consumers. They usually involve several industries at a time.

Table 1.1. *Definitions of snacks and snacking as defined in scientific literature. Dimensions are expressed in bold.*

Authors and year of publication	Definition	Dimensions						
		Moment	Purpose	Type	Nutrition	Duration	Context	PPP*
McArthur et al., 2021	"Any **food or beverage** consumed **before or after meals**"	✓		✓				
Gage et al., 2021; Hess et al., 2017; Taillie et al., 2015	"All **foods and drinks (>0 kcal)** consumed **between or outside the three main meals**", or "Any **food or beverage**, **excluding water**, consumed **in-between main meals** (breakfast, lunch, or dinner)" or similar	✓		✓	✓			
Ait-Hadad et al., 2020; Damen et al., 2021; Forbes et al., 2015; Franja et al., 2021	"Any **between-meal food** intake" or "All **foods, excluding beverages**, healthy and unhealthy, **consumed in between regular meals**" or similar	✓		✓				
De Cock et al., 2018	"All **food items** consumed **outside (>30 minutes) of breakfast, lunch, and dinner**"	✓		✓		✓		
Piernas & Popkin, 2010	"Event of intake of **foods within a 15-minute period** and excludes all food that are defined as snacks **but eaten as part of a meal**"	✓		✓		✓		
van den Broek et al., 2018	"The consumption of **sweet or savoury palatable food** products"			✓	✓			
Gatenby, 1997	"Snacks refer to other **eating episodes**, generally **smaller** and **less structured** than meals, while snacking refers to the patterns of frequency of these eating events consumed **at times other than recognized meal times**"	✓		✓			✓	✓

PPP = Portion, package, price

On the contrary, trends emerge from rather specific industries or consumer groups and last around two to three years. "Health and Wellbeing" and "Gut Health" are examples of macro-trends and trends, respectively. Fads differ from trends in the sense that they are short living; they develop fast, and disappear suddenly (e.g., "Goji berries"). They reach a sudden popularity, but within one year they will be replaced by another fad (Boschetto Doorly, 2020). Driven by the mega-trend of urbanisation, snacking began to take off particularly in the United States around the 1950's. In recent years, our lifestyles became busier than ever, and consumers seek more convenient food solutions due to time constraints. It were mainly the millennials that turned snacking into the prevailing trend of Snackification (CSNews, 2016; Mondelez International et al., 2023), and it may well be that this trend will persist and gradually evolve the coming years into a macro- or even a mega-trend.

Table 1.2. *Definitions of snacks and snacking as perceived by consumers. Dimensions are expressed in bold.*

Authors and year of publication	Definition	Dimensions						
		Moment	Purpose	Type	Nutrition	Duration	Context	PPP*
Chaplin & Smith, 2011	"The best definition of snacking was **food or drink** eaten **between main meals**"	✓		✓				
Wansink et al., 2010	"**Eating alone**, **paper napkins**, **10 minutes**, **paper plates, standing, inexpensive**, **small portion**, **low quality and quantity**, **packaged**, **unhealthy**"			✓	✓	✓	✓	✓
Younginer et al., 2016	"Individuals' definitions of snacks are based on the interrelated dimensions of **types of food**, **time**, **location**, **portion size**, and the **purpose** for giving a snack"	✓	✓	✓			✓	✓
Crofton et al., 2013	"A snack was described as a **small**, **tasty**, **convenient food** that is typically eaten **between the regular mealtimes** of breakfast, lunch and dinner"	✓	✓	✓				✓
Gangrade et al., 2021	"A **small**, **unhealthy food** item that can be **quickly eaten** to **reduce hunger between meals**"	✓	✓	✓	✓	✓		✓

PPP = Portion, package, price

1.2.3 Consumer snacking behaviour

The snack food sector is growing in response to increasing consumer snacking behaviour. In 2023, the revenue in the snack food segment is worth more than 500 billion dollars, and the market is expected to grow annually by 5.6% (compound annual growth rate of 2023-2027) (Statista, 2023). According to the State of Snacking Global Trend Study 2022, 71% of consumers worldwide reported to snack at least twice a day. Despite current increasing food prices, consumers – especially millennials – acknowledge to always have room in their budget for snacks (Mondelez International et al., 2023). Not only adults are increasingly snacking, toddlers and children have been shown to frequently snack too (Dunford & Popkin, 2018; Ziegler et al., 2006). While snacking usually happens mainly in the mid-morning, mid-afternoon, or during the evening (Chaplin & Smith, 2011; Forbes et al., 2015), consumers are now increasingly replacing meals by spontaneous ewating moments which are not restricted to specific times or locations (Doppler & Steffen, 2020). In fact, the majority of households (55%) make a meal out of snacks on a weekly basis, preferring a variety of small plates rather than one big plate (Mondelez International et al., 2023). Boundaries between meals and snacks are clearly fading, with 69% of snack consumers considering "anything" can be a snack, including pizza, soups, and other traditionally meal-focused foods (Mintel, 2019a).

In general, people's attitudes towards food and food choice are greatly influenced by their cultural beliefs as well as contextual circumstances (Hess et al., 2016; Rodríguez-Arauz et al., 2016). Depending on the context (i.e., time of the day, location, social context, etc.), there may be different motivations driving consumer's snacking behaviour. Hunger, nutrition/energy, cravings, and pleasure are examples of such snacking motivations (Forbes et al., 2015; Hess et al., 2016; Nielsen Company, 2014; Phan & Chambers, 2016a, 2016b). Hunger has been reported to be an important motivation for mothers too, when providing a snack to their children. Damen et al. (2021) showed that many mothers of 2-3-year-old toddlers give a snack to satisfy their child's hunger in-between the main meals (Damen et al., 2021). Furthermore, snacks may also be given for calming/soothing reasons, or to introduce the baby to different textures and flavours (Moore et al., 2021).

1.2.4 Effects of COVID-19 on consumer snacking behaviour

The COVID-19 pandemic disrupted the lives of many families and negatively impacted both mental and physical health of many individuals. People suffered from stress and anxiety, which in turn was associated with food motivation (Smith et al., 2020). Increased mindless eating and snacking was designated as the most frequent COVID-19-related eating disturbance (Simone et al., 2021). In fact, snacking behaviour increased during this period for a substantial part of children (Androutsos et al., 2021; Cena et al., 2021; Zemrani et al., 2021) and adults (Bakaloudi et al., 2021; Chee et al., 2020; Sideli et al., 2021) worldwide. It seems that snacks remain essential for consumers in tough times as they "help them take their mind off the issues of the world", as evidenced by the State of Snacking Global Trend Study (Mondelez International et al., 2023). During the pandemic, consumers highly demanded treats and comfort foods as a coping mechanism, with both chocolate and sugar confectionery growing in most countries (Mellentin, 2021). In contrast, health and wellness also became a significant priority during the pandemic (Lockyer, 2020; Mintel, 2020a; Rodríguez-Pérez et al., 2020). This reinforced the need for immunity-boosting foods to prevent illness (Mintel, 2021a) and increased the consumption of healthy snacks (Mayra et al., 2022). Now, while the majority of the world has gone back to the "new normal", many people will continue to work from home for at least a part of the week. Hence, the need for products that can be healthy lunches and/or snacks at home will remain (Mellentin, 2021).

1.3 Food healthiness

1.3.1 Snacking in relation to health outcomes

Snacking has been linked in scientific literature to both positive and negative health outcomes. The increase in body weight, in children as well as in adults, has partly been attributed to the increased consumption of energy-dense, discretionary snacks, which are often high in sugar, salt, and fat (Almoraie et al., 2021; Dunford & Popkin, 2018; Johnson et al., 2017; Maalouf et al., 2017; Shroff et al., 2014; Skoczek-Rubińska & Bajerska, 2021). Nonetheless, some studies could not find an association between snack frequency and body weight (Cowan et al., 2020; Field et al., 2004; Gibson et al., 2020; Hartmann et al., 2013; Tucker et al., 2021), while others even found beneficial effects of snacking on health (Keast et al., 2010; Larson & Story, 2013) and diet quality (Zizza & Xu, 2012). Discrepancies in results indicate that the effects of eating frequency on weight and other health outcomes are still not well understood. The inconsistency in research designs (e.g., the way snacks are defined), as well as the variety of potential confounders (e.g., sleep deprivation, physical activity), make interpretation of findings challenging and has led to little agreement on the optimal number and composition of snacks for bodyweight control and health (Mielmann & Brunner, 2019; Miller et al., 2013).

Despite common belief that snacking inherently implies deterioration of the diet, it has been shown that adequate snacks could perfectly fit within a healthy dietary pattern (Marangoni et al., 2019). Snacking as part of a balanced diet may improve diet quality, and even moderate blood sugar and metabolic disease risk factors (Hunter & Mattes, 2020). Hence, the development of healthier snacks high in beneficial nutrients is imperative to foster healthier diets (Almoraie et al., 2021).

1.3.2 Healthy foods: consumer preference and perception

Health is a frequently stated and growing determinant in consumer food choices (Cunha et al., 2018; Pinto et al., 2021). Consumers are becoming more knowledgeable and concerned about their health and well-being and are making informed decisions to prioritize healthy food purchases (Arenas-Jal et al., 2019). Nevertheless, consumer perception of food healthiness is not a single unifying construct. Healthiness perceptions are shown to be based on multiple underlying factors related to nutrients, animal origin, preservation, freshness, and processing (Lusk, 2019). Furthermore, healthiness perceptions may differ among consumers. Yarar & Orth (2018) showed that four types of consumer groups exist. Consumers perceive healthy nutrition either as "what tastes good, in moderation", "expensive and inconvenient", "everything that makes me slim and pretty" or "only home-made, organic, and vegetarian food" (Yarar & Orth, 2018). More specifically, when rating healthiness of snack foods, research suggests that the content of sugar, salt, fat, protein, fruit, vegetable, nut, vitamins, and minerals, and the level of processing and naturalness are relevant criteria for consumers (De Vlieger et al., 2017). However, experts may view health differently as compared to consumers (Bisogni et al., 2012). According to Bucher et al. (2017), expert and consumer definitions of nutritious snacks differ indeed considerably, with experts using terms such as nutrient density, macro- and micronutrients, and calories, while consumers use descriptions such as fuel, fresh, natural, body needs, and functioning (Bucher et al., 2017). Both consumers' and experts' health perceptions should be taken into account in the development of healthier snacks to meet consumer expectations and increase public health.

1.3.3 Measuring food healthiness

Assessment of food healthiness, in this thesis sometimes also referred to as nutritional quality, is usually based on the nutrient composition of a certain food product. Macro- and/or micronutrients could be examined individually or combined using a nutrient profiling model. Nutrient profiling is defined by the World Health Organization as "the science of classifying or ranking foods according to their nutritional composition for reasons related to preventing disease and promoting health" (World Health Organization, 2022). Many nutrient profiling models exist worldwide (Labonté et al., 2018) and serve a number of public health goals, including establishing the scientific foundation for front-of-pack labelling (Julia & Hercberg, 2017) and child marketing and advertising regulations (Rayner et al., 2013).

To promote healthier diets, the European Commission aims to introduce a uniform mandatory front-of-pack label on packaged foods across member states of the European Union as part of its Farm to Fork strategy (European Commission, 2020). A growing body of evidence shows that such labels may be effective to enable consumers in better assessing the healthiness of products (Temmerman et al., 2021), making healthier product choices at the point of purchase (Cecchini & Warin, 2016), and to drive healthier product (re)formulation (Ni Mhurchu et al., 2017). In 2017, the French health authorities selected the Nutri-Score as a voluntary front-of-pack label for packaged food (Julia & Hercberg, 2017). The Nutri-Score labelling system is based on the Food Standard Agency nutrient profiling system and is calculated according to unfavourable and favourable nutrient content per 100g of food and beverages as sold (Julia & Hercberg, 2017). The algorithm computes a numerical score and classifies the product in one of the five categories: A (dark green) for products with the best nutritional quality, to E (red) for products with the worst nutritional quality (Julia & Hercberg, 2017). Following the launch of the Nutri-Score in France in 2017, the label was adopted in Belgium, Switzerland, Luxembourg, Germany, and announced to be adopted in Spain and the Netherlands (AESAN, 2022). A growing number of other European countries are considering the implementation of the Nutri-Score too, strengthened by increasing evidence of the effectiveness of the tool to accurately discriminate the nutritional quality of foods (Dréano-Trécant et al., 2020; Szabo De Edelenyi et al., 2019) and snacks in particular (Hagmann & Siegrist, 2020).

The nutrient profiling model underlying the Nutri-Score is based on the nutritional needs of healthy adults (Santé Publique France, 2022). Since infants and toddlers have different nutritional needs as compared to adults, the World Health Organization proposed another nutrient profiling model especially designed for infants and toddlers aged 6 months to 3 years (World Health Organization, 2022). This model specifies nutritional and promotional requirements for several product categories. Composition requirements include lowering the content of sugar and sweet taste profile of products, while the promotional requirements include improving product naming and messaging to caregivers around product age suitability, warning for high sugar content, and limiting the use of nutritional, health, and marketing claims. The aim of World Health Organization's nutrient profiling model is to evaluate the suitability of existing products for this age group, encourage product reformulation, and guide policy and legislation reform to support public health goals (World Health Organization, 2022). Both the Nutri-Score as well as the World Health Organization's nutrient profiling model are in this thesis used to measure the healthiness of different snacks.

1.4 Food naturalness

1.4.1 What is food naturalness?

The term "naturalness" is used in different contexts and may describe different things. In the context of nature, naturalness can refer to "the quality or state of being natural, that is, not made or caused by humans". In the context of food, naturalness can refer to "the degree to which a food is minimally processed (i.e., preparation, change, or treatment of food) and has nothing added to it" (Cambridge Dictionary, 2023). In line with the latter, it has been described in literature that as products that are processed are perceived as less natural than products that have not been (or only minimally) processed, the absence of human influence is strongly related to naturalness (Siipi, 2013). Rozin described that "naturalness is a desirable state that is hard to maintain […] adding small amounts of nonnatural entities seems to effectively destroy naturalness, whereas adding small amounts of natural entities does little to improve the quality or naturalness of unnatural entities" (Rozin, 2005). In 2017, the International Organization for Standardization (ISO) developed ISO TS 19657, which includes definitions and technical criteria for food ingredients to be considered natural. ISO considers in its criteria a non-natural ingredient what is "not already in nature" (Battacchi et al., 2020). Concluding from these definitions, processing and (the addition or absence of) ingredients are often included in the concept of naturalness (Evans et al., 2010), but a universal, regulated definition is lacking. Moreover, it seems that consumers do not always agree on which ingredients are natural and which are not, implying that individual definitions for what constitutes natural exist (Chambers et al., 2018). In the absence of a regulatory definition, the concept's ambiguity leaves ground for diverse interpretations of the term – both by the consumer as well as by the industry.

1.4.2 Natural foods: consumer preference and perception

Even though the concept of naturalness is ambiguous, consumers do have a clear preference for natural foods (Román et al., 2017; Rozin et al., 2004), resulting in consumers to seek out and purchase foods that are labelled as natural (Cao & Yan, 2016; Cargill, 2017; Liu et al., 2017). Consumers assess the entire product and employ a variety of cues to determine the degree of naturalness of a food (Murley & Chambers, 2019). A systematic review by Román et al. (2017) examining over 70 studies involving nearly 86,000 consumers from 32 countries, indicated that relevant contributors to the perception of food naturalness are related to 1) how the food is grown (relating to its origin), 2) how the food is produced and processed, and 3) the properties of the final product. Consumers prefer organic and local foods that have been minimally processed, and that are free from artificial ingredients, additives, and preservatives. Properties that are often associated by consumers to natural food are healthiness, tastiness, freshness, and eco-friendliness (Román et al., 2017). Furthermore, in a study by Menegassi et al. (2019) natural foods were perceived by consumers as "foods in the form they are found in nature, i.e., having undergone no or little transformation and presented for consumption without additives" (Menegassi et al., 2019). In order for foods to be perceived as natural by consumers, natural-influencing characteristics found in such studies should be properly addressed during product development (Battacchi et al., 2020).

1.4.3 Measuring food naturalness

Built on the framework provided by Roman et al. (2017), Sanchez-Siles et al. (2019) developed a comprehensive index to asses food naturalness which is based on consumer, legal, and technical perspectives (Sanchez-Siles et al., 2019). This comprehensive index – The Food Naturalness Index – allows us to score and compare food naturalness, based on four components, namely: 1) farming practice, 2) free from additives, 3), free from unnecessary/unexpected ingredients, and 4) degree of processing. Scores can be allocated to each of the components and range from 1 (not natural at all) to 5 (extremely natural), except for farming practice that ranges from 2 (slightly natural) to 5 (extremely natural) (**Figure 1.1**).

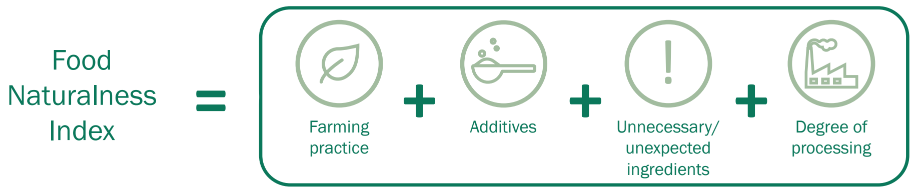

Figure 1.1. *The Food Naturalness Index comprises of four components, namely, farming practice, free from additives, free from unnecessary/unexpected ingredients, and degree of processing.*

The farming practice component distinguishes four categories: conventional, pesticide controlled (i.e., baby food grade), organic, and organic pesticide controlled (i.e., organic baby food grade and biodynamic certified products). These four types of farming practices differ in the use of pesticides and fertilizers and contaminant limits. The components of free from additives, free from unnecessary/unexpected ingredients, and degree of processing consider the number of additives, unnecessary/unexpected ingredients and processed ingredients in a product's formulation. The definition of additives is based on CODEX (Codex Alimentarius Commission, 2013) and the EU legislation (Commission Regulation (EC) No 1333/2008, 2008) and includes additives both with an E-number or chemical name. Unnecessary/unexpected ingredients are ingredients that are not easily recognised or understood by consumers, and usually these ingredients cannot be found in one's kitchen cupboard (e.g., thickeners, non-commercial fats and oils, artificial flavours, glucose/fructose syrups). Processed ingredients involve isolated ingredients, refined/processed fats, any type of flavour or sugar, dehydrated/concentrated and powdered ingredients, and refined, hydrolysed, and extruded cereals. The overall Food Naturalness Index score is computed by taking the average score of the four components and ranges from 1 (not natural at all) to 5 (extremely natural) (**Table 1.3**). The Food Naturalness Index is a novel and validated methodology and will in this thesis measure the degree of food naturalness.

Table 1.3. *Scoring system of the Food Naturalness Index. Table is adopted from Sanchez-Siles et al. (2019).*

Food Naturalness Index scores	Farming practice	Number of additives	Number of unnecessary/ unexpected ingredients	Number of processed ingredients
1 Not natural at all	-	>3	>3	>3
2 Slightly natural	Conventional	3	3	3
3 Moderately natural	Pesticide controlled	2	2	2
4 Very natural	Organic	1	1	1
5 Extremely natural	Organic pesticide controlled	0	0	0/1*

**One processed ingredient only if: 1) declared gentle process on label and/or 2) stored chilled/frozen.*

1.5 New product development and reformulations: opportunities and challenges

Concluding from the previous, healthier and more natural snack developments are essential to keep up with the rapidly evolving consumer and public health expectations. New product developments include, for instance, line extensions, innovative products, or reformulations of existing products (Fuller, 2016). As thoroughly described by Raikos & Ranawana (2019), food reformulation is usually done by the industry to redesign a recipe of an existing processed food to improve its nutritional profile, and different approaches could be taken. First, a single-nutrient approach aims to reduce specific food ingredients which are considered harmful for health (e.g., sugar, salt, saturated fat). Second, a whole-food approach aims to reduce either the portion size or the energy density of food products. In that sense, the composition of the product is not altered but intakes of harmful nutrients may be reduced. Reformulation could also be a strategy to improve the nutritional profile by increasing essential macro- and micronutrients or bioactive components, or to improve a product's naturalness or sustainability. It offers the opportunity for manufacturers to provide healthier and more natural/sustainable food choices to consumers and consequently improve people's health and contribute to food security (Drewnowski et al., 2022; Raikos & Ranawana, 2019). Nonetheless, reformulation poses a challenge for manufacturers as technological, safety, and sensory aspects should always be met (Belc et al., 2019). Taste and cost considerations are often critical, as consumers may reject a reformulated product that is healthier but tastes worse or costs more (Drewnowski et al., 2022). At all times, the key priority for successful innovation and reformulation is to respond to consumers' needs and wishes (Isaías et al., 2023; Linnemann et al., 2006). Commercial success and impact on public health requires not only efforts from the industry; policymakers, health professionals and consumers should be involved too (Drewnowski et al., 2022; Raikos & Ranawana, 2019).

1.6 Aim and thesis outline

The aim of this thesis was to gain a better understanding of healthiness and naturalness in the formulation of snacking products. We have approached this main objective from different angles. The first part of the thesis explored trends in snacking and focused on (cereal) snack bars. The second part of the thesis focused on snacks and cereals for babies and children. A schematic overview of this thesis is presented in **Figure 1.2**.

Chapter 2 provides a comprehensive review of the definition, types, composition, and production methods of cereal bars. Additionally, we analyse the current and emerging trends in cereal bars, that provide practical implications for the design and development of cereal bars. In **Chapter 3**, healthiness and naturalness of cereal bars are evaluated and compared to chocolate bars, using the Nutri-Score and the Food Naturalness Index, respectively. We also explore the extent to which healthiness is correlated to food naturalness. **Chapter 4** adds to that knowledge, by exploring healthiness and naturalness in biscuits, a common type of snack given in (early) childhood. We identify the differences between baby, children, and adult biscuits, and assess the compliance of baby biscuits with the World Health Organization's proposed nutrient profile model. **Chapter 5** provides a review on the benefits and challenges of whole grain cereal, an often-used ingredient in snacks and infant cereals. In **Chapter 6**, we evaluate consumer acceptance of healthier and more natural reformulated baby yogurt snacks. Finally, in

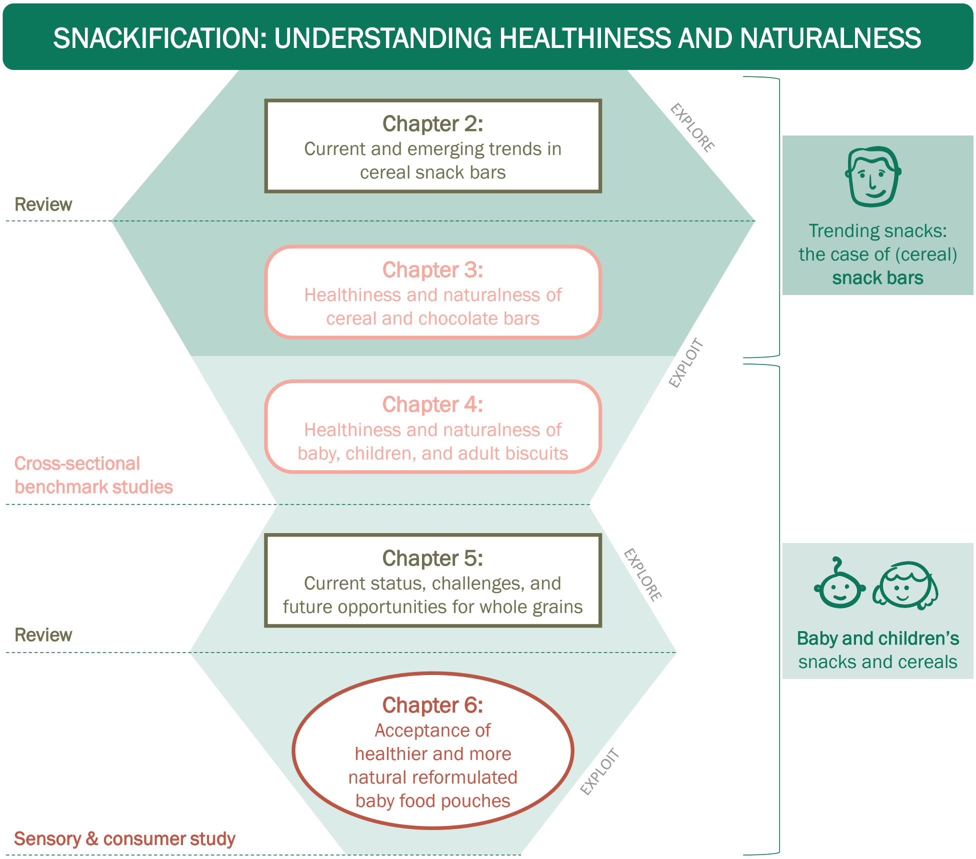

Figure 1.2. *Schematic overview of this thesis. The different colours represent the different types of studies (review, cross-sectional benchmark study, and sensory & consumer study). Chapter 2 and 3 are focused on trending snacks (cereal snack bars), while Chapter 4, 5, and 6 are focused on baby and children's snacks and cereals.*

Chapter 7, I will summarize the main findings of **Chapters 2-6**, put them in a broader perspective, reflect on the methodologies used throughout this thesis, and suggest future research directions.

CHAPTER 2

2

Current and emerging trends in cereal snack bars: Implications for new product development

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Abstract

The change in consumers' lifestyle promoted "snackification" favoring the commercialization of on-the-go products such as cereal bars (CBs). Manufacturers are encountering challenges to develop healthy, natural, tasty, and affordable CBs. This article focuses on production methods, the current and emerging market trends, and practical implications for developing new CBs. The future of the CBs industry is associated with finding the right balance between nutritional value, sensory attributes, naturalness, and sustainability. Manufactures have a toolbox with a large portfolio of ingredients and processing techniques to develop CBs that can be a meal substitute, a supplement, or a snack.

2.1 Introduction

Snacking has been generally defined either as "all foods and drinks with calories consumed between or outside the three main meals" (Chaplin & Smith, 2011; Taillie et al., 2015), or as "an event of intake of foods within a 15-minute period, excluding all foods that are defined as snacks but eaten as part of a meal" (Piernas & Popkin, 2010). Regardless of the definition used, "snackification" has become a solid trend in the food market. In 2018, 70% of US adults snacked two or more times per day and 17% snacked four or more times per day (Mintel, 2019a). In recent years, consumers are increasing the percentage of calories ingested outside the main meals. In 2019, the boundaries between snacks and meals have further blurred, with 69% of snackers considering that anything can be a snack (Mintel, 2019a). Furthermore, childhood snacking is moving toward three snacks per day, covering more than a quarter of children's daily calories (Piernas & Popkin, 2010).

Despite the common belief, snackification does not automatically imply a worsening of the dietary pattern: in some cases, snacking has been shown to enhance intakes of fruit (Sebastian et al., 2008), and to contribute significantly into intakes of whole grains and fiber (McGill et al., 2015). In recent years, the snacks market has expanded from the conventional unhealthy products (e.g., chocolates, biscuits, and chips) toward healthy snacks such as fruits, dairy products and different types of snack bars. The change in consumers' lifestyle has been a main driver promoting the increasing trend toward snacking and grazing favoring on-the-go products such as cereal bars (CBs) (Sousa et al., 2019). CBs have emerged as one of the most common on-the-go products and they are playing a pivotal role in response to consumers' health and natural consciousness (Pallavi et al., 2015).

Within snacks, the global CB market is expected to grow exponentially in the next few years (Transparency Market Research (TMR), 2018). Geographically, the CB market concerns mainly the advanced markets (North America, Europe and South America) and is spreading in the emerging markets (Asia-Pacific region and Africa) according to the forecasts for the period 2018 - 2023 (Mordor Intelligence, 2017). This growth is likely to come from low consumption markets, such as Turkey and India (Mintel, 2020b).

For the first time, the present review is a compilation of scientific literature published in the last decade and market reports to fill the gap between research and commercial reality of CBs. Google Scholar, Pubmed, and Scopus were used to search for appropriate keywords such as cereals, cereal bars, snacks, snack bars, snackification, clean label, food naturalness, Nutri-Score, fiber, whole grains, and related words for relevant publications. Market reports included but were not limited to those from Mintel, Nielsen, and Innova

Market Insights. In this review, we first focus our attention on the definition, types and characteristics of CBs as well as the existing composition and production methods. This provides us with a solid basis for conducting a comprehensive analysis of the most relevant current and emerging CBs trends. Based on these insights, this is the first study to provide practical implications particularly focused on CB design and product development.

2.2. Definition, types and key characteristics of CBs

In general, CBs are a combination of pre-mixed and compressed food items that are held together by a binder and cut and shaped in the form of a bar. Such a product is a simple and convenient ready-to-eat food that requires no cooking and can be formulated with a variety of ingredients (Carvalho & Conti-Silva, 2018). The term CBs is sometimes interchangeably used in scientific literature with "granola bars" or "muesli bars" (Curtain & Grafenauer, 2019).

CBs are versatile vehicles of components including cereals, dried fruit, nuts, honey, and chocolate (Carvalho & Conti-Silva, 2018; Granato et al., 2011) conferring pleasant flavors and tastes as well as diverse textures. A wide spectrum of types of CBs is currently available in the market: standard or fortified (e.g., fruits, pseudo-cereals, pulses, and insects); gluten-free or gluten-containing; reduced in sugar or fat; laminated or extruded; single, multilayer or sandwich format (IRI, 2018; Padmashree et al., 2012). In a nutshell, CBs are emerging as multipurpose food items used as on-the-go snacks, meal replacers, and pre- or post-workout foods.

CBs are primarily formulated with refined or whole grain cereals and are a good source of energy, carbohydrates including fiber, and proteins (Oliveira Silva et al., 2016). The satiation capacity is one of the main consumers' requirements for the CBs thus explaining the increasing success of the products formulated with the addition of fiber and proteins. It has been shown that a morning consumption of a CB high in protein and fiber reduces the energy intake in women at lunch by 5% compared to a conventional isocaloric CB high in fat and refined carbohydrates (Williams et al., 2006). The consumption of CBs with a proper nutrient profile can favorably influence nutrient status, suggesting that CBs can play a role in improving nutrient intake (Trier & Johnston, 2012). Findings from Smith & Wilds (2009) revealed that the intake of CBs (each bar provided 555/133 kJ/kcal, 25.5 g carbohydrate, 1.5 g protein, 2.96 g fat and between 0.75 and 1.11 g fiber) in the early and mid-morning had positive effects on mental health and cognitive performance compared to other snacks (e.g., crisps, sweets, biscuits, and cakes) (Smith & Wilds, 2009).

In addition, healthy ingredients rich in vitamins, minerals, amino acids, omega-3, and bioactive compounds are used to formulate CBs with a high nutritional value in response to various but specific target groups (Farinazzi-Machado et al., 2012). On-the-go CBs rich in fiber can help in improving intestinal health through modulating the bowel movements frequency, alleviating symptoms of constipation and reducing the occurrence of diarrhea (Hess & Slavin, 2017; Slavin, 2013). Fiber-rich pseudocereals such as quinoa can be successfully included in CBs and contribute to reduce total cholesterol, low-density lipoproteins (LDL) cholesterol and triglyceride levels, as demonstrated in young adults that consumed two quinoa bars for 30 days (Farinazzi-Machado et al., 2012).

Despite its benefits, CBs might have some drawbacks as well, such as the free sugar added to the formulation of the binder (in some cases up to 30% of total product weight) to act as sticky-agent in the product's assembly. There is evidence that high intakes of added and free sugars increase the risk of developing chronic metabolic diseases including obesity, non-alcoholic fatty liver disease, type 2 diabetes, dyslipidaemia and hypertension, possibly through an increase in energy intake and body weight, among other mechanisms (World Health Organization, 2015). There also is wide consensus that the intake of dietary sugars is causally related to the development of dental caries at all ages (Jepsen et al., 2017). Sugar (as a binder) can be replaced by other ingredients, even though finding the right balance between technological, sensorial and nutritional quality is very challenging. To have a better understanding of the obstacles and the possibilities offered by the design of CBs, in the next sections we provide an overview about their composition and current production methods.

2.3. Composition and production of cereal bars

In the composition and production of CBs, we can distinguish: i) a solid phase that includes a variety of cereals, pulses, nuts and dried fruits; and ii) a binding phase (e.g., honey, molasses, brown sugar, sucrose, glucose syrup, invert sugar, soy lecithin, glycerin, citrus pectin, oils, dried fruits and fat) ensuring agglomeration of the pieces of the solid phase (Mendes et al., 2013), and iii) a production phase.

2.3.1 Basic cereal matrix and fortifying ingredients

Cereals are the primary ingredient of CBs, encompassing about 40-80% of the total weight of the bar. A mixture of gluten-containing grains (e.g., wheat) or gluten free-cereals (e.g., corn and rice) and other grains (e.g., pseudocereals and/or some minor cereals) is commonly used to provide a versatile and nutrient-rich product (Garcêz De Carvalho et al., 2011; Khouryieh & Aramouni, 2013), as they are a good source of energy, complex carbohydrates (including fiber), protein, and bioactive components (Padmashree et al., 2012; Silva de Paula et al., 2013).

Different ingredients can be added to enhance either the technological or nutritional quality of CBs. Some examples illustrative of the main categories (nuts, fruits, seeds, vegetables, pulses, and proteins) are given in **Table 2.1**. A CB with high consumer acceptability can be made from, for instance, quinoa, flaxseed, brown rice, nuts and honey (Kaur et al., 2018). Besides their sensory characteristics, products of these categories provide a characteristic nutritional profile to CBs. Nuts are a rich source of unsaturated fatty acids and their presence increases the energy content of the CBs: they have also plenty of other bioactive components (fiber, minerals, tocopherols, phytosterols, and phenolic compounds) making them a desired component in the bar formulation (Garcêz De Carvalho et al., 2011). Dried fruits and/or seeds are used to enhance the content

Table 2.1. *Source and function of ingredients.*

Ingredient	Source	Function	References
Nuts	Chichá, sapucaya, gurguéia nuts	- source of fiber, protein, minerals and antioxidants	Garcêz De Carvalho et al., 2011
Fruits	Jackfruit, strawberry, raspberry, cranberry, raisin, dates, apple	- minerals, vitamins, fiber and antioxidants.	Heenan et al., 2012; Potter et al., 2013
Seeds	Flaxseed	- enhance the sensory characteristics - excellent source of fiber and omega 3 fatty acids. - rich in antioxidants	Colussi et al., 2014; Khouryieh & Aramouni, 2013
Vegetables	Welsh onion	- source of minerals, vitamins, fiber and antioxidants.	Sung et al., 2014
Legumes and pulses	Lentil, beans, soybeans, bambara groundnut	- protein source: rich in essential amino acids (e.g., lysine), fiber, minerals and antioxidants	Iqbal et al., 2006; Oyeyinka et al., 2018; Ramírez-Jiménez et al., 2018; Ryland et al., 2010
Protein	Milk, whey protein, soy protein, egg white solids, wheat, insects, legumes	- increase moistness retention and chewiness - maintain product shape and texture - increase shelf life. - provide mechanical stability - reduce the amount of carbohydrate needed to achieve the desired texture - provide higher levels of branched-chain amino acids, such as leucine.	U.S. Pat. No. 3,821,443 U.S. Pat. No. 3,821,443 U.S. Pat. No. 3,903,308 /US20120269939 Loveday et al., 2009
Flavoring ingredients	Candies, chocolates, cookies, cocoa, spices (e.g., cinnamon), marshmallows	- enhancing flavor, texture and physical characteristics (e.g., point of balance of water activity)	Garcêz De Carvalho et al., 2011; Khouryieh & Aramouni, 2013

of minerals, vitamins, omega 3 fatty acids and fiber as well as to give versatile taste and flavor (Heenan et al., 2010; Potter et al., 2013). However, adding fruits to CBs will increase, often undesirably, the overall sugar content. Vegetables and pulses are also gaining interest, given their nutritious composition, especially fiber, minerals, antioxidants, and proteins rich in essential amino acids. Isolated/extracted proteins, derived from conventional (i.e., milk, soy, oat, pea or wheat) or innovative (algae and insects) sources, are also included in CB formulation to enhance the nutritional value of the product (Ballard & Morrow, 2013; Boukid, 2021; Boukid, Rosell, & Castellari, 2021; Boukid & Castellari, 2021; Boukid & Rosene, 2020; Caporgno & Mathys, 2018; Corrochano et al., 2018; Nascimento et al., 2012).

2.3.2 Binding phase

The term “binder” refers to the “edible glue” used to wrap the dry ingredients of the bar, and to allow their aggregation. Binding agents are generally mixed with softening agents and dissolved in water to obtain a binding dispersion. A variety of ingredients can be used to form the binding dispersion, and commonly more than one binder is used simultaneously. The main binding agents are sugar syrups and/or polysaccharides. Each type of binder presents advantages and limitations, as summarized in **Table 2.2**.

Syrups and sugars (e.g., dextrose syrup, sucrose, maltodextrin, invert sugar syrup, dextrose, and fructose) are widely used as binders and sweeteners, but they also act as improvers of product stability during storage (due to the water binding ability of amorphous sugars) (Farahnaky et al., 2016; Wang & Ryu, 2013). When present in an amorphous status, they also confer to the bar a chewy and flexible texture. The major drawback of these ingredients is related to their negative effects of increasing glycaemia (Pallavi et al., 2015). Alternative gluing agents (i.e., fibers and polyols) with low glycemic response can be used to promote the binding effect and to substitute sugar based syrups (Pallavi et al., 2015; Srebernich et al., 2016).

Polysaccharides (e.g., starches, modified starches, agar, and xanthan gum) are normally used in a solution to increase the viscosity of the binding agent (Sikora et al., 2007). Starch (e.g., tapioca, corn, and potato starch) is most frequently inserted into binder formulation to achieve a better thickening property and stabilization (Sikora et al., 2007). Algal polysaccharides such as alginates have been used as thickeners in snack bar formulation (Mattes, 2007). Different polysaccharides provide different textural characteristics to the CB covering an array of possibilities from crisp and brittle to gummy and jelly.

Fats, from vegetal or animal origin, are mainly used as a carrier of flavor, or to shorten or tenderize the binding dispersion. Butter is the most appreciated, as it gives better

Table 2.2. *Binder ingredients: their source and effects.*

Component	Source	Desirable effect	Undesirable effect	References
Syrup and sugar	Honey, corn syrup, soluble corn fiber, fructose, rice syrup, sucrose, sugar syrup, dextrose syrup, sucrose, maltodextrin, invert sugar syrup, dextrose, and/or fructose, sugar syrup of molasses	- holding the cereal components together - enable to achieve the desired flexibility - contribute to caloric content of the product. - flavoring - chewy texture - retaining desired water activity.	- contribute to caloric content of the product. - hyperglycemic effect - sugar alcohols have reduced shelf life, undesirable texture, dryness, and/or reduced stability.	US20120269939 Heenan et al., 2010, 2012 U.S. Pat. No. 4,689,238
Polysaccharides	Starch, modified starch	- thickening agent - contribute to caloric content of the product	- hyperglycemic effect (but less glycemic effect than simple sugar) - contribute to caloric content of the product.	U.S. Pat. No. 4,055,669
Fat	- Animal origin (butter, lard…) - Vegetable origin (coconut, sesame, peanuts, chocolate…) - Synthetic (trans-esterified, Olestra and similar ingredients)	- weakening the binder - avoid sugar crystallization - shortening - contribute to caloric content of the product	- undesirable mouthfeel - contribute to caloric content of the product - oxidation during storage	U.S. Pat. No. 3,582,336; U.S. Pat. No. 3,821,443; Mendes et al., 2013; Padmashree et al., 2012
Emulsifiers	Lecithin, hydrocolloids	- combine the water and the oil	- allergic reactions - negative organoleptic features	U.S. Pat. No. 4,451,488
Gelatinizing agent	Glycerin, glycerol, pectin, gelatin, sorbitol and glycerin,	- agglomerate the binder	- reduced shelf life - undesirable texture - dryness, and/or reduced stability	Lira-Ortiz et al., 2014; Niu et al., 2019; Salgado et al., 2017

mouthfeel as compared to hydrogenated fat (Padmashree et al., 2012), yet it is rich in saturated fats. Among the most used vegetarian or vegan alternatives, tropical oils like palm or coconut oil efficiently replace hydrogenated oils or fats. However, they are also rich in saturated fats suggesting the need to find unsaturated fat substitutes (Boateng et al., 2016).

Others binding ingredients like emulsifying and thickening agents can be added to enhance viscosity, thickening ability, and stability (Molina-Rubio et al., 2010; Pong-sawatmanit et al., 2013). Furthermore, the binder can be fortified with various vitamins, minerals, flavoring and coloring agents. Some preservatives (e.g., salt) can also be added to extend CB shelf life. Summarizing, from a product development point of view the objective is to formulate a good binder that enables the desired texture and moistness of the final bar without compromising flavor or the texture of the dry ingredients.

2.3.3 Production phase

A general diagram for CB production is illustrated in **Figure 2.1**. Through this section, each step is discussed to enable a better understanding of the progress and the limitations in the CB processing.

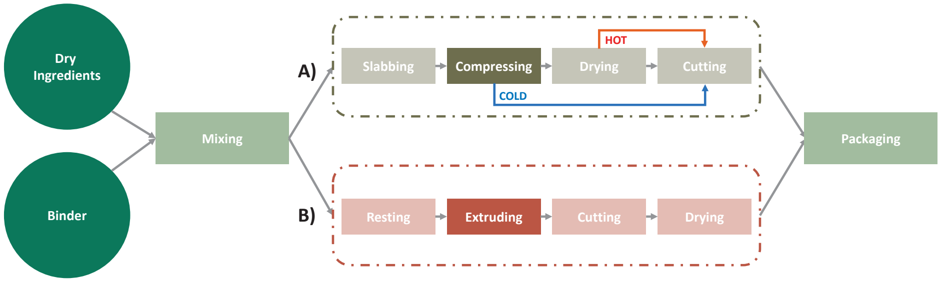

Figure 2.1. *General diagram of CB production. A) Pressed CBs, where the mixture is slabbed and then gradually compressed through a series of rollers until it reaches the desired thickness. Then bars can be dried and then cut (hot processing) or directly cut (cold processing). B) Extruded CBs, where the mixed ingredients are left to rest to soften the texture of dry ingredients and then extruded, cut and dried.*

2.3.3.1 Ingredients preparation

The initial step is the preparation of the binder dispersion obtaining a binder system with a high brix value. The main goal is to produce a "glue" which can be achieved through several means, such as: i) cooking the binder to remove water, ii) using concentrated juices and blending them with dried fruits and cereals, or iii) baking the whole mixture.

Main structural and consistency modifications include subjecting the grains to cooking, extrusion, puffing/popping, and germination. Main nutritional modification includes reduction of fiber and micronutrients (dehulling), increase of starch availability (cooking, extrusion, puffing/popping, germination), modification of amount and accessibility of micronutrients and bioactive components (germination).

2.3.3.2 Mixing and processing

*Mixing (**Figure 2.1**):* Dry ingredients (e.g., cereals, nuts and/or pseudocereals) are generally combined with the binder at a ratio of 1:1 to 4:1. These ingredients are gradually added and thoroughly mixed (30 seconds to 5 min, depending on whether it is a continuous or batch mixing process) with the binder using a paddle mixer to enable the homogeneous distribution of the binding phase on the dry ingredients surface.

Compression-based processing (Figure 2.1A):

- Hot processing: The mixture is slabbed and then gradually compressed (laminated) through a series of rollers until it reaches the desired thickness. The slab is then dried, toasted or baked to the desired moisture and then cut into bars. Noteworthy, this processing presents some economic limitations due to time-energy required for slicing and cutting and the production of a large amount of non-recyclable waste. This waste is often ground and remixed in the following production, but it can create some quality defects (e.g., color and consistency) due to changes in the intrinsic properties or particle size heterogeneity.
- Cold processing: Based on compression and lamination of the mixture of dry ingredients (water activity value < 0.5) and binder system at or near room temperature but then directly cut into bars, without drying, toasting or baking the product.

Extrusion-based processing (Figure 2.1B): After the mixing of dry ingredients and binder system, the blend (also called "dough", which is about 6% moisture content) is left to rest to allow the water to act as a plasticizing agent (to soften the dry ingredients texture due to water migration). Then, the obtained mix is transferred to an extruder, where it is further mixed and shaped into a bar that will be dried or baked to obtain a moisture content below 4%.

2.3.3.3 Coating

Coating with syrup, caramel, chocolate or a glaze is an optional yet key step to obtain shiny and attractive final products. Only when applied to the full bar, coating has an important role as a protective barrier reducing the moisture migration, flavor loss and oxidation prevention as well as preserving the structural integrity of the product thereby contributing to the extension of CBs' shelf life (Pavithra et al., 2013; Tunnarut & Pongsawatmanit, 2018). Coatings like drizzles or bottom coatings do not act as a water barrier but only as a physical support of the bar since these types of coatings are usually firm at room temperature.

2.3.4 Nutritional composition

As it will be further elaborated in the next section, CBs were introduced in the market as a wholesome alternative snack for health-conscious consumers (Yadav, 2020). Indeed, CBs have the potential to be perceived by consumers as a healthier option to other snacks (Bucher et al., 2016; Vasiljevic et al., 2015). However, as CBs are a versatile product and available with a wide variety of ingredients, the nutritional composition and quality can differ largely (Aleksejeva et al., 2017; Curtain & Grafenauer, 2019; Sharma et al., 2014). In general, CBs are often a great source of fiber, but also have a high sugar content (Aleksejeva et al., 2017; Curtain & Grafenauer, 2019). An overview of the nutritional composition of CBs launched between 2018-2020 in the European and North American

Table 2.3. *Nutritional composition of CBs (per 100g) in Europe, USA, and Canada (2018-2020).*[*]

Nutrients	Mean	SD	Median	IQR
Portion size (g)	37.5	15.4	37.0	19.0
Energy (kcal/100 g)	417.5	63.8	415.0	73.2
Fat (g/100 g)	16.8	8.4	15.3	10.0
Of which saturated (g/100 g)	5.9	4.4	5.0	5.5
Carbohydrates (g/100 g)	54.3	13.8	56.0	21.0
Of which sugars (g/100 g)	24.5	11.3	25.0	13.8
Fiber (g/100 g)	8.3	5.8	6.7	5.2
Protein (g/100 g)	12.6	8.6	9.1	10.0
Sodium (mg/100 g)[**]	188.9	145.3	176.0	192.0

[*]*Table based on Mintel's GNPD database, using the following criteria: food category "snack/cereal/energy bars"; launched in the "last three complete years" (2018-2020); regions "Europe" and "North America"; "cereals" in the ingredient list. The search resulted in a sample of 4064 bars.*
[**]*Missing sodium levels in mg/100 g were obtained by conversion of salt levels in g/100g (multiplying by 400).*
IQR: interquartile range.

markets is shown in **Table 2.3**. Our analysis, based on Mintel's data on more than 4000 commercially available CBs, indicates that CBs have a mean sugar content of 24.5 ± 11.3 g/100 g, mainly due to the binder and/or inclusion of dried fruits. Fats in the binder formulation and/or ingredients with high fat content like chocolate or nuts are mainly responsible for the mean saturated fat content of 5.9 ± 4.4 g/100 g. Cereals, often oat and/or wheat, contribute to the high mean fiber content of 8.3 ± 5.8 g/100 g.

2.4 Trends in cereal bars new product development

In this section, we draw on scientific research and industry market reports to provide a detailed analysis of the most important current market trends and developments within CBs, namely: health and well-being, naturalness, sustainability, and convenience. These trends reflect the top five positionings in all regions of the world, as tracked by their launches in 2017-2018 (IRI, 2018): "high/source of protein", "gluten free", "high/source of fiber" (related to health and well-being), "no additives/preservatives" (related to naturalness) and "vegan" (related to health and well-being and sustainability). In addition, as depicted in **Figure 2.2**, we look at the newest, emerging trends for CBs: chilled and frozen, functional formulations and new flavors.

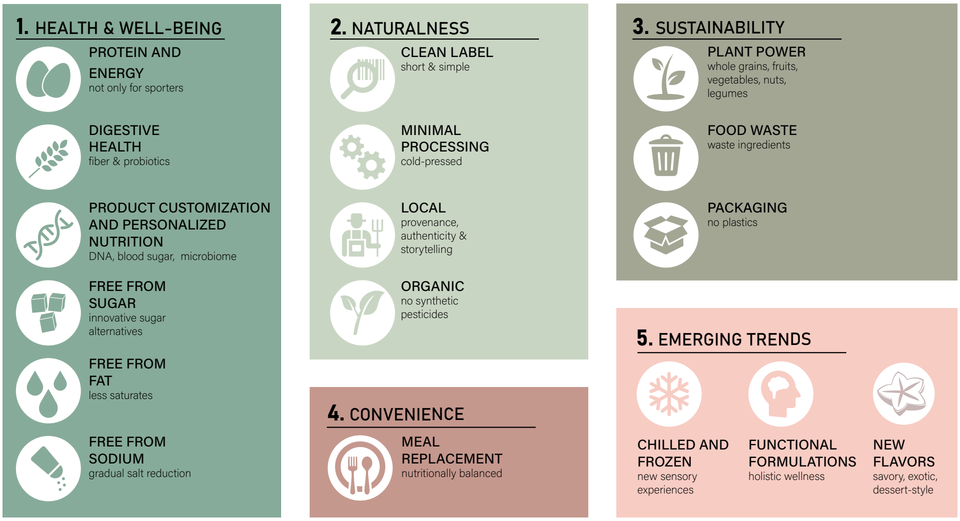

Figure 2.2. *Summary of current and emerging trends in new product development of CBs.*

2.4.1 Health and well-being

In the last decade, consumers have become more concerned on health and well-being and are paying more attention to the food that they eat (Mardon et al., 2015; Mordor Intelligence, 2021). As consumers become more health-conscious, CBs have gradually gone from a "standard" product to a "custom-made" product integrating different functional ingredients (Pallavi et al., 2015). This opens opportunities for CBs aiming to support both physical as well as mental well-being, in line with Sustainable Development Goal 3 that seeks to ensure health and well-being for all (United Nations, 2015). Four major sub-trends under the category health and well-being can be identified: (1) protein and energy, (2) digestive health, (3) product customization and personalized nutrition, and (4) "free from" added sugar, fat, sodium.

2.4.1.1 Protein and energy

Protein fortification is one of the emerging market trends in many food sectors and continues to be highly demanded by snack bar consumers. Sports bars (i.e., cereal-based supplemental bars initially targeted at sportspeople to provide the requested plus of energy and/or proteins) represent the fastest growing subcategory with a compound annual growth rate (CAGR) of 34.5% during 2016-2018 (Innova Market Insights, 2019). Protein CBs are gaining popularity among conscious consumers due to the implication of proteins in weight management, through appetite control, satiety, and daily food intake reduction (Leidy et al., 2010, 2013; Samakradhamrongthai et al., 2021; Shang et al., 2018; Sung et al., 2014). In fact, research has shown that a high protein content claim on CBs increased consumer's interest, especially among exercisers and men (Salazar et al., 2019). Proteins elicit reward by different postprandial mechanisms involving neural signals from the gastrointestinal tract to the brain (Leidy et al., 2013; Peuhkuri et al., 2011). For instance, a protein CB recently was developed using miller flour that provided 15.74–18.32 g of protein, 332–379 kcal energy, 74.53–83.87 mg calcium, and 555.93–603.80 mg phosphorous per 100 g. The current portfolio expansion is triggering a large differentiation in protein source: many brands are entering the protein category by focusing on a specific source of protein as alternative to traditional soya and dairy: pea, lupin and lentils proteins are frequently adopted and sometimes microalgae or insect proteins are also proposed (Mintel, 2019b). Moreover, research findings suggest that the application of wine fermentation residues in CBs is a viable and sustainable alternative to increase protein content (Borges et al., 2021).

Besides protein CBs, energy bars are gaining momentum among the sports bars too. They are basically consumed as a dietary supplement by athletes and other physically active people to maintain their energy needs (da Silva et al., 2014; Norajit et al., 2011). These bars can be considered a fuel to sustain training load and maintaining a high performance during training (Tanskanen et al., 2012). The type of carbohydrates is linked to the rate and the quality of energy (short-term or long-term release) provided. Fast digesting carbohydrates (dextrose, maltodextrin, pre-gelatinized starch) can be a source of short-term energy, whereas slowly digesting carbohydrates (cereals, waxy starch, and legumes) provide sustained energy for endurance athletes that require steady energy over longer periods (da Silva et al., 2014; Mendes et al., 2013; Ryland et al., 2010). Seeds can also be used as a source of energy due to their important amounts of fat. Their inclusion in CB formulation provide a significant amount of polysaccharides, improving at the same time the lipid profiles (Mridula et al., 2013). A study on the sensory evaluation of high energy CBs shows that it is possible to develop a high energy CB with good texture properties and high consumer acceptance and purchase intention, using cereals, nuts, seeds, mixed fruits, corn syrup and honey (Samakradhamrongthai et al., 2021).

2.4.1.2 Digestive health

High-fiber bars have a growing market that can be justified by the positive effects of dietary fiber on the digestive tract, energy balance, and several non-communicable diseases (Garcia et al., 2012; Hess & Slavin, 2017; Marques et al., 2015). Consumers are becoming familiar with the health effects dietary fiber has and especially associate the consumption of dietary fibers with the beneficial effects on the gut (Zank & Kemp, 2012). This opens an opportunity to communicate on other benefits beyond the link between fiber and gut health. Lately, launches have focused mainly on linking fiber with low glycemic index and linking fiber with satiety (Mintel, 2019c). Particularly high viscous fibers have been associated with a greater satiety as compared to those snack bars low in viscous fibers (Possinger, 2014; Williams, 2007). Combining protein with fiber seems to be a potential opportunity for sports bars manufacturers to differentiate themselves from many other brands in the market (Mintel, 2019c).

In Europe, CBs can be claimed as "source of fiber" if they have a fiber content ≥ 3 g of fiber per 100 g or "high fiber" (≥ 6 g of fiber per 100 g) (Regulation (EC) No 1924/2006). The use of whole grains can increase the content of dietary fiber (Dutcosky et al., 2006). Besides rich in dietary fiber, whole grains are a great source of many bioactive compounds (e.g., vitamins, minerals, and phytochemicals), and have been demonstrated to aid in reducing the risk of several non-communicable diseases (Fardet, 2010). Hence, it has been suggested to incorporate whole grains in cereal products (Klerks et al., 2019). Importantly, given that sensory appeal remains a key factor for CBs, recent studies have shown the positive results for liking and acceptability for whole grains when they were included in the diet, both in adults (Mellette et al., 2018; Neo & Brownlee, 2017) and in infants (Haro-Vicente et al., 2017). Furthermore, oat-based bars are also trending for their β-glucan content, acceptable sensory properties and stability during storage up to 60 days (Gutkoski et al., 2007; Marques et al., 2015). Roasted rice bran was also used as an ingredient in high-fiber CBs ranging between 10-20%, which were well accepted by consumers (Garcia et al., 2012). Bean addition to bars increased total fiber by 60% without compromising sensorial acceptance of the products (Ramírez-Jiménez et al., 2018). Inulin was also included in CB formulation for its ability to reduce cholesterol and to improve the glycemic effect, however high amounts (>10 g/day) were reported to be associated with gastrointestinal discomforts (Possinger, 2014). Inulin, along with other fibers, can also act as prebiotics supporting the growth of positive microorganisms such as Bifidobacteria and Lactobacilli and decreasing pathogenic bacteria populations (Makki et al., 2018; Slavin, 2013). Prebiotic dietary fibers act as carbon sources for primary and secondary fermentation pathways in the colon (Carlson et al., 2018). These prebiotics can also increase calcium absorption (Carlson et al., 2018). Finally, as the importance of gut health becomes more familiar to consumers, brands try to experiment with ingredients beyond fiber. The technological possibility to incorporate probiotics in bars, which generate many positive effects for human health, gave a further boost to these types of CBs (Quigley, 2019). For example, Europe has seen several bars launches that included probiotics to promote gut health (Food Business News, 2019).

2.4.1.3 Product customization and personalized nutrition

Personalization is a major global trend that poses some challenges for the industry as it goes further than customizing mass-produced products (Bennett, 2012; Nadathur et al., 2017). Personalized nutrition offers an opportunity to increase consumers' compliance with dietary guidelines by shifting focus of nutrition recommendations from population-based to individual needs (Qi, 2014). Currently some CB manufacturers offer the option to customize and individualize the packaging and ingredients to produce tailor-made CBs. In particular, Mymuesli® customers can mix more than 80 ingredients to make their own muesli (www.mymuesli.com/mixer/). However, this brand also takes a step further by including DNA, blood sugar or microbiome tests to create personalized breakfast cereals and to provide personal recommendations tailored to the consumers' metabolism.

2.4.1.4 Free from sugar, fat, and sodium

The snack industry keeps investing to find innovative alternatives or substitutes to design bars with reduced content of some nutrients such as sugar, fat and sodium. A closer look to the market of nutrition-claimed products reveals that bars claimed to be low in or free from something are gaining popularity (Mintel, 2019d). Not only free from sugar, fat or salt but also absence of gluten (Kaur et al., 2018), lactose or animal ingredient: the use of absence claim is perceived by consumers as a positive indication of the nutritional quality of a product. This is particularly true for CBs: consumers' choice is strongly related to the list of ingredients and health claims (Brito et al., 2013). Incorrect or absent information can lead to incorrect choices and potential health issues (Brito et al., 2013). An accurate food labeling where all ingredients and their amounts must be clearly declared on the label can definitively help the product selling performance (Miraballes et al., 2014; Pinto et al., 2017). To encourage manufacturers to (re)formulate and produce healthier foods and help consumers make better food choices the French front-of-pack (FOP) nutrition labeling Nutri-Score has been implemented in many countries recently, among which France, Belgium, Germany, and Spain. The Nutri-Score is a nutrient profiling system where the score (letters A to E) depends on the amount of unfavorable content (energy, total sugar, saturated fatty acids, and sodium), and favorable content (fruits, vegetables, nuts, fiber, and protein) (Buscail et al., 2017). Based on EU regulations, the use of Nutri-Score is voluntary for manufacturers (Buscail et al., 2017), but once adopted it have shown promising results in terms of helping consumers to discriminate between products based on their nutritional quality.

<u>Sugar:</u> In Europe, bars claimed to be "low in sugar" should contain no more than 5 g of sugar per 100 g, while bars claimed to be "sugar-free" should contain no more than 0.5 g of sugar per 100 g (Regulation (EC) No 1924/2006). Reducing sugar in CBs is challenging given the many other sugar techno-functional properties, besides bringing sweetness. Sugar act as bulking agent and improve the gluing capacity of the binder. Intensive sweeteners provide an efficient solution to replace the main sugar sensory function. Stevia is gaining popularity as a natural low-calorie sweetener. It is 250–300 times sweeter than table sugar, with no effect on blood glucose and insulin levels (Manisha et al., 2012; Thorup et al., 2014). Synthetic low-calorie sweeteners (e.g., saccharin, aspartame, neotame, and sucralose) have been used as intense sugar alternative in some

CBs on the market. Sugar alcohols (e.g., sorbitol, mannitol, xylitol, glycerol, and maltitol) are also widely used in CB manufacturing, and they are classified as natural sweeteners providing 0 to 3 kcal/g compared to sucrose or other sugars (4 kcal/g) (Allan et al., 2018). Besides sweetness, polyols function as a bulking agent in the binding solution to promote and stabilize the texture of the syrup thereby the final bar (Pallavi et al., 2015; Srebernich et al., 2016). Unfortunately, when consumed in high amounts, polyols may result in laxative effect (Grembecka, 2015). Therefore, products containing more than 10% added polyols must include the advisory statement "excessive consumption may produce laxative effects" (EFSA, 2011). Lastly, prebiotic fibers such as inulin, oligofructose, and gum-arabic, are increasingly added to CB formulations to bring sugar levels down and are shown to successfully reduce energy content and increase fiber content (Krasina et al., 2021).

In most cases, commercial products are made with blends of intensive sweeteners and polyols. However, new innovative low-caloric sugar replacers are of more importance for CBs development than sweeteners because sweeteners can fulfil one function of sugar (add sweetness) but cannot provide the binding effect. Psicose, also known as allulose, is a promising new innovative sugar replacer holding a great promise for the near future (Mooradian et al., 2017).Sugar reduction greatly affects the texture of a CB often resulting in a hard product. To overcome such issue, in some cases adjusting the formulation through the addition of fat and/or glycerin, testing different combinations of syrups, or by making changes to processing could be still insufficient and keeping sugar or honey in the formulation seems inevitable (Di Monaco et al., 2018; Srebernich et al., 2016).

<u>Fat:</u> In Europe, CBs claimed to be "low in fat" should not contain more than 3 g of fat per 100 g of product, while those claimed to be "fat-free" should not contain more than 0.5 g of fat per 100 g (Regulation (EC) No 1924/2006). Fat can be present in CBs as an ingredient of the binder and/or as a main constituent of some ingredients (e.g., chocolate and nuts). A recent Italian survey showed that CBs, along with muesli, are among the products with the highest content of saturate and total fat among the 371 analyzed breakfast cereal products (Angelino et al., 2019). Therefore, trying to reduce fat content as much as possible while preserving sensory acceptability is an important challenge to reduce CB calorie density. Fat reformulation can take two mains pathways: moving from saturated to unsaturated fats (especially in the binder formulation) and/or reducing the amounts of ingredients with high fat contents.

<u>Sodium:</u> Sodium is an ingredient commonly used in CBs for sensory reasons as it contributes to the taste and overall flavor, especially in sugar free bars. Nutrition claims in Europe on sodium content in foods are "low in sodium" (<0.12 g of sodium per 100

g), “very low in sodium” (<0.04 g of sodium per 100 g) and “sodium-free” (<0.005 g of sodium per 100 g) (Regulation (EC) No 1924/2006). In a list of the most consumed CBs, the content of sodium ranged from 20 to 230 mg in commercial CBs (Possinger, 2014). This suggests the urgent need for public health efforts to reduce the content of sodium in food products, particularly in bars for kids (Maalouf et al., 2017). One of the best strategies recommended to lower sodium intake is the gradual reduction to enable consumers' taste buds to become accustomed to less salt (Scourboutakos et al., 2018). The use of contrasting salt level (use of larger encapsulates which increases the salt perception at lower concentrations) is very promising in different bakery products, but it has not yet been tested in CBs. In order to have a better, deeper understanding of this major trend of health and wellbeing in CBs, and to conclude this section, the most common claims of CBs related to body functions (**Table 2.4**) and to nutrients and

Table 2.4. *Top ten claims of CBs related to body functions in Europe, USA, and Canada (2018-2020).*[*]

Functional claims	Nº of products (%)	Examples of health claims on pack[**]
Energy	705 (63.7%)	- “Slow-release energy bar” - “Sustained energy from 100% whole grains”
Slimming	121 (10.9%)	- “Clinically proven: Lose weight and keep it off” - “Helps manage blood sugar”
High Satiety	94 (8.5%)	- “Satisfying energy” - “Healthy metabolism support”
Weight & Muscle Gain	93 (8.4%)	- “High in protein, which contributes to the growth and maintenance of muscle mass”
Antioxidant	52 (4.7%)	- “With antioxidants, for healthy joints, faster recovery and energy release” - “With vitamin E, that protects cells against oxidative stress”
Brain & Nervous System	47 (4.2%)	- “With iron, that contributes to normal cognitive development in children” - “DHA Omega-3s that fuel your brain”
Probiotic	47 (4.2%)	- “Bifidobacterium lactis BB-12 may help support healthy digestion when consumed daily”
Digestive	38 (3.4%)	- “Advanced digestive support” - “Supports good gut health”
Cardiovascular	34 (3.1%)	- “Heart-healthy” - “Designed to minimize blood sugar spikes compared to high-glycemic carbohydrates”
Bone Health	26 (2.4%)	- “Source of calcium, which is needed for the maintenance of normal bones” - “With Vitamin D, that contributes to healthy bones and teeth”

[*]*Table based on Mintel’s GNPD database, using the following criteria: food category “snack/cereal/energy bars; launched in the “last three complete years” (2018-2020); regions “Europe” and “North America”; “cereals” in the ingredient list, claim “functional”. The search resulted in a sample of 1106 bars.*

[**]*Claims as displayed on front- or back-of-pack. It does not imply that these claims are authorized by local regulations.*

bioactive compounds (**Table 2.5**) launched between 2018-2020 in Europe, USA, and Canada have been summarized.

Our analysis, based on Mintel's data on more than 1100 commercially available CBs, shows that health claims related to energy, slimming, satiety and weight and muscle gain were the most popular. This reflects a clear response from the food industry to consumers' interest in weight management. In addition, there has been a substantial interest products having claims related to antioxidant and probiotic effects. This suggests that consumers have fundamentally changed their lifestyle to include snacks with health benefits relying on functional claims declared on the package.

As evidenced in **Table 2.5**, nutrition claims involving added benefits such as added protein and fiber are more popular than those representing low/reduced ingredients or even absence from ingredients such as sugar.

Table 2.5. *Top 5 claims of CBs related to nutrients and bioactive components in Europe, USA, and Canada (2018-2020).*[*]

Type	Nº of products (%)	Nutrition claim
Plus	301 (27.2%)	High/Added Protein
	220 (19.9%)	High/Added Fibre
	217 (19.6%)	Vitamin/Mineral Fortified
	23 (2.1%)	Added Calcium
	10 (0.9%)	Stanols/Sterols
Minus	160 (14.5%)	No Added Sugar/Low Sugar
	68 (6.1%)	Low/No/Reduced Glycemic
	62 (5.6%)	Diet/Light
	39 (3.5%)	Low/No/Reduced Trans fat
	24 (2.2%)	Low/No/Reduced Sodium

[*]Table based on Mintel's GNPD database, using the following criteria: food category "snack/cereal/energy bars; launched in the "last three complete years" (2018-2020); regions "Europe" and "North America"; "cereals" in the ingredient list, claim "functional" "minus" "plus". The search resulted in a sample of 1106 bars. The list does not imply that these claims are authorized by local regulations.

2.4.2 Naturalness

Consumers have a strong preference for foods that are free from additives and preservatives and that are grown and produced with respect to nature (Román et al., 2017). Preferences for naturalness are reflected in the snack category too, as over half of consumers in 2018 in the US let their snack purchase drive by claims such as "made with natural ingredients", "organic" or "free-from" (IRI, 2018). Similarly, 60% of German, Italian and Spanish snack bar consumers indicate that bars made with natural ingredients are worth paying more for (Mintel, 2020b). Many mothers, especially Polish mothers, indicated to value the level of naturality of snacks they buy for their children (Damen, Hofstede, et al., 2019). In what follows, we focus on several key aspects of CBs naturalness, namely: clean label, minimal processing, local and organic production.

2.4.2.1 Clean label and minimal processing

CB manufacturers are embracing simplicity and naturalness via "clean label" formulations and transparent brand communication (Mintel, 2019e). To date there is no established definition of the term "clean label", leaving the interpretation as rather subjective for consumers and the industry. Asioli et al. (2017) proposed that consumers could access information on clean label by looking at the front-of-pack (FOP) and back-of-back (BOP) information (Asioli et al., 2017). In a broad sense, "clean label" products are defined by FOP textual or visual claims (i.e., "natural products" "free-from additives/preservatives") and/or logos (e.g., "organic"). In strict sense, "clean label" products have BOP ingredient lists that are "short and simple", not containing "artificial ingredients", "not chemical sounding", and only containing "kitchen cupboard ingredients" which are expected to be familiar for consumers (Asioli et al., 2017). Recently, comprehensive index (Food Naturalness Index) was developed, which is built on consumer, legal, and technical perspectives (Román et al., 2017). The index is comprised of four component measures, namely farming practices, free from additives, free from unexpected ingredients, and degree of processing. The use of this type of indexes as a FOP label by manufacturers can improve transparency and offer another tool do differentiate the products in the CB marketplace.

The presence of artificial colors and flavors, additives, and ingredients with chemical names negatively influence consumers' perception of naturalness (Murley & Chambers, 2019). Under this scenario, many CB brands are focusing on eliminating unwanted artificial ingredients (Mintel, 2019d), and additives (E-number ingredients). Also, CB brands are highlighting their commitment to "clean label" by communicating their "simple recipes" or "simple ingredients". Another strategy is to highlight the exact number of ingredients that the bar contains, mostly ranging from two to five ingredients (Mintel, 2019e). Although this trend is still relatively small, it has been growing over the last few years. In particular, 0.9% of snack bar launched in 2014-2015 were focused on the "simple" concept, while it represented 2.3% of the launches in 2018-2019 (Mintel, 2019e).

Manufacturing processes also influence the consumer's perception on naturalness (Román et al., 2017). Food products that underwent unfamiliar technological processes were perceived to be less natural compared to those products of which consumers might have an idea of the processing method (Mintel, 2019e). CBs represent a good example in this respect: their manufacturing process is simple, and it is possible to keep intactness of many ingredients that remain recognizable in the final bar. Accordingly, besides highlighting few and simple ingredients, adopting minimal processing such as cold-pressing is a method for CBs to change consumers' perception and move away from the processed food bad image (Mintel, 2020b).

2.4.2.2 Local and organic

The proximity between the place of production and consumption is perceived by consumers as a guarantee of authenticity. The so-called "zero mileage philosophy" has been born, where consumers prefer local and seasonal foods. These foods "tell a story", referring to nature and the preparation needed, but also to culture, place of origin and the people involved in production (Barilla Center for Food & Nutriton, 2012; Food Ingredients First, 2019). Examples of the local food trend applied in the CB market include engaging stories on packaging of farmers behind specific ingredients, or the usage of traditional and local ingredients in the formulation of the bar (Mintel, 2020b).

Consumers' awareness that chemical contaminants can be found into our food is increasing, resulting in rising interest in organic foods. Organic foods underpin the concept of food naturalness (Román et al., 2017). They are produced in accordance with the standards of organic agricultural farming practices avoiding the use of synthetic pesticides and following strict agronomical or husbandry practices (Seufert et al., 2012). Furthermore, concerns about the environment could drive the future growth of natural and organic market. In a recent Mintel survey, 73% of those aged between 25 and 34 years agreed with the statement that natural/organic foods are safer for the environment than conventional foods (Mintel, 2019f). CB manufacturers are therefore encouraged to use organic raw materials as much as possible.

2.4.3 Sustainability

Sustainability is becoming essential in the food industry, and CB producers are well aware of it. This aligns with Sustainable Development Goals number 12, 13, and 15 of the 2030 Agenda for Sustainable Development, focusing on responsible consumption and production, climate action, and life on land (United Nations, 2015). A recent survey highlighted that consumers consider food and beverage manufacturers responsible for an environmentally friendly production more than packaging manufacturers, retailers, or governmental organizations (Mintel, 2019g). Interestingly, 22% of snack bar launches in 2018-2019 carried an environmental or ethical claim. However, many consumers find it difficult to estimate if companies are truly committed to ethical practices (Mintel, 2020b). In this context, the provision of clear and transparent information to consumers plays a key role. Indeed, different sustainability measurements have been developed (e.g., Eco-Score) to assess the impact of the food product on the environment, although they still need to be further developed (Bunge et al., 2021). There is some initial evidence that measurements like Eco-Score may encourage environmentally friendly food choices (De Bauw et al., 2021). Furthermore, recent findings from Stelick et al. show that providing information on product sustainability increases consumers purchase intentions of cereal bars containing upcycled ingredients (Stelick et al., 2021). Within the umbrella of sustainability issues, three trends named plant power, food waste and packaging were identified.

2.4.3.1 Plant power

Current food systems are threatening both human health and environmental sustainability. In this context, the EAT-Lancet Commission has recently determined what a healthy and sustainable diet is, and how to achieve it. The so-called planetary health diet consists largely of a diversity of plant-based foods. By 2050, consumption of whole grains, vegetables, fruits, nuts, and legumes should be doubled (Willett et al., 2019). Furthermore, Sustainable Development Goal number 2 of the 2030 Agenda for Sustainable Development emphasizes the role of plants and seeds in achieving food security and improved nutrition, and promotes sustainable agriculture (United Nations, 2015). The consumer's desire for healthier lifestyles is already motivating consumers to prioritize plant-based sources like fruits, vegetables, nuts, seeds, and grains (Boukid, Rosell, Rosene, et al., 2021; Ohr, 2019). The CB market could take great advantage of this shift toward consumption of plant-based sources by focusing on their link with the planetary health diet and Sustainable Development Goal 2, and consequently their contribution to healthy diets as well as a healthy planet.

2.4.3.2 Food waste

As consumers are getting more concerned with the impact of their food consumption on the environment, special attention has been given to reduce or reuse waste generated by industrial processes, thus avoiding the loss of remaining substances, economic losses, and environmental pollution (Jahanzeb, M., Atif, R. M., Ahmed, A., Shehzad, A., & Sidrah Nadeem, 2016). In this context, the use of industrial residues (e.g., banana peel flours (Carvalho & Conti-Silva, 2018), brewery spent grains (Stelick et al., 2021), pineapple peel or skin (Fonseca et al., 2011; Garcêz De Carvalho et al., 2011), acerola seed flours and acerola bagasse flours (Marques et al., 2015), guava peels and cashew bagasse (Amorim et al., 2018), Araucaria angustifolia seeds coats (Timm et al., 2020) have contributed to the production of new alternatives to traditional CBs, rich in fiber, proteins, essential amino acids, polyunsaturated fatty acids and minerals without hindering their technological quality. This underlines that CB production chain aligns with Sustainable Development Goal number 2 of the 2030 Agenda aiming to reduce agri-food ingredients waste and give value to by-products (United Nations, 2015). Importantly, CBs can be produced with mildly refined ingredients without thermal processing. They have a relatively low water activity and a shelf life of 12 months or longer and can be distributed at ambient temperature (Corrigan et al., 2012). All these features typically lead to a lower carbon footprint allowing CBs manufacturers to support sustainability-related statements.

2.4.3.2 Packaging

Besides its relevance in CB stability and protection, packaging design is oriented toward the sustainability aspects through minimizing the environmental footprint (Mintel, 2019g). Recyclability is a key property of circular packaging, which implies that the packaging contains renewable or recycled content or reused parts and is compostable, recyclable, or reusable (Sturtewagen et al., 2016). Accordingly, some CB brands have changed from plastic to plastic-free types of packaging by using, for example, renewable and plant-based materials (Mintel, 2019f).

2.4.4 Convenience

Currently, many factors are boosting the growth of convenient foods, and in this context, a CB is a forerunner product. The rapid urbanization, together with smaller households, shifting generational needs and the uptake of technology are shaping the need for convenience solutions (Nielsen, 2018). Consumers are seeking for grab-and-go breakfasts, quick snacks and dinnertime solutions (Nielsen, 2018). Food is increasingly eaten individually in the shortest time possible (Barilla Center for Food & Nutriton, 2012). In this frame, consumers are gradually moving from seeing snacks as only indulgent treats to a way of "sustaining" energy throughout the day (Barnes et al., 2015). Therefore, market reports show that demand has grown for more nutrient-dense portable snacks and snack-sized portions of meals with a special emphasis on sports CBs. In short, many consumers snack to substitute a standard meal at least sometimes (Technomic, 2018). In fact, the main motive for the consumption of CBs has been shown to be convenience (Salazar et al., 2019). Thus, there is a need to provide healthy and nutritionally balanced CBs to fulfil this need.

2.4.4.1 Meal replacement bars

Meal replacement bars are designed to replace one or two meals per day for consumers following a low-calorie diet (400-800 kcal/day). Meal replacement bars do not require meal preparation, they are relatively inexpensive, convenient, palatable and versatile (Sung et al., 2014). These bars are commercialized as a nutritionally balanced meal with a specific focus on hunger control and weight reduction. However, none of these bars can entirely replace a properly-balanced meal (Reents, 2019). Numerous studies have attempted to formulate CBs for meal replacement (Pinto et al., 2017; Suhem et al., 2013, 2017; Sung et al., 2014). In a randomly controlled study, the consumption of replacement bars used for replacing lunch for 10 days in 17 subjects resulted in an average reduction in energy intake of 250 calories per day (from 2057 to 1812 kcal) (Levitsky & Pacanowski, 2011). Another study investigated the partial replacement of dinner (night snacking) using two types of bars (cereal based and non-cereal based) in randomized 25 adults (Waller et al., 2004). After 4 weeks, the cereal group had an important reduction of total daily caloric intake (-396.5 ± 641.6 kcal/ day) with respect to the other group (-23.2 ± 889.6 kcal/day). This evidence suggests that the partial replacement of meals by these bars can be useful in reducing daily energy intake and promoting weight loss.

2.4.5 Emerging trends

In what follows, the latest, emerging trends in CBs, namely chilled and frozen, functional formulations, and new flavors are discussed.

2.4.5.1 Chilled and frozen CBs

"Fresh" CBs are gaining interest in consumers are looking for natural and "clean labels" (Asioli et al., 2017). Chilled or frozen CBs have started to gain steam over the traditionally shelf-stable CBs. This shift requires designing microbiologically stable CBs, which also implies an intense effort in designing suitable ingredients to these bars. As these products are not stable at ambient temperature, appropriate packaging, storage and distribution is needed. It is predicted that in the next couple of years many food manufacturers will step out of the ambient shelf and explore the chilled aisle. Moving CBs to the chilled segment provides a great opportunity for snack brands to stand out from other brands, as the ambient shelf is getting crowded. Approximately half of Polish, French and Spanish consumers find chilled snack bars appealing, whereas a quarter of US consumers is open to trying chilled bars (Mintel, 2019b). Beyond chilled bars, frozen bars are also starting to attract the attention. Frozen CBs can reveal new textural experiences, boosting indulgence and growing the appeal of CBs among adventurous and novelty seeking consumers. However, one limitation of frozen CBs is the lack of convenience and portability (Mintel, 2019h).

2.4.5.2 Functional formulations

Functional formulations will increasingly be demanded by consumers. Seven out of ten respondents in Spain, Poland, France and Italy would like to see a wider choice of bars with added health benefits (Mintel, 2019b). CBs could play a key role in this area and brands could capitalize on the "energy" claim and expand beyond by innovating CBs focusing on brain health, stress, sleep, detox, and immunity, among others. New functional ingredients are to be explored, examples are collagen, and healthy fats (avocado oil, medium chain triglycerides from coconuts), and insect protein (Mintel, 2019b).

2.4.5.3 New flavors

Despite the relevance of health and nutrition, indulgence remains key for CB formulation. According to Innova Market Insights (2019), the global top five flavors in 2017-2018 in CBs, as measured by their launches, included milk chocolate, almond, coconut, peanut butter and dark chocolate (Innova Market Insights, 2019). Milk chocolate was the leading flavor worldwide, which is in line with recent findings indicating claiming "with chocolate" on pack increases the interest of consumers to choose a CB (Salazar et al., 2019). In addition, chocolate- and cereal-flavored bars are shown to be preferred over fruit-flavored bars (Kim et al., 2016). Launches with dessert-style flavors like Greek yogurt, brownie, cookie dough, and fudge are also increasing. Furthermore, experimenting with unusual and exotic flavors in CBs is trending too. In this vein, pumpkin spice, goji, mocha coffee, and ginger are among the upcoming flavors (Innova Market Insights, 2019). Interestingly, Mintel highlighted the increase in the number of launches from 2014-2018 that experimented with savory flavors by including vegetables. This is predicted to expand in the future in the form of savory bars tasting like meals, which will bring greater flavor variety into the category (Mintel, 2019b). In fact, a recent study explored the formulation of a savory CB, including seed, fruit peel, and fish meal. Addition of up to 15% fish meal was shown to be improve nutritional quality while still being sensory accepted by consumers (Matiucci et al., 2020).

In **Table 2.6**, we provide specific implications for future CB product development as a result of the examination of the most relevant current and emerging trends in the CB market. Importantly, most of the implications represent straight-forward industry applications such as the addition of more whole grains whereas only a few of them such as moving from the ambient to the chilled or freezer aisle represent more challenging implications that require extensive company resources, logistics, and capacities.

2.5 Concluding remarks

This article has described the current state of CBs in terms of types, key characteristics, composition, and production methods. A comprehensive review of the most significant existing (i.e., health and well-being, naturalness, sustainability, and convenience) and emerging (i.e., chilled and frozen, functional formulations and new flavors) market trends is also offered along with specific practical implications for CB new product development. Some trends and subtrends were not completely caught by the industry, thus they offer future opportunities for CBs development mostly in terms of ingredients used, processing and formulation. An important aspect is to leverage on the nutritional features of the food matrix: physico-chemical characteristics of the matrix deeply influence the behavior of single nutrients during the digestion (Capuano et al., 2018). CBs can be a perfect vehicle to modulate the food matrix, where ingredients with different structures (e.g., blends of pulses and cereals) can be included at different levels of processing (whole, crushed, milled, and thermally treated and at different particle size). Reformulation is usually the strategy used to upgrade the nutritional value of CBs; yet

Table 2.6. *Practical implications of current and emerging trends for CB new product development.*

Trend	Sub-trend	Implications for new product development
Health and well-being	Protein	• Use other sources of proteins as alternative to traditional soya and dairy, such as proteins coming from: peas, lupin, lentils, microalgae or insects.
	Energy	• Seeds could be used as a source of energy. Their inclusion in CBs could improve lipid profiles.
	Digestive health	• Communication on other benefits beyond the link between fiber and gut health, for example linking fiber with low glycemic index or linking fiber with satiety. • Combine protein with fiber in sports bars to differentiate from other brands in the market. • Incorporate whole grains or legumes in cereal products to increase fiber content. • Use other beneficial ingredients to promote gut health, like probiotics.
	Product customization and personalized nutrition	• Explore the possibilities to customize or even nutritionally personalize CBs.
	Free from sugar	• Food labeling should be accurate and clear (e.g., NutriScore). • Reduce the sugar content, by replacing sugar for new innovative low-caloric sugar replacers that add sweetness and maintain the right texture, for example psicose (allulose).
	Free from fat	• Food labeling should be accurate and clear (e.g., NutriScore). • Replace saturated fats by unsaturated fats in the binder formulation. • Reduce the amount of ingredients with high fat contents.
	Free from sodium	• Food labeling should be accurate and clear (e.g., NutriScore). • Gradually reduce the salt content of CBs.
Naturalness	Clean label	• Offer CBs with a clean label. • The use of a FOP index indicating the naturalness of the product can improve transparency.
	Minimal processing	• Adopt minimal processing and keep ingredients intact that remain recognizable in the final bar.
	Local	• Use traditional or local ingredients and use storytelling to connect the bar with the origin of the raw materials.
	Organic	• Consider using organic raw materials.
Sustainability	Plant power	• Focus on the link between plant-based ingredients of CBs like (whole) grains, vegetables, fruits, nuts and legumes with the planetary health diet and consequently their contribution to healthy diets as well as a healthy planet.
	Food waste	• Reduce or reuse waste, for example by using industrial residues to produce CBs
	Packaging	• Rethink CB packaging, by making it recyclable, compostable or reusable. Move from plastic to plastic-free options. Renewable and plant-based materials could offer a solution.
Convenience	Meal replacement	• Provide healthy and nutritionally balanced CBs that could potentially be used as meal replacers.
Emerging trends	Chilled and frozen	• Move from the ambient to the chilled or even freezer aisle with fresher and less processed CBs.
	Functional formulations	• Communication beyond "energy", for example brain health, stress, sleep, detox, and immunity. • New functional ingredients are to be explored, such as collagen, avocado oil and insect protein.
	New flavors	• Launch CBs with dessert-style, unusual and exotic flavors. • Move from sweet to savory flavors by including vegetables.

modulating matrix structure can open up new opportunities for the design of healthier foods (Capuano & Pellegrini, 2018).

Based on insights from this article, we encourage the industry to keep investing in finding new innovative alternatives to design CBs with reduced content of sugar, fat and salt. Research and innovation initiatives need to be conducted towards the formulation of healthier and more sustainable binders that enable the desired texture of the final CB without compromising flavor of the ingredients. With regards to lowering salt content, future research may test the extent to which contrasting salt level can be successfully applied to CBs. Furthermore, it would be interesting to investigate how potential FOP labels such as the Nutri-Score or the Food Naturalness Index could be used by CB manufacturers to reformulate their products towards healthier and more natural ones. In terms of sustainability, future research could explore: (1) how to reduce the large amount of non-recyclable waste during processing as well as the total carbon footprint, and (2) how to use more environmentally friendly materials for CB packaging.

In conclusion, the future of the CB industry is associated with the development of formulations with a high nutritional value, without compromising sensory attributes or product quality, while raising its naturalness and sustainability levels as much as possible. CBs are portable foods that can be used as meal substitute, supplement, or snack. Processing and formulation required to achieve a good sensory performance and stability during storage are available, also for small companies and startups, thus favoring innovation and tailoring to the various consumers' needs (Pinto et al., 2017; Suhem et al., 2013, 2017). Manufactures have a toolbox with a large portfolio of ingredients and processing techniques, but there is no one size fitting all: product customization and personalized nutrition will be two fundamental drivers of the future nutrition. CBs are food items that can be well combined with the modern and multiple consumers' needs such as healthy, natural, and sustainable nutrition.

CHAPTER 3

Are cereal bars significantly healthier and more natural than chocolate bars? A preliminary assessment in the German market

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Abstract

The main aim of the current study was to examine and compare the nutritional quality and degree of naturalness of chocolate and cereal bars. Our analysis relied on a dataset (*n*=100) of the most consumed chocolate and cereal bars in Germany in 2019. The Nutri-Score and the Food Naturalness Index were calculated to measure nutritional quality and naturalness of the bars, respectively. Cereal bars were nutritionally better and slightly more natural, but had longer ingredient lists, as compared to chocolate bars. Nutritional quality and food naturalness were only weakly correlated, which suggests that they are two distinct food characteristics. Despite increased criticism regarding the effects of ultra-processed foods on health, our results suggest that not all ultra-processed foods are necessarily unhealthy. Although there is plenty of room for improvement in the formulation of cereal bars, they have the potential to be a healthier and more natural alternative to chocolate bars.

3.1 Introduction

In recent decades, consumers have become increasingly concerned about their own and the planet's health. Consumers are currently more knowledgeable about how healthier food choices play a key role in the prevention of future health problems; hence they request foods that exert certain health benefits (Dolgopolova & Teuber, 2018; Santeramo et al., 2018; Topolska et al., 2021). Simultaneously, consumers demand "clean label" foods that do not contain any additives and preservatives, and that are produced with respect to nature (Asioli et al., 2017; Maruyama et al., 2021; Román et al., 2017). Reinforced by the advent of COVID-19 (Lockyer, 2020; Rodríguez-Pérez et al., 2020), the highly demanding consumer of today has set the trend not only for convenient, but also for natural, healthy and sustainable food products (Arenas-Jal et al., 2019; Battacchi et al., 2020; Carfora et al., 2021). The change in consumers' lifestyle has driven a solid movement towards the consumption of convenient foods (Nielsen, 2018). Within convenience foods, snacks are gaining increased market popularity (Nielsen, 2018). In fact, many consumers see them as a way of "sustaining" energy throughout the day rather than merely as indulgent treats (Damen et al., 2020; Forbes et al., 2015; Saint Pol & Hébel, 2021). This has shifted the snack market from mainly traditional snack options (e.g., chocolate bars) towards the formulation of functional and more innovative products such as cereal bars (Glanbia Nutritionals, 2021). The global cereal bar market is expected to grow at a CAGR of 8.5% between 2021-2026, which is 4% more as compared to the full chocolate market (CAGR of 4.5%) (Mordor Intelligence, 2020a, 2020b).

Although cereal bars are often perceived or designated as a healthier alternative to, for instance, chocolate bars (Bucher et al., 2016; Huitink et al., 2020; Poquet et al., 2020; Vasiljevic et al., 2015), they may also be discouraged by several governmental organisations worldwide (e.g., the Netherlands, New Zealand) (New Zealand Ministry of Health, 2020; Voedingscentrum, n.d.). Reasons for discouragement are attributed to the high content of saturated fat, (added) sugar and/or salt (New Zealand Ministry of Health, 2020; Voedingscentrum, n.d.), and the high degree of processing (New Zealand Ministry of Health, 2020). Indeed, previous research on the nutritional quality of cereal bars has shown that sugar content is high, however, they also seem to provide valuable amounts of fibre (Aleksejeva et al., 2017; Curtain & Grafenauer, 2019). On the other hand, chocolate bars are generally known to be high in saturated fat (Omeroglu & Ozdal, 2020) and sugar (Hashem et al., 2019), and are perceived as highly processed, high in artificial additives, and thus unnatural (Perkovic et al., 2021). The question still remains: are these "new" snacks (i.e., cereal bars) really healthier and more natural than traditional snacks (i.e., chocolate bars)? Or is it all smoke and mirrors?

The voluntary front-of-pack label Nutri-Score, developed by academic researchers (Hercberg et al., 2021; Julia & Hercberg, 2017), is gaining increased acceptance and adoption in many countries in Europe (European Commission, 2020; Storcksdieck et al., 2020), and has been applied by multiple food product databases (e.g., OpenFoodFacts, Yuka). Research has shown that the Nutri-Score is a very effective tool for consumers to accurately estimate the nutritional quality of foods (Egnell et al., 2018, 2020; Packer et al., 2021) and snacks in particular (Hagmann & Siegrist, 2020; Poquet et al., 2019).

Even though such tools that evaluate and communicate the nutritional quality of foods like Nutri-Score exist, the term "natural" has not been regulated so far. Thus, an objective measure of food naturalness has been lacking over the years. In response, Sánchez-Siles et al. (2019) developed the Food Naturalness Index (FNI), which integrates insights from consumer, legal and technical perspectives. Consumers' perceptions of food healthiness and naturalness are often linked (Hartmann et al., 2018; Román et al., 2017), but little is known about whether in reality a product's healthiness (i.e., nutritional quality) is related to its naturalness. Only recently, preliminary findings on 28 snacks in the Swiss market showed a weak relationship between the Nutri-Score and FNI (Michel et al., 2021).

In the light of these facts and considerations, the first objective of the current research is to compare the nutritional quality (measured through Nutri-Score (Julia & Hercberg, 2017)) and degree of naturalness (measured through the FNI (Sanchez-Siles et al., 2019)) between chocolate and cereal bars in Germany, a market with the most new snack bar launches in Europe in the last three years (Mintel GNPD, 2021). In addition, given the increasingly relevant "clean label" trend, a second, related objective of this study is to identify the most frequently used additives, unnecessary/unexpected ingredients, and processed ingredients in chocolate and cereal bars. A final objective is to analyse the extent to which nutritional quality is correlated to food naturalness.

3.2 Material and methods

3.2.1 Selection of product groups

Data were collected using the market research database of The Nielsen Company. The database was searched for the most sold chocolate and cereal bars in German retail and drug stores in 2019, based on their sales in volume. The terms "schokoriegel" and "muesliriegel" were used (German for "chocolate bar" and "cereal bar"). Product duplicates (i.e., identical products sold in different quantities per pack) and mixed products (i.e., several varieties per pack) were identified and removed. Products from private labels were also removed since their brand and product names were unknown. Products were added until a maximum of 50 most sold products was reached for each snack bar category. The 50 most sold chocolate and cereal bars included in this study represented approximately 50% of total market share of each category in 2019. Twenty-one and nine different brands could be distinguished among the most sold chocolate and cereal bars, respectively. **Figure 3.1** depicts a flowchart of the product selection.

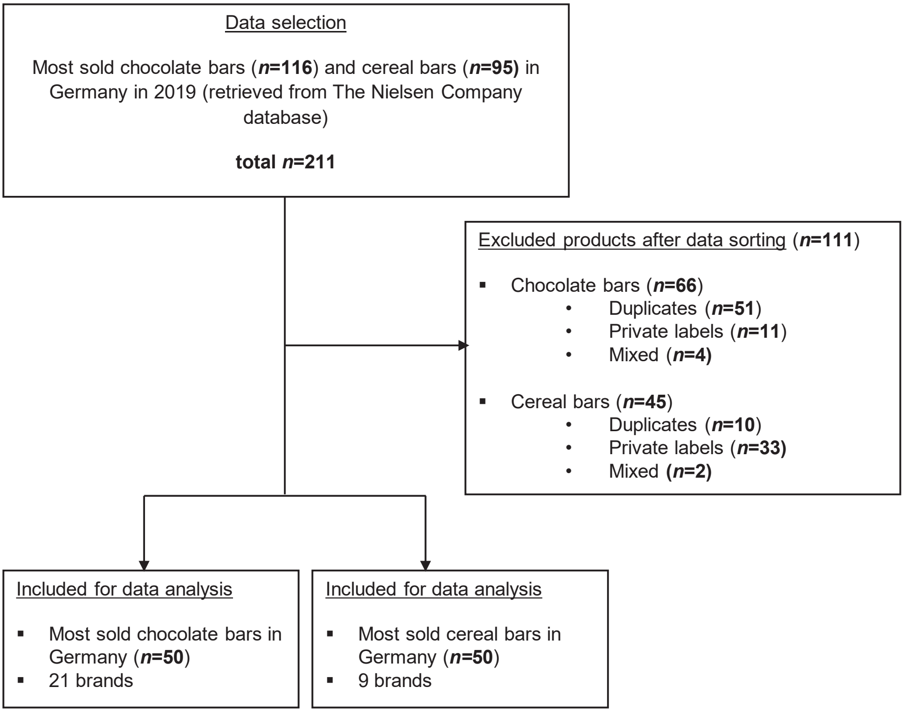

Figure 3.1. *Flowchart of data selection, data sorting, and data inclusion.*

3.2.2 Data collection

After product selection, the internet was searched for product information. Product information refers to the ingredient lists, farming practices (conventional or organic), and nutritional values per 100g of energy (kJ), saturated fat (g), sugar (g), protein (g), fibre (g), and salt (g) and/or sodium (mg). Most recent nutritional data for all products were obtained by extraction of online data from the brands' or retailers' websites. However, data on fibre content was often missing, since fibre declaration on nutrition labels is voluntary according to EU legislation (Regulation (EC) No 1169/2011, 2011). Multiple websites and databases needed to be consulted and compared (e.g., brands' or retailers' websites in other countries, USDA Food Data Central, FDDB) to obtain the most accurate values for fibre content. The same regulation requires mandatory nutrition declaration of salt content by using the term 'salt' instead of the corresponding term of the nutrient 'sodium'. Sodium content was therefore calculated using the formula (Regulation (EC) No 1169/2011, 2011).

The resulting dataset was then complemented with calculations of the number of ingredients per recipe, portion sizes, and total percentages of fruit, vegetables, nuts, legumes, and oils (% FVNLO). Portion sizes were calculated based on total pack weight, quantity of single units per pack, and number of bars per unit (e.g., two bars packed in a single packaging was considered one portion). The total % FVNLO was quantified by evaluating the ingredient lists of all products. The procedure for calculating % FVNLO is described in a report of Santé publique France outlining the application of Nutri-Score (Santé Publique France, 2021). However, in some cases, this procedure could not be used due to unknown percentages for some of the FVNLO ingredients. Accordingly, assumptions about the content of ingredients were made based on 1) known proportions of other ingredients, 2) position of ingredients in the ingredient list, and 3) similar bars of which the proportions were known. Considering these assumptions, a rough estimation of the proportion of FVNLO could be made (**Figure 3.2**).

3.2.3 Nutritional quality: Nutri-Score computation

The nutritional quality of the bars was assessed by means of nutritional values per 100g and by using the Nutri-Score labelling system. The Nutri-Score is based on the Food Standards Agency nutrient profiling system (FSAm-NPS). Positive points were allocated

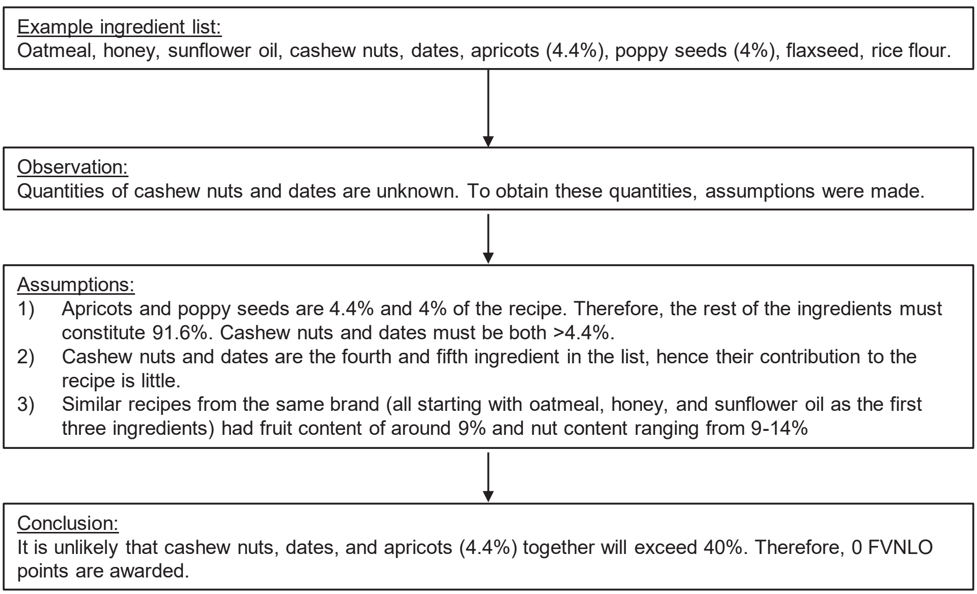

Figure 3.2. *Example estimation % FVNLO of a recipe with unknown quantities for some of the FVNLO ingredients.*

to unfavourable variables among which are energy (kJ, 0-10 points), total sugar (g, 0-10 points), saturated fat (g, 0-10 points) and sodium (mg, 0-10 points). Negative points were allocated to favourable variables among which are protein (g, 0-5 points), fibre (g, 0-5 points), and proportion of FVNLO (%, 0-5 points). Based on these positive and negative points, the FSAm-NPS score was computed that could range from -15 (high nutritional quality) to 40 points (low nutritional quality). The FSAm-NPS score was then reflected in a corresponding colour and letter: -15 to -1 points in dark green/A for the best nutritional quality, 0 to 2 points in light green/B, 3 to 10 points in yellow/C, 11 to 18 points in orange/D and 19 to 40 points in red/E for the worst nutritional quality. The full description of the algorithm to calculate the Nutri-Score has been explained previously (Julia & Hercberg, 2017; Santé Publique France, 2021).

3.2.4 Degree of naturalness: Food Naturalness Index computation

The degree of naturalness of the bars was calculated by means of the FNI (Sanchez-Siles et al., 2019), which considers the farming practice, the number of additives, the number of unnecessary/unexpected, and the number of processed ingredients. Scores were allocated to each of the FNI components and ranged from 2 (slightly natural) to 4 (very natural) for the component farming practices, from 1 (not natural at all) to 4 (very natural) for the component degree of processing, and from 1 (not natural at all) to 5 (extremely natural) for free from additives and free from unnecessary/unexpected ingredients. The overall FNI score was computed by taking the average score of the four components (Sanchez-Siles et al., 2019). As indicator for "clean label", the total number of ingredients in each bar was calculated.

3.2.4.1 Farming practice

The farming practice of the studied bars was either conventional or organic. The current study did not include any products targeted at infants and young children, hence none of the bars were designated pesticide controlled (i.e., baby food grade) nor organic pesticide controlled (i.e., organic baby food grade). Distinction between conventional and organic farming practices was clear from labelling, in accordance with EU legislation (Council Regulation (EC) No 834/2007, 2007).

3.2.4.2 Number of additives

The definition of additives was based on CODEX (Codex Alimentarius Commission, 2013) and EU legislation (Commission Regulation (EC) No 1333/2008, 2008) and included additives both with an E-number or chemical name.

3.2.4.3 Number of unnecessary/unexpected ingredients

We have followed the definition and examples of unnecessary/unexpected ingredients offered by Sánchez-Siles et al. (2019), namely, ingredients that are not easily recognised or understood by consumers and usually these ingredients are hardly found in one's kitchen cupboard (i.e., thickeners, non-commercial oils and fats, artificial flavours, glucose/fructose syrups, unexpected added sugar and salt, and other ingredients that are not expected to be in the product or recipe). However, some clarifications to the original list needed to be made. More specifically, caramel sugar syrup and fruit juice concentrates were only counted as unnecessary/unexpected ingredients if addition was not reflected in the bar's name or appearance (e.g., pineapple juice in a cranberry cereal bar). All isolated protein and fibre related ingredients were only counted as unnecessary/unexpected ingredients in bars which did not mention protein or fibre in the product's name. Barley malt extract, added salt, and added vitamins/minerals were not considered unnecessary/unexpected ingredients. Neither were milk-derived ingredients in cereal bars with chocolate penalised.

3.2.4.4 Number of processed ingredients

Processed ingredients included isolated ingredients, refined/processed fats, natural and artificial flavours, any refined sugar, dehydrated/concentrated and powdered ingredients, and refined, hydrolysed, and extruded cereals (Sanchez-Siles et al., 2019). Refined flours were only counted as processed ingredients if more than half of the proportion of cereals in the product was refined. We excluded minimally processed ingredients from a penalisation, such as fruit flakes or chips (e.g., coconut flakes), cocoa mass, and powdered herbs/spices.

3.2.5 Statistical data analysis

Statistical analyses were performed using IBM SPSS Statistics version 27.0 (Armonk, NY: IBM Corp). Before conducting the analyses, normality of the data was checked using the Shapiro-Wilk test. The normality of data distribution was rejected, and therefore data were presented as median and interquartile range (IQR). Categorical variables were reported in percentages. Mann-Whitney U non-parametric tests for independent samples were performed to compare FSAm-NPS points, nutrient data, FNI, number of additives, unnecessary/unexpected ingredients, and processed ingredients, and total number of ingredients between groups. Spearman's correlation was run to determine the relationship between FSAm-NPS points (nutritional quality) and FNI (food naturalness). P-values below 0.05 were considered significant. In addition, Microsoft Excel version 11.0 was used to identify the most frequently used additives, unnecessary/unexpected ingredients, and processed ingredients, by using the IF function including multiple possible word options (e.g., "lactose" and "milk sugar" or "lecithin" and "E322").

3.3 Results

3.3.1 Nutritional quality of chocolate and cereal bars

Mean portion sizes were quite similar between categories, with cereal bars being slightly smaller (31 g) than chocolate bars (35 g). Chocolate bars had significantly a higher FSAm-NPS score (median (IQR), 25.0 (2.0)) compared to cereal bars (median (IQR), 12.5 (8.0)) (P<0.001). Also, chocolate bars had a lower variability of FSAm-NPS score compared to cereal bars (**Figure 3.3a**). All chocolate bars were graded as Nutri-Score E (100%), whereas four classes of the Nutri-Score were observed for cereal bars (B, C, D, and E). Most cereal bars were classified as Nutri-Score D (50%), followed by Nutri-Score C, E, and B with 22%, 16%, and 12%, respectively. Cereal bars having a Nutri-Score B were characterised by low sugar levels (due to the use of sweeteners), high fibre levels (due to the addition of whole grains), and relatively low salt levels. Neither chocolate bars nor cereal bars were qualified as Nutri-Score A (**Figure 3.3b**).

Regarding the nutritional values of the bars, chocolate bars showed significantly higher median values in terms of energy, sugar, and saturated fat, but a lower median value for fibre, compared to cereal bars (all P<0.001). In addition, chocolate bars had lower median values for sodium and protein, but this difference was not statistically significant (**Table 3.1**, **Figure 3.4**). Most common cereals found in cereal bars were (whole grain) oats and wheat, followed by barley, rice, and corn (or a combination thereof). Cereals were added in quantities up to 62%. In total, 54% and 18% of cereal bars included ≥25% and ≥50% of whole grain cereals, respectively. Most chocolate bars were based on milk chocolate, with main ingredients like sugar, cocoa mass, milk powder, cocoa butter, and other vegetable oils or fats.

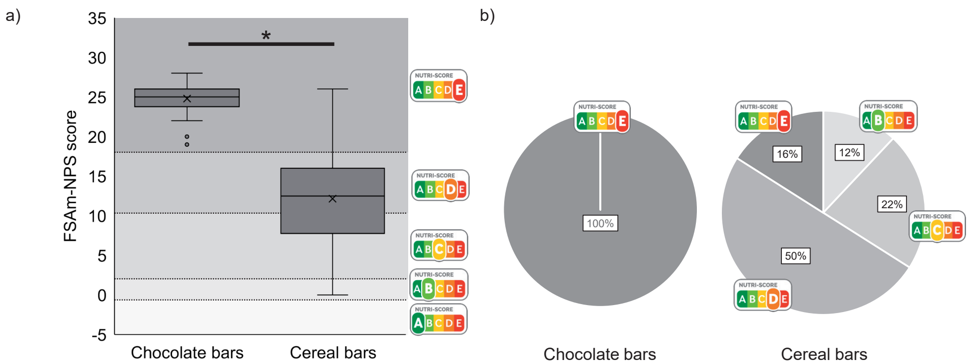

Figure 3.3. *a) Boxplots FSAm-NPS score distribution chocolate bars (n=50) and cereal bars (n=50). The boxplots are divided into the five Nutri-Score classifications: A, B, C, D and E. *P<0.001, Mann-Whitney U test for two independent samples. b) Nutri-Score distribution (%) of chocolate bars (n=50) and cereal bars (n=50).*

***Table 3.1.** FSAm-NPS score and nutritional composition of chocolate bars (n=50) and cereal bars (n=50).*

Nutrients	Chocolate bars		Cereal bars		P-value
	Median (IQR)	Range (min – max)	Median (IQR)	Range (min – max)	
FSAm-NPS score	25.0 (2.0)	19.0 – 28.0	12.5 (8.0)	0.0 – 26.0	0.000
Energy (kcal/100g)	527.0 (63.8)	448.0 – 596.0	434.5 (57.3)	336.0 – 553.0	0.000
Energy (kJ/100g)	2200.0 (259.0)	1882.0 – 2482.0	1824.0 (240.8)	1405.0 – 2303.0	0.000
Sugars (g/100g)	47.4 (8.1)	33.7 – 63.0	25.0 (6.5)	1.5 – 41.1	0.000
Saturated fat (g/100g)	16.1 (5.2)	7.9 – 26.6	6.7 (6.1)	1.0 – 18.2	0.000
Sodium (mg/100g)	140.0 (97.1)	12.0 – 284.0	162.0 (118.0)	16.0 – 368.0	0.304
Protein (g/100g)	6.8 (2.9)	3.6 – 10.0	7.3 (1.6)	4.0 – 17.0	0.355
Fibre (g/100g)	1.5 (1.5)	0.0 – 8.4	5.1 (1.5)	0.7 – 12.0	0.000

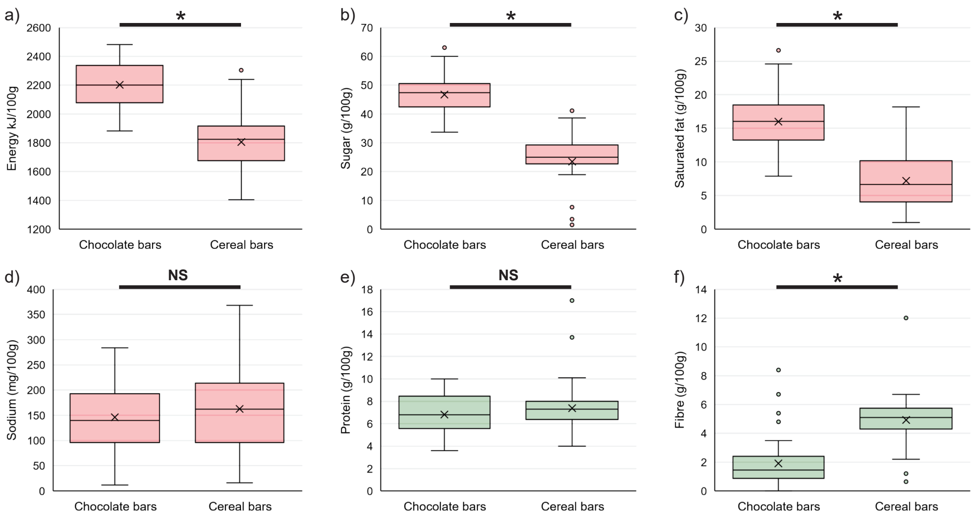

***Figure 3.4.** Boxplots nutritional composition chocolate bars (n=50) and cereal bars (n=50). a) energy (kJ/100g), b) sugar (g/100g), c) saturated fat (g/100g), d) sodium (mg/100g), e) protein (g/100g), and f) fibre (g/100g). Red plots (a to d) are unfavourable content, green plots (e and f) are favourable content according to Nutri-Score scoring system. *P<0.001 and NS = not significant, Mann-Whitney U test for two independent samples.*

3.3.2 Degree of naturalness in chocolate and cereal bars

Chocolate bars had a significantly lower FNI (median (IQR), 1.8 (0.5)) compared to cereal bars (median (IQR), 2.0 (0.8)) (*P*=0.005). Chocolate bars reached a maximum score of 3.3, whereas cereal bars reached a maximum score of 4.0 (**Figure 3.5a**). These bars were regarded as outliers. As depicted in **Figure 3.5b**, the majority of chocolate bars was "not natural at all" with 54% of them having a FNI below 2.0. Nearly half of chocolate bars (44%) was "slightly natural" with scores ranging between 2.0 and <3.0. Only 2% of chocolate bars was "moderately natural" with one bar obtaining a FNI of 3.3. In comparison, most cereal bars were "slightly natural" as 54% obtained a FNI between 2.0 and <3.0, followed by 32% that was qualified as "not natural at all". With respect to the more natural bars among the cereal bars, 10% and 4% were "moderately natural" and "very natural", respectively.

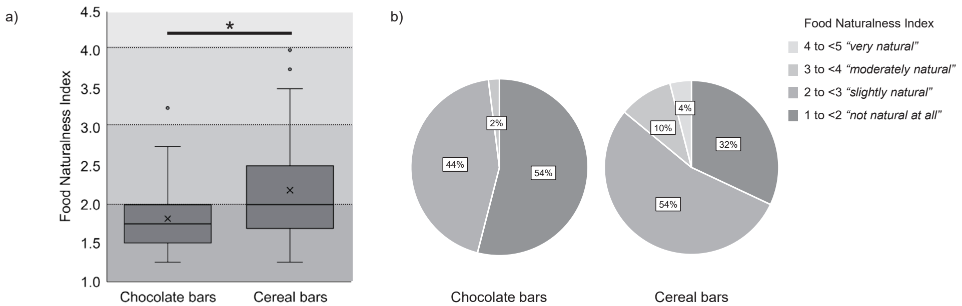

Figure 3.5. *a) Boxplots FNI distribution of chocolate bars (n=50) and cereal bars (n=50). *P=0.005, Mann-Whitney U test for two independent samples. b) FNI distribution of chocolate bars (n=50) and cereal bars (n=50).*

In addition to FNI scores and the total number of ingredients, **Table 3.2** presents the scores for three of the four components that entail the FNI (the number of additives, unnecessary/unexpected ingredients, and processed ingredients). As for the fourth component of the FNI (farming practices), all chocolate bars (100%) relied on conventional farming, and almost all cereals bars did too (96%). The number of additives and processed ingredients were both slightly higher in chocolate bars than in cereal

Table 3.2. *FNI, FNI components (number of additives, unnecessary/unexpected ingredients, processed ingredients) and number of ingredients of chocolate bars (n=50) and cereal bars (n=50).*

Components FNI	Chocolate bars		Cereal bars		P-value
	Median (IQR)	Range (min – max)	Median (IQR)	Range (min – max)	
FNI	1.8 (0.5)	1.3 – 3.3	2.0 (0.8)	1.3 – 4.0	0.005
Nº additives	3.0 (2.0)	1.0 – 6.0	2.0 (2.0)	0.0 – 7.0	0.102
Nº unnecessary/ unexpected ingredients	4.0 (3.0)	0.0 – 10.0	3.0 (3.0)	0.0 – 7.0	0.014
Nº processed ingredients	11.0 (3.0)	3.0 – 23.0	9.0 (7.0)	1.0 – 18.0	0.203
Nº ingredients*	17.0 (7.0)	6.0 – 32.0	22.0 (15.0)	6.0 – 44.0	0.026

Number of ingredients is not part of the FNI, but generally used as an attribute for "clean label"* bars, however, no significant differences for these two components were found (both *P*>0.05). On the contrary, chocolate bars consisted of significantly more unnecessary/unexpected ingredients (median (IQR), 4.0 (3.0)) compared to cereal bars (median (IQR), 3.0 (3.0)) (*P*=0.014). The total number of ingredients was found to be significantly lower in chocolate bars compared to cereal bars (*P*=0.026). **Figure 3.6 shows the frequency of chocolate and cereal bars according to the number of additives, unnecessary/unexpected ingredients, processed ingredients, and ingredients in their recipes.

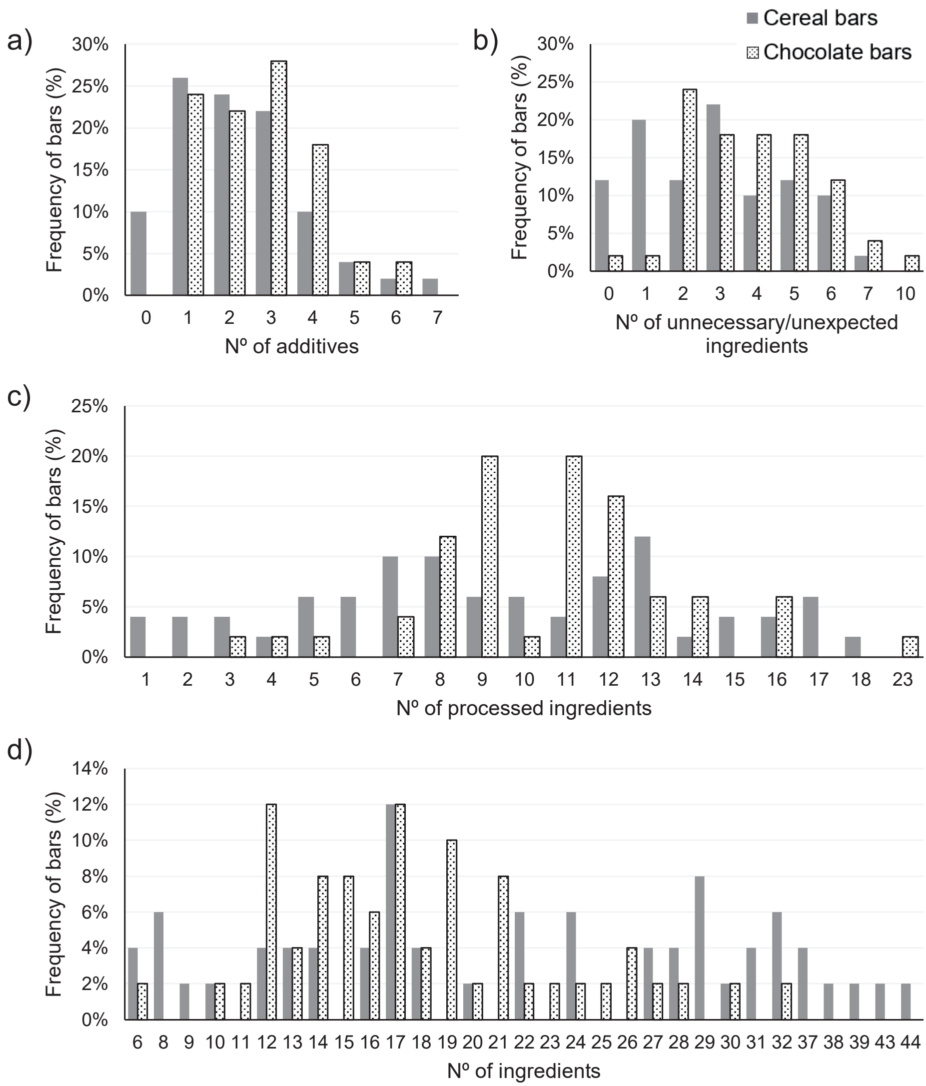

Figure 3.6. *Frequency of bars (%) according to number of a) additives, b) unnecessary/unexpected ingredients, c) processed ingredients, and d) ingredients in chocolate bars (n=50, dotted bars) and cereal bars (n=50, grey bars).*

3.3.3 Most frequently used additives, unnecessary/unexpected ingredients, and processed ingredients

As shown in **Table 3.3**, the most common additives found in chocolate and cereal bars were soy or sunflower lecithins, followed by leavening agents sodium and ammonium hydrogen carbonate in chocolate bars, and glycerol/glycerin in cereal bars. The most frequently used unnecessary/unexpected ingredient in chocolate bars was palm fat or oil, while in cereal bars it was glucose syrup. The most frequently used processed ingredients in chocolate bars were milk powder and cocoa butter, while in cereal bars it was coconut fat or oil (**Table 3.3**).

3.3.4 Relationship between nutritional quality and degree of naturalness

A significant moderate negative correlation was found between FSAm-NPS score (nutritional quality) and FNI (food naturalness) in the overall sample of bars (ρs = -0.288, *P*=0.004). Given that higher points in the FSAm-NPS score signal worse levels of nutritional quality as explained earlier in the methodology section, our results show a weak and positive relationship between nutritional quality and food naturalness.

Table 3.3. *Top 5 additives, unnecessary/unexpected and processed ingredients used in chocolate (n=50) and cereal bars (n=50). Data is expressed in % of total products containing the ingredient.*

Top 5	Chocolate bars	%	Cereal bars	%
Additives	1. Lecithin (E322)	100	1. Lecithin (E322)	90
	• *Soy lecithin*	*68*	• *Sunflower lecithin*	*60*
	• *Sunflower lecithin*	*12*	• *Soy lecithin*	*10*
	• *Unknown*	*16*	• *Unknown*	*20*
	• *Both*	*4*	• *Both*	*0*
	2. Sodium hydrogen carbonate (E500)	68	2. Glycerol/glycerin (E422)	46
	3. Ammonium hydrogen carbonate (E503)	30	3. Citric acid (E330)	14
	4. Citric acid (E330)	12	4. Maltitol (syrup) (E965)	14
	5. Mono- and diglycerides of fatty acids (E471)	12	5. Pectin (E440)	8
Unnecessary unexpected ingredients	1. Palm (kernel) fat or oil	86	1. Glucose syrup	58
	2. Artificial flavours	64	2. Glucose-fructose syrup	44
	3. Glucose syrup	36	3. Palm (kernel) fat or oil	28
	4. Wheat starch	16	4. Dextrose	26
	5. Shea fat	14	5. Maltodextrin	18
Processed ingredients	1. Milk powder	94	1. Coconut fat or oil	64
	2. (strongly deoiled) cocoa butter	94	2. Natural flavours	62
	3. Palm (kernel) fat or oil	86	3. Milk powder	60
	4. Artificial flavours	64	4. Glucose syrup	58
	5. Glucose syrup	36	5. Barley malt extract	50

3.4 Discussion

The main aim of the current study was to examine and compare the nutritional quality (Nutri-score) and degree of naturalness (FNI) of the most sold chocolate and cereal bars in Germany. In general, the results showed that cereal bars had a higher nutritional quality and slightly higher degree of naturalness as compared to chocolate bars. More specifically, the majority of cereal bars obtained a better Nutri-Score, which ranged from E to B, as compared to chocolate bars, which was E in all cases. The main reasons can be attributed to the fact that cereal bars were higher in favourable content of fibre, and lower in unfavourable content of energy, sugar, and saturated fat as compared to chocolate bars. Approximately half of cereal bars contained at least 25% of whole grain cereals, mainly from oat and wheat, which is considered as the minimum contribution of a dietarily meaningful amount of whole grain (Whole Grain Initiative, 2020). Whole grains in cereal bars increase fibre content but also deliver important other bioactive compounds like vitamins and minerals (Klerks et al., 2019). For example, a cereal bar with 30 g whole grain oats per 100 g, would theoretically be a source of selenium according to Regulation No 1169/2011 and considering chemically analysed nutrients in oats provided by the USDA Food Data Central (U.S. Department of Agriculture, 2020). Those bars with 50 g whole grain oats per 100 g would in addition theoretically be a source of iron, magnesium, zinc, copper, and vitamin B1. In contrast, high quantities of base ingredients of milk chocolate like sugar and cocoa butter are mainly responsible for the substantial content of sugar and saturated fat in chocolate bars, while milk powder may contribute to the content of calcium. Nonetheless, given the average quantities of milk chocolate in our chocolate bar sample, they will hardly be a source of calcium (U.S. Department of Agriculture, 2019). Clearly, there is an opportunity for manufacturers to chemically analyse their products to explore potential nutrition claims.

Importantly, the nutritional quality of cereal bars varied greatly, which is consistent to the nutritional profile of grain-based muesli bars found in Australia (Curtain & Grafenauer, 2019). Yet, similar to prior research conducted in 8 European countries (Dréano-Trécant et al., 2020), D was the predominant Nutri-Score grade within cereal bars. This implies that there is still plenty of room for improvement such as the reduction of sugar levels. Reducing sugar levels in both cereal and chocolate bars is urgently needed as it has recently been shown that these type of foods are among the five food categories that contribute the most to sugar intake in the UK (Bandy et al., 2021). High sugar levels are the consequence of the binder, generally existing of sugar, sugar syrups, and/or honey (Pallavi et al., 2015). Although reducing sugar levels in cereal bars is challenging due to the functional and technological properties it has, ingredients like prebiotic fibres (e.g., inulin) seem to be excellent alternatives (Di Monaco et al., 2018). Besides sugar, saturated fat is another key nutrient in cereal bars that needs attention. Chocolate drizzles or bottom coatings are in many cereal bars one of the contributors to the saturated fat content. Hence, limiting the use of chocolate could be a solution to bring saturated fat levels down. Manufacturers need to find the sweet spot between healthier but still tasty bars when (re)formulating, as chocolate has been shown to play an important role in consumers' liking for (cereal) bars (Kim et al., 2016; Salazar et al., 2019). Ultimately, manufacturers could explore ways to partially substitute refined cereals by legumes, given their healthier nutritional profile (Tas & Shah, 2021). Legumes could be added as functional ingredients in snack bars as they enhance the nutritional value (Ramírez-Jiménez et al., 2018). In contrast to cereals, legumes are considered by the Nutri-Score system as favourable content and account for the proportion of FVNLO (Santé Publique France, 2021). For instance, replacing 30% refined wheat flour by pea or lentil flour in a bar with 11% nuts, would increase FVNLO content from 11% to 41% and therefore would get a point for favourable content. In addition, legumes contain a higher percentage of protein as compared to cereals (Tas & Shah, 2021). Feasibility and sensory acceptance of legumes in snack formulations (i.e., extruded snacks, snack bars) has previously been studied (Proserpio et al., 2020; Ramírez-Jiménez et al., 2018; Tas & Shah, 2021). These studies have shown that consumers moderately accept the addition of legumes, and flavour and mouthfeel are sensory attributes that need to be optimised. Future studies will benefit from identifying the right combination of flours and other ingredients, and finding the right processing conditions to improve consumer acceptance.

Remarkably, if the NOVA classification system developed by Monteiro and colleagues (Monteiro, Cannon, Levy, et al., 2019) is to be followed, then chocolate and cereal bars would be considered as "intrinsically unhealthy", since the NOVA scheme classifies them as "ultra-processed foods". There is increased negativity and misunderstandings concerning processed foods by consumers, policy makers, and in the media (Sadler et al., 2021). The present study shows, however, that degree of processing should not be confused with nutritional quality (Derbyshire, 2019; Jones, 2019), as some cereal bars had the possibility to obtain a Nutri-Score B even though they are qualified as ultra-processed foods. This is particularly relevant as a recent critical review on processed food classification systems concluded that "From the perspective of food science and technology, processing and nutritional value do not have a linear relationship and these concepts need to be dissociated" (p.157) (Sadler et al., 2021).

In line with preliminary findings from Michel et al.'s (2021) study, our analysis shows that cereal bars were slightly more natural than chocolate bars, although the median FNI value (2.0) was rather low. The difference between the two groups could be attributed to the significant higher number of unnecessary/unexpected ingredients in chocolate bars. In particular, palm oil and artificial flavours were highly prevalent unnecessary/unexpected ingredients in the chocolate bars' formulations. Almost all (chocolate and cereal) bars were based on conventional farming. Production of organic snack bars poses an opportunity for manufacturers to offer consumers more natural alternatives. In fact, shifting from conventional to organic farming practices will lead to an increase of 0.5 in the FNI score. Furthermore, the majority of (chocolate and cereal) bars contained two or more additives, with lecithin being the most common one. Lecithin is often used as emulsifier and stabiliser in biscuits and cake-like products (Chazelas et al., 2020), and it was not perceived as natural by 86% of consumers in prior research (Chambers et al., 2018). In addition, in a context of increasing demand for low-sugar foods, the sweeteners that make them feasible are key. Many artificial sweeteners (e.g., aspartame, sucralose) have been developed, but consumers' aversion to synthetic ingredients has led the industry to explore alternative sweeteners sourced from nature. Innovative and promising alternatives that have been approved in many countries include natural sweeteners such as erythritol, tagatose, and steviol glycosides (Saraiva et al., 2020b). In our sample, maltitol was the most often used (natural) sweetener. As there is no definition of natural sweeteners, they are integrated in the EU into the same E-number classification as all artificial counterparts (Carocho et al., 2015). Consequently, both artificial and natural additives are penalised equally in the FNI scoring system. Further research could examine the ability of consumers to distinguish natural from artificial sweeteners. Notably, some cereal bars included in this study evidenced that it is feasible to produce cereal bars without additives, including lecithin and sweeteners, while still being highly accepted by consumers (being among the 50 best-selling products in the German market).

Although not part of the FNI, we have also investigated the length of the ingredient lists. A short ingredient list is one of the attributes that help consumers to identify "clean label" products (Cargill, 2017). Surprisingly, despite the higher FNI value, cereal bars had longer ingredient lists as compared to chocolate bars. This can probably be explained by the wide variety of ingredients that are found in cereal bars (i.e., various cereals, nuts, fruits, chocolate, sugars, fats) (Curtain & Grafenauer, 2019). These results suggest that the number of ingredients only reduces food naturalness when the "additional" ingredients are not perceived as "understandable", "known", or "simple" by the consumer. Accordingly, the mere length of the ingredient list as an attribute for the "clean label" concept should be considered with care. Interestingly, similar to recent findings from Michel et al. (2021), nutritional quality and food naturalness were only weakly correlated. Altogether, these results indicate that even though consumers tend to overlap concepts such as healthiness (i.e., nutritional quality) and food naturalness (Román et al., 2017); from a technical perspective, nutritional quality and food naturalness are indeed separate properties of processed food products like snack bars. Products qualified as more natural (e.g., those having higher FNI levels), will solely be more nutritious (those having a better Nutri-score) if the "natural" ingredients used in the foods also deliver high levels of good quality nutrients (Meijer et al., 2021), and vice versa. For future studies it would be interesting to investigate in other product categories (e.g., dairy) how a product's nutritional quality relates to its naturalness.

Our analysis relied on a dataset (*n*=100) of the most consumed chocolate and cereal bars in Germany in 2019. Even though they represented approximately 50% of total market share, future studies are needed to include larger sample sizes as well as other countries. The nutritional information was carefully sought for. As values for fibre content were often missing on the German brands' or retailers' websites, or simply presented as 0.0 g/100g when not declared on pack, extra attention was paid to obtaining reliable data for fibre content. However, as acknowledged in previous research (Vergeer et al., 2020), for a few bars it was not possible to calculate the exact content quantity of FVNLO due to missing information on product labels. The study is also strengthened by the fact that Nutri-Score and FNI were used to examine nutritional quality and the degree of naturalness in snack bars. Importantly, prior research has been unable to measure naturalness of food products. For instance, De Vlieger et al. (2017, p.61) acknowledged that: "due to lack of an objective measuring scale, it was not possible to quantify the degree of perceived 'naturalness' of snack foods in the current study" (De Vlieger et al., 2017). Fortunately, the FNI was found to be a simple and useful tool to measure and compare the degree of naturalness of foods. Nonetheless, although the FNI includes a detailed list of unnecessary/unexpected ingredients, we encountered some ingredients that were not covered in this in- or exclusion list (e.g., barley malt extract) and were thus open to interpretation. Hence, further research is needed to examine which ingredients (in different foods) are perceived as unnecessary and/or unexpected by consumers. Such research will aid in improving the FNI. Lastly, this study successfully applied the FNI to snack bars, but future studies may apply the FNI in other product categories too.

3.5 Conclusions

In conclusion, even though ultra-processed foods have received criticisms from numerous consumer groups, media publics and policy makers, our study shows that cereal bars have the potential to be a healthier and more natural alternative to chocolate bars. Still, there is plenty of room for improvement in the formulation of cereal bars towards higher levels of healthiness and naturalness. In this study, nutritional quality and food naturalness were only weakly correlated, thus signalling that they are two different food attributes. We believe that the Nutri-Score and FNI are valuable tools to measure and compare the nutritional quality and degree of naturalness in snack bars. These tools provide the food industry with great insights about how their products can be improved and communicated. We strongly encourage manufacturers to employ these tools in their (re)formulations towards healthier and more natural foods. Employment of Nutri-Score and FNI will increase transparency towards the consumer, that could lead to better-informed choices and a positive contribution to public health.

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CHAPTER 4

Baby, children, and adult biscuits. Differences in nutritional quality and naturalness

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Abstract

This study examined and compared the nutritional quality and degree of naturalness between baby biscuits (<3 years), children biscuits (>3 years), and adult biscuits. Mintel's Global New Products Database was searched for "Baby Biscuits & Rusks" and "Sweet Biscuits/Cookies" (re)launched between July 2019 and July 2022 in four European countries (Germany, the Netherlands, Spain, and the UK), which resulted in 1280 products to be analysed. Nutritional quality was measured by means of nutrient values per 100g, and baby biscuits were assessed for compliance with the World Health Organization's latest Nutrient Profile Model (NPM). Degree of naturalness was measured using the Food Naturalness Index (FNI). Baby biscuits had the best nutritional quality and were the most natural as compared to children and adult biscuits, but their energy density and sugar content require further attention. Nutritional quality was comparably poor in children and adult biscuits, and children biscuits were the least natural of the three groups. The strict NPM requirements of not adding any sugar at all to baby biscuits may drive parents to purchase alternative sweeter biscuits originally formulated and meant for children and adults. Reasonable regulations are needed to support product (re)formulations and to improve the current market food offer for babies and children.

4.1 Introduction

A balanced and varied diet in the first years of life is crucial for the development of taste preferences and healthy eating habits that persist into later years (Langley-Evans, 2015). Yet, there is increasing concern about the suitability of some commercially available products for infants, toddlers[1], and children (World Health Organization, 2022). Biscuits are common snacks given to babies and children (Damen, Luning, et al., 2019; Demonteil et al., 2019; Moore et al., 2019) and are frequently used in food marketing particularly aimed at children (Allemandi et al., 2020; Pombo-Rodrigues et al., 2020). Criteria for the appropriate nutritional composition of baby biscuits (i.e., for infants and toddlers <3 years) exist, but they may differ per country or region. For instance, international global standards have been developed by Codex Alimentarius (Codex Alimentarius, 2019), while in Europe requirements for baby food composition are laid down by European legislation (Commission Directive 2006/125/EC, 2006). When biscuits are targeted at older children (>3 years), this legislation does not apply anymore, and nutrient limits are no longer in place. Regardless of whether the nutritional composition is regulated or not, extant research has shown that foods (including biscuits) targeted at babies (Elliott, 2011; Elliott & Conlon, 2014; Garcia et al., 2020; Grammatikaki et al., 2021; Hutchinson et al., 2021; Katiforis et al., 2021; McCann et al., 2022) as well as children (Beltrá et al., 2020; Elliott, 2019; Machado et al., 2019; Pombo-Rodrigues et al., 2020; Richonnet et al., 2022; Santos et al., 2022) are high in nutrients of concern such as sugar, salt, and/or fat. In fact, both baby and child-oriented foods are not always nutritionally different and in some cases even worse than the adult equivalents (Beltrá et al., 2020; Cogswell et al., 2015; Elliott, 2011; Lapierre et al., 2016; Lythgoe et al., 2013; Machado et al., 2019).

A traditional basic biscuit usually consists of cereal flour, table sugar, fat/oil and a raising agent (Arepally et al., 2020). However, according to NOVA's classification system they are by definition ultra-processed, due to the addition of sugar, fat/oil, and additives (Monteiro, Cannon, Levy, et al., 2019). Still, it is surprising that many baby biscuits across Europe have a "natural" or "free from artificial ingredients" claim (Grammatikaki et al., 2021). Since the term "natural" has not been regulated yet, the question remains as to how "natural" these products are according to the most objective approach to assess the degree of naturalness, namely the Food Naturalness Index (FNI) (Sanchez-Siles et al., 2019), and if there are differences compared to child-oriented biscuits and adult biscuits.

Given these facts, baby and children's food manufacturers have been encouraged to reformulate their products and limit their marketing/advertising activities (Y.-C. Koo et al., 2018). Public health agencies such as World Health Organization (WHO) and Public Health England (PHE) have recently created nutritional guidelines for commercial baby

1 For the sake of brevity, in this paper "infants" and "toddlers" are together referred to as "babies"

foods (Public Health England, 2020; World Health Organization, 2022). For instance, the WHO's latest Nutrient Profile Model (NPM) for the European Region and PHE's draft guidelines do not permit the addition of sugar and sweetening agents in foods targeted at babies up to 36 months of age, and limits apply for salt and fat content. In fact, according to these organisations sweet snacks like biscuits should not be marketed as suitable for babies at all. Furthermore, the EU Pledge, a voluntary initiative by leading companies, establishes not to advertise food and beverage products to children under the age of 13 unless they meet specific nutrition criteria (EU Pledge, 2021).

As shown earlier, several studies have investigated the nutritional quality of commercial baby foods (<3 years) and children's foods (>3 years) and only few of them have compared baby or children's foods to adult foods. However, to the best of our knowledge, there are no studies comparing the nutritional quality and degree of naturalness of foods targeted at three different target populations (i.e., babies, children, and adults). Accordingly, the purpose of this study was to compare the nutritional quality and degree of naturalness and its components (farming practice, additives, unnecessary/unexpected ingredients, and processed ingredients) between recent launches of baby biscuits (<3 years), children biscuits (>3 years), and adult biscuits, available in four European countries. Additionally, added sugar sources and the compliance of baby biscuits with the WHO's proposed NPM were evaluated too.

4.2 Materials and methods

4.2.1 Data collection

Cross-sectional data were collected using the Global New Products Database (GNPD) tool from Mintel Group Ltd. The database was searched for "Baby Biscuits & Rusks" and "Sweet Biscuits/Cookies" (re)launched between July 2019 and July 2022 in four European countries (Germany, the Netherlands, Spain, and the UK). According to Mintel's category definitions, "Baby Biscuits & Rusks" includes all biscuits, rusks, and crackers positioned for babies and toddlers. "Sweet Biscuits/Cookies" includes cookies, sweet rice cakes, digestive biscuits, butter cookies, some chocolate covered biscuits/cookies, sandwich cookies, but also French macarons, sweet puff pastry twists, egg rolls, wafer rolls, and palmier cookies. For the scope of this research, "biscuits" had to be present in the product name to exclude products other than biscuits. Products with sweeteners falling under the "Sweet Biscuits/Cookies" category were also excluded, as these products made it impossible to have a fair comparison with baby biscuits, which by legislation, are not allowed to contain sweeteners (Commission Regulation (EC) No 1333/2008, 2008). The initial sample of baby biscuits was quite limited and was then expanded by the addition of biscuits of main baby food brands (which represent >70% of market share in snacks and biscuits) in order to have a larger and more balanced sample size in each country.

4.2.2 Sorting children and adult biscuits

Children biscuits were distinguished from adult biscuits by using the demographic filter "Children (5-12)" in the GNPD database. Mintel defines this demographic category as foods designed for the consumption by children, depending on presentation and format, such as child-inspired graphics like cartoon characters, bright colours, pictures of children, and/or particular language. An additional manual sorting check was carried out to differentiate children biscuits from adult biscuits. Children biscuits were defined based on marketing techniques for packaging design to attract children, as in previous studies (Beltrá et al., 2020; Elliott, 2019; Lapierre et al., 2016; Machado et al., 2019; Mehta et al., 2012; Missbach et al., 2015; Savio et al., 2013). In particular, a child-oriented biscuit had to meet at least two of the following criteria: 1) colourful packaging (e.g., multiple and/or bright colours), 2) child-oriented text/brand or simply "child" or "kid" in the brand or product name, 3) promotional characters (e.g., cartoons, celebrities), 4) novel or unique packaging and/or food shapes, 5) references to play or education (e.g., games, puzzles), and 6) captions that exaggerated the attributes of the food (e.g., "dangerously cheesy").

4.2.3 Data cleaning

Products that lacked the complete list of nutrient values, and product duplicates within a country and target group were identified and removed from the dataset. A product duplicate was considered when a product was released with a new packaging design, or when a recipe had been updated. In case of a product duplicate, the latest addition to the GNPD database was maintained. To avoid misclassification, baby biscuits without age indication were removed. Missing information regarding portion sizes were individually searched for on the products' websites. This procedure resulted in 1280 products to be included for analyses. See **Figure 4.1** for an overview of data collection, sorting, and cleaning.

4.2.4 Nutritional quality

Nutritional quality was measured by means of nutrient values (energy, fat, saturated fat, carbohydrates, total sugars, fibre, protein, and salt) per 100g. Since baby food is not eligible for the application of the Nutri-Score (Santé Publique France, 2022), biscuits in this study were not evaluated with this nutritional labelling system. Instead, baby biscuits were checked for compliance with the proposed revised NPM for commercially available complementary foods of the WHO European Region (World Health Organization, 2022). In particular, baby biscuits were compared to the requirements set for the sub-category "Dry or semi-dry snacks and finger foods", in terms of energy density (kcal/serve), so-

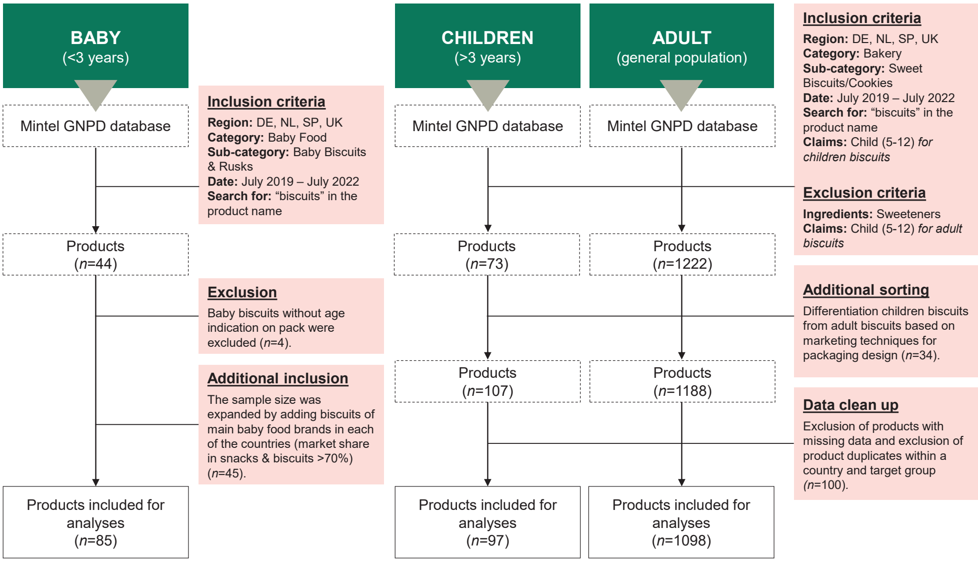

Figure 4.1. *Data collection, sorting, and cleaning. Total sample biscuits n=1280; baby biscuits (<3 years) n=85, children biscuits (>3 years) n=97, adult biscuits n=1098.*

dium (mg/100kcal), total sugar (%/energy), added sugar, fat content (g/100kcal), and age on pack (months). The adherence to the criteria for protein (i.e., "Biscuits, if made with high protein food, total protein ≤5.5 g/100kcal and added protein ≥1.5 g/100kcal") could not be determined as quantities of possible high protein ingredients (e.g., milk powder) were not quantified in the ingredient lists.

4.2.5 The Food Naturalness Index (FNI)

Food naturalness was computed with the FNI, a validated methodology that is explained in more detail elsewhere (Sanchez-Siles et al., 2019). The FNI considers the biscuit's farming practice, the number of additives, unnecessary/unexpected ingredients, and processed ingredients. We have followed the definitions for each of the components as described in Sanchez-Siles et al. (2019), but some additional adaptations and updates were made. In particular, mineral salts like calcium carbonate were counted as additives, unless it was clear from the label that it was added for fortification purposes. Sugar/sucrose, panela, demerara, and inverted sugar were not categorised as unnecessary/unexpected ingredients, as we considered sugar part of a traditional biscuit's recipe (Arepally et al., 2020). On the contrary, fruit juice concentrates not used for flavouring or colouring but only for sweetening purposes (e.g., grape juice concentrate, or apple juice concentrate when "apple" was not reflected in the product's name or packaging) were classified as unnecessary/unexpected ingredients. Concerning processed ingredients, a combination of different refined cereals (e.g., wheat flour, corn flour, rice flour) was considered as "refined cereals". In the case of a combination of whole grain and refined cereals, the ingredients were not considered processed if the majority of cereals (≥50% of total cereals) were whole grain. Vanilla extract was excluded from the list of processed ingredients. Lastly, ingredients that were found multiple times in the ingredient list were only counted once in the corresponding components, except for ingredients of which the exact type was unclear (e.g., "flavour" without designation of which flavour).

4.2.6 Data analysis

Statistical analyses were conducted in IBM SPSS Statistics version 27 (Armonk, NY: IBM Corp). Normality of the data was checked using the Shapiro-Wilk test. The normality of the data was rejected, and variables were expressed as median (Q1-Q3). Data of energy and nutrient content, and FNI and its related components, were tested for differences between the three target groups using the Kruskal-Wallis non-parametric test for independent samples with multiple pairwise comparisons. The Bonferroni correction was applied and P-values below 0.05 were considered significant. Microsoft Excel 365 was used to identify the different sources of added sugars, additives, unnecessary/unexpected ingredients, and processed ingredients by using the IF function including multiple possible word options (e.g., "sugar" and "sucrose", "lecithin" and "E332").

4.3 Results

A total of 1280 biscuits from Germany, the Netherlands, Spain, and the UK were included in the analysis: 85 baby biscuits (6.6%), 97 children biscuits (7.6%), and 1098 adult biscuits (85.8%). **Table 4.1** shows all biscuits analysed per country and target group.

4.3.1 Nutritional quality

A description of the nutritional composition of the biscuits is provided in **Table 4.2** and **Figure 4.2**. Median sugar content was found to be significantly lowest in baby biscuits (18.0 g/100g), followed by children and adult biscuits (27.0 g/100g and 29.9 g/100g,

Table 4.1. *Distribution of biscuits among countries and target groups.*

Country	**All biscuits** *n* (%)	**Baby biscuits** *n* (%)	**Children biscuits** *n* (%)	**Adult biscuits** *n* (%)
Germany	531 (41.5%)	27 (2.1%)	41 (3.2%)	463 (36.2%)
Netherlands	128 (10.0%)	15 (1.2%)	19 (1.5 %)	94 (7.3%)
Spain	287 (22.4%)	17 (1.3%)	17 (1.3%)	253 (19.8%)
UK	334 (26.1%)	26 (2.0%)	20 (1.6%)	288 (22.5%)
All countries	1280 (100%)	85 (6.6%)	97 (7.6%)	1098 (85.8%)

The number of biscuit launches in each country are consistent with the market volumes of biscuits, cookies, and crackers (Mintel, 2022).

Table 4.2. *Nutritional composition per 100g of biscuits and comparison between the three target populations.*

	Baby biscuits (*n*=85)	**Children biscuits** (*n*=97)	**Adult biscuits** (*n*=1098)	***P*-value**
Energy (kcal)	434.0 (414.5-444.2) ^{a}	475.0 (446.5-504.2) ^{b}	487.0 (459.0-508.0) ^{b}	<0.001
Fat (g)	12.8 (10.7-14.0) ^{a}	20.0 (14.0-24.1) ^{b}	22.5 (18.0-26.0) ^{c}	<0.001
Saturated fat (g)	3.1 (1.5-5.2) ^{a}	8.0 (5.4-12.3) ^{b}	10.7 (6.0-14.3) ^{c}	<0.001
Carbohydrates (g)	71.0 (68.0-74.7) ^{a}	66.0 (62.7-69.2) ^{b}	63.3 (59.5-68.0) ^{c}	<0.001
Total sugars (g)	18.0 (15.7-22.2) ^{a}	27.0 (20.6-34.5) ^{b}	29.9 (23.0-36.2) ^{c}	<0.001
Fibre (g)	3.1 (2.2-4.6)	3.1 (2.5-4.7)	3.0 (2.2-4.5)	0.636
Protein (g)	7.7 (6.8-8.4) ^{a}	6.9 (5.8-7.8) ^{b}	6.5 (5.5-7.5) ^{b}	<0.001
Salt (g)	0.21 (0.09-0.43) ^{a}	0.64 (0.45-0.78) ^{b}	0.50 (0.30-0.73) ^{c}	<0.001

Values are expressed as median (25th-75th percentile). Kruskal-Wallis non-parametric test was used to compare the energy and nutrient values between the different target populations. Different superscript letters in the same row indicate significant differences.

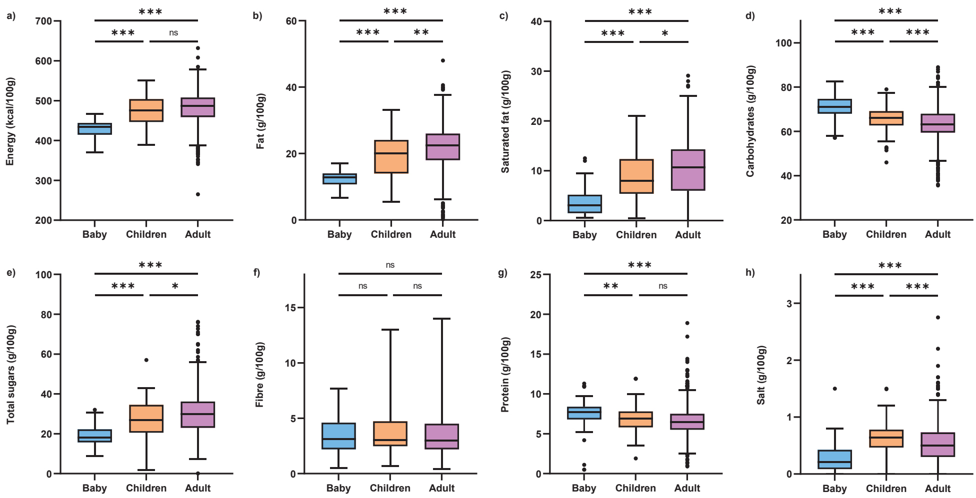

Figure 4.2. *Boxplots of the nutritional composition of baby, children, and adult biscuits. a) energy (kcal/100g), b) fat (g/100g), c) saturated fat (g/100g), d) carbohydrates (g/100g), e) total sugars (g/100g), f) fibre (g/100g), g) protein (g/100g), and h) salt (g/100g).* $^{*}P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$, *ns = not significant.*

respectively). Saturated fat was also lower in baby biscuits (3.1 g/100g), as compared to children (8.0 g/100g) and adult (10.7 g/100g) biscuits. Salt was lowest in baby biscuits (0.21 g/100g), and highest in children biscuits (0.64 g/100g).

Notably, 99.8% of all biscuits contained added sugars. In baby biscuits, most common added sugar source was sugar (47.1%), followed by fruit juice concentrates (42.4%). Almost all children and adult biscuits contained sugar (93.8% and 98.0%, respectively), often in combination with another sugar source such as glucose syrup, inverted sugar syrup, or glucose-fructose syrup (**Table 4.3**).

Table 4.3. *Top 5 added sugar sources.*

Baby biscuits (*n*=85)	**%**	**Children biscuits** (*n*=97)	**%**	**Adult biscuits** (*n*=1098)	**%**
1. Sugar	47.1	1. Sugar	93.8	1. Sugar	98.0
2. Fruit juice concentrate*	42.4	2. Glucose syrup	24.7	2. Glucose syrup	26.2
3. Glucose syrup	5.9	3. Inverted sugar syrup	18.6	3. Glucose-fructose syrup	19.5
4. Rice syrup	5.9	4. Glucose-fructose syrup	12.4	4. Inverted sugar syrup	12.9
5. Honey	3.5	5. Dextrin	12.4	5. Lactose	9.1

**Lemon juice concentrate was excluded.*

As shown in **Table 4.4**, all baby biscuits (100%) complied with the criteria set for total fat, and nearly all of them (96.5%) complied with the required minimum age on the label of six months. Most baby biscuits adhered to the limit of 50 mg/100kcal of sodium (87.1%), while only 36.4% contained the established energy content of ≤50 kcal/serve, and only 30.5% were in line with the total sugar limit of ≤15%/energy. None of the biscuits were formulated without added sugar.

4.3.2 Food naturalness

Approximately half of baby biscuits were pesticide controlled, and half were organic pesticide controlled, while the majority of biscuits for children and adults were conventional (**Figure 4.3**). Baby biscuits had the highest median FNI of 3.3 compared to 1.8 and 2.0 in children and adult biscuits, respectively (P<0.001). Furthermore, baby biscuits had significantly the lowest scores in terms of additives, unnecessary/unexpected ingredients, and processed ingredients. On the contrary, children biscuits had significantly the highest scores in terms of additives and processed ingredients (**Table 4.5**). As shown in **Table 4.6**, sodium carbonate and ammonium carbonate (raising agents), and lecithin (emulsifier) were the most common additives in all biscuits. Palm oil was the most frequently added unnecessary/unexpected ingredient in all biscuits. Children and adult biscuits shared a similar top 5 of unnecessary/unexpected ingredients, which included (other than palm oil) artificial flavour, wheat starch, glucose and glucose-fructose syr-

Table 4.4. *Compliance of baby biscuits (<3 years) in line with the proposed NPM for commercially available complementary foods of the WHO European Region (World Health Organization, 2022).*

Criteria for **"Dry or semi-dry snacks and finger foods"** *	**All baby biscuits** (*n*=85)	**Germany** (*n*=27)	**Netherlands** (*n*=15)	**Spain** (*n*=17)	**UK** (*n*=26)
Energy density** ≤50 kcal/serve	36.4% (12/33)	41.7% (5/12)	50.0% (2/4)	75.0% (3/4)	15.4% (2/13)
Sodium ≤50 mg/100kcal	87.1% (74/85)	85.2% (23/27)	73.3% (11/15)	94.1% (16/17)	92.3% (24/26)
Total sugar ≤15%/energy	30.5% (26/85)	48.1% (13/27)	13.3% (2/15)	35.3% (6/17)	19.2% (5/26)
Added sugar None	0% (0/85)	0% (0/85)	0% (0/85)	0% (0/85)	0% (0/85)
Total fat ≤4.5 g/100kcal	100% (85/85)	100% (27/27)	100% (15/15)	100% (17/17)	100% (26/26)
Age on pack 6 – 36 months	96.5% (82/85)	100% (27/27)	100% (15/15)	94.1% (16/17)	92.3% (24/26)

**This category includes any grain, starch, pulse/lentil or root vegetable snack such as cracker, bread, biscuit, pastry, cake or pancake etc. Includes rusks, crackers and biscuits intended to be eaten dry or pulverised with liquid.*

***Portion size data is missing for n=52.*

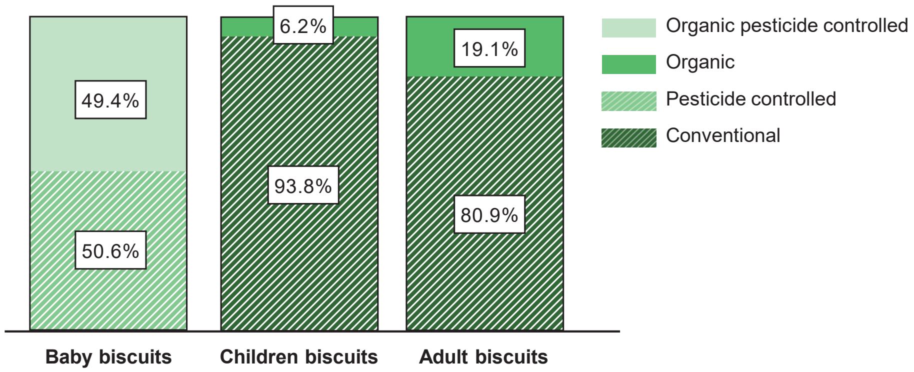

Figure 4.3. *Distribution of farming practices (conventional, pesticide controlled, organic, organic pesticide controlled).*

ups. Fruit juice concentrates used for sweetening purposes were common unnecessary/unexpected ingredients in baby biscuits. Refined flour was the most frequently used processed ingredient in baby and children biscuits, whereas for adult biscuits it was sugar. Sunflower oil was a commonly used fat in baby biscuits, unlike palm oil that was more common in children and adult biscuits.

Table 4.5. *FNI and FNI components of biscuits and comparison between the three target populations.*

	Baby biscuits (*n*=85)	**Children biscuits** (*n*=97)	**Adult biscuits** (*n*=1098)	***P*-value**
FNI	3.3 (2.5-3.5) [a]	1.8 (1.4-2.0) [b]	2.0 (1.5-2.8) [c]	<0.001
No. of additives	2.0 (1.0-3.0) [a]	4.0 (3.0-5.0) [b]	3.0 (2.0-5.0) [c]	<0.001
No. of unnecessary/unexpected ingr.	1.0 (0.0-2.0) [a]	3.0 (1.0-4.0) [b]	2.0 (1.0-4.0) [b]	<0.001
No. of processed ingredients	5.0 (4.0-6.0) [a]	9.0 (7.0-11.5) [b]	8.0 (5.0-11.0) [c]	<0.001
Total no. of ingredients	10.0 (8.0-13.0) [a]	17.0 (13.0-21.5) [b]	15.0 (11.0-20.0) [b]	<0.001

Values are expressed as median (25th-75th percentile). Kruskal-Wallis non-parametric test was used to compare FNI and its components between the different target populations. Different superscript letters in the same row indicate significant differences. Total no. of ingredients is not a component of the FNI, but generally used as an attribute for "clean label".

Table 4.6. *Top 5 additives, unnecessary/unexpected ingredients, and processed ingredients.*

Baby biscuits (*n*=85)	**%**	**Children biscuits** (*n*=79)	**%**	**Adult biscuits** (*n*=1098)	**%**
Additives					
1. Sodium carbonate	74.1	1. Sodium carbonate	94.8	1. Sodium carbonate	77.2
2. Ammonium carbonate	38.8	2. Lecithin	81.4	2. Lecithin	58.2
3. Lecithin	24.7	3. Ammonium carbonate	59.8	3. Ammonium carbonate	51.1
4. Calcium carbonate	21.2	4. Citric acid	23.7	4. Citric acid	18.8
5. Potassium tartrate	16.5	5. Caramel colour	7.2	5. Disodium diphosphate	8.2
Unnecessary/unexpected ingredients					
1. Palm oil	35.3	1. Palm oil	59.8	1. Palm oil	53.5
2. Fruit juice concentrate*	32.9	2. Artificial flavour	56.7	2. Artificial flavour	42.4
3. Wheat starch	23.5	3. Glucose syrup	24.7	3. Glucose syrup	26.2
4. Artificial flavour	15.3	4. Wheat starch	23.7	4. Glucose-fructose syrup	19.5
5. Corn starch	10.6	5. Glucose-fructose syrup	12.4	5. Wheat starch	19.1
Processed ingredients					
1. Refined flour	75.3	1. Refined flour	94.8	1. Sugar	98.0
2. Sunflower oil	57.6	2. Sugar	93.8	2. Refined flour	88.3
3. Sugar	47.1	3. Palm oil	59.8	3. Palm oil	53.5
4. Fruit juice concentrate	42.4	4. Artificial flavour	56.7	4. Artificial flavour	42.4
5. Skimmed milk powder	35.3	5. Skimmed milk powder	35.1	5. Natural flavour	30.5

**Fruit juice concentrates not used for flavouring or colouring but only for sweetening purposes (e.g., grape juice concentrate, or apple juice concentrate when "apple" was not reflected in the product's name or packaging) were classified as unnecessary/unexpected ingredients. Lemon juice concentrates were excluded.*

4.4 Discussion

This is, to the best of our knowledge, the first study to compare the nutritional quality and degree of naturalness of baby, children, and adult biscuits in four European countries. Additionally, the most frequently added sugar sources, additives, unnecessary/unexpected ingredients, and processed ingredients in all biscuits' formulations were investigated. The results showed that baby biscuits had the best nutritional quality and were the most natural as compared to children and adult biscuits. Furthermore, all baby biscuits complied with the WHO NPM criteria in terms of fat, and the majority complied with the required age indication and sodium content. Yet, improvements need to be made in terms of energy density and sugar levels. Surprisingly, children biscuits, in comparison to adult ones, had higher levels of salt. In addition, they were the least natural of the three target groups, mainly due to the higher number of additives. Below we highlight our main findings along with their implications for health authorities, policy makers and food manufacturers.

4.4.1 Nutritional quality evaluation of biscuits

Overall, the nutritional quality of baby biscuits in this study was very similar to recent findings from Grammatikaki et al. (2021) on 233 baby biscuits and rusks from 27 European countries. In contrast, some studies have described lower values of salt as compared to the present study (Elliott, 2011; Elliott & Conlon, 2014; Garcia et al., 2020; McCann et al., 2022). This might be explained by the small differences in the products tested; that is to say, the present study focused solely on baby biscuits, while the others examined "snacks", or "sweet dry snacks", which not only included biscuits, but also other snacks such as fruit-based snacks.

Notably, sugar content in our baby biscuit sample was much lower as compared to children and adult biscuits, however, there is room for improvement. For example, only <20% of baby biscuits in the Dutch and UK markets complied with the WHO sugar criteria of ≤15%/energy. Manufacturers should find ways to reduce the sugar levels as much as possible. However, sugar gives volume and texture to the product (Buttriss, 2013; Mamat & Hill, 2018), which facilitates melting and hence reduces the likelihood of choking. Hence, formulation of baby biscuits with sugar needs to be kept to a minimum, but should be allowed in the absence of other current viable alternatives. Otherwise, the latest recommendations from public health agencies (i.e., WHO, PHE) of not adding any sugar at all to a baby biscuit formulation may drive parents to purchase alternative sweeter biscuits (as evidenced in our research) originally formulated and meant for children and adults. This would be particularly concerning as prior research has found that not only infants and toddlers consume family foods such as adult biscuits and cereals (Robinson et al., 2007; Roess et al., 2018), but also hyperpalatable foods, primarily through the exposure to adult foods (Kong et al., 2021).

Besides the quantity of sugar, the type of added sugar and the presence of "hidden sugars" in baby food is being debated too. An example of "hidden sugars" are added fruit juice concentrates that are not clearly stated as sugars on pack, despite contributing to total free sugars. Fruit juice concentrates are being criticised and said to mislead parents who may not be aware of buying sugary options (Action On Sugar, 2021). In fact, consumers perceive a food to be healthier if the food is labelled with "fruit sugar" instead of "sugar" (Sütterlin & Siegrist, 2015). In our study, we found that fruit juice concentrates were the second most common added sugar sources in baby biscuits which is in line with previous research (Cogswell et al., 2015; García et al., 2019; Hutchinson et al., 2021). Accordingly, confusion and misguidance among consumers would be reduced if manufacturers were more transparent about the fact that fruit juice concentrates are not nutritionally superior to table sugar, since both are classified as free sugars (EFSA Panel on Nutrition Novel Foods and Food Allergens (NDA) et al., 2022).

Our study also evaluated the recommended portion sizes on baby biscuits' packs in order to assess the compliance with the WHO NPM criteria for energy density (kcal/serve). While doing so, two main findings need special attention. First, not many manufacturers provided a suggested portion size (only found on 39% of baby biscuits), which may result in portion sizes being decided by parents (and therefore not necessarily nutritionally adequate). Second, a large variability in portion sizes was observed for those biscuits that did carry a suggested portion size on pack. Therefore, we strongly believe that manufacturers should clearly provide a suggested portion size on pack in line with the WHO NPM so as to prevent babies from overeating occasional food items such as biscuits. In this regard, given the median energy content of baby biscuits of 434 kcal/100g in the current sample, and WHO's energy density requirement of 50 kcal/serve (World Health Organization, 2022), an ideal portion size would be no more than 10g.

While previous studies clearly found worse nutritional quality in child-oriented foods as compared to adult foods (Beltrá et al., 2020; Lapierre et al., 2016; Lythgoe et al., 2013; Machado et al., 2019), the present study showed slightly but significantly worse (i.e., higher) values for carbohydrates and salt, but better (i.e., lower) values in terms of fat, saturated fat, and total sugar, in children biscuits as compared to adult biscuits. Although significant differences between children and adult biscuits were found for some nutrients, nutritional quality was found to be comparably poor in both groups. The low nutritional quality of children biscuits, in addition to the substantial gap in terms of sugar, saturated fat, and salt between baby and children biscuits are worrisome.

4.4.2 Naturalness assessment of biscuits

Our analysis showed that baby biscuits were the most natural. This result was expected , since according to EU legislation many additives and other substances are not allowed in commercial baby foods (Commission Directive 2006/125/EC, 2006; Commission Regulation (EC) No 1881/2006, 2006). Farming practices were one of the main drivers in this regard as baby biscuits were either pesticide controlled or organic pesticide controlled. This implies stricter limits for the amount of pesticide residues applied as compared to conventional children or adult biscuits (Commission Directive 2006/125/EC, 2006; DeMaria & Drogue, 2017). Furthermore, baby biscuits were more natural thanks to a cleaner label in general; in other words, they had significantly the lowest number of additives, unnecessary/unexpected ingredients, and processed ingredients. On the contrary, children biscuits were the least natural, which could mainly be attributed to the high number of additives. Indeed, the usage of multiple raising agents, emulsifiers, and colourants were highly prevalent in children biscuits. Also, they were characterised by combinations of several sugars, fats, and artificial flavours. Overall, this may result in highly palatable and sensory appealing biscuits with low levels of nutritional quality and naturalness which should be closely monitored by health authorities.

Taking in mind the basic formulation of a biscuit (Arepally et al., 2020), there are certain ways for manufacturers to improve their degree of naturalness such as the replacement of whole grain flours for refined flours, adding extra virgin olive oil or a cold-pressed oil instead of palm oil, lowering the amount of sugars and additives to one, and/or avoiding the use of starches and artificial flavours (Sanchez-Siles et al., 2019).

4.4.3 Strengths, limitations, and future research

The present study should be interpreted in view of its strengths and limitations. First, our analysis relied on a dataset of biscuits launched in the last three years in four European countries. Although such recent launches reflect the trends in new product developments and reformulations, they do not necessarily represent the best-selling biscuits per se. We encountered that the sample size of recent baby biscuits launches was small and did not entirely mirror the current market, hence we enlarged the sample size by including biscuits from best-selling brands, which accounted for >70% of the market share in each country. Second, our study is strengthened by the fact that an additional and manual sorting task was carried out to make a distinction between children and adult biscuits based on child-oriented marketing techniques used for packaging design. This procedure allowed us to identify 34 children biscuits that were initially grouped as adult biscuits by Mintel. Third, this study is the first to objectively measure the degree of naturalness of baby, children, and adult biscuits. Our results further prove that the FNI is a valuable tool to evaluate the degree of naturalness in line with recent results from various product categories (Michel et al., 2021; Sanchez-Siles, Román, Fogliano, et al., 2022; Sanchez-Siles, Román, Haro-Vicente, et al., 2022). Nevertheless, in line with the limitations described earlier (Klerks et al., 2022), some ingredients could not be found in the pre-defined list of unnecessary/unexpected ingredients as specified in Sanchez-Siles et al. (2019). Thus, consistent adaptations and updates were made. Future research needs to further evaluate consumers' perception on unnecessary/unexpected ingredients in different food categories, so that the "inclusion" and "exclusion" criteria of these ingredients could be expanded. Finally, future studies could evaluate and compare the nutritional quality and degree of naturalness of other foods frequently given to babies and children such as breakfast cereals, savoury snacks, and dairy products, which would provide valuable insights for product (re)formulations towards healthier and more natural foods.

4.5 Conclusion

In conclusion, although baby foods, in particular sweet snacks like biscuits, are highly being criticised by policy makers, findings from the current study evidence that they are a healthier and more natural alternative to both children and adult biscuits that parents might occasionally offer to their offspring. Nonetheless, baby food manufacturers need to continue their efforts in improving the nutritional composition of their products, for example by reducing sugar levels while maintaining desirable sensory characteristics (e.g., texture). Suggested portion sizes in line with the required energy density should be clearly stated on pack so that biscuits do not displace meals. This study has demonstrated a big gap between baby biscuits (<3 years) and biscuits marketed at older children (>3 years). Children biscuits were nutritionally poor and not naturally formulated. To protect children from an unhealthy food environment, and to enable children to develop healthy eating habits, there is an urge and opportunity for manufacturers of child-oriented biscuits to narrow the market gap by drastically improving their offer towards nutritionally balanced and natural food products. Strict, but realistic, regulations need to be in place to support product (re)formulations and to improve the current market offer for babies and children.

CHAPTER 5

5

Infant cereals: Current status, challenges, and future opportunities for whole grains

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Abstract

Infant cereals play an important role in the complementary feeding period. The aim of this study was to review existing research about the quantity, type, and degree of infant cereal processing, with a special focus on whole grain infant cereals. Accumulating evidence shows many benefits of whole grain consumption for human health. Likewise, consumers are frequently linking the term whole grains to healthiness and naturality, and sustainable food production becomes a more important aspect when choosing an infant cereal brand. Whole grain cereals should be consumed as early as possible, i.e., during infancy. However, there are several challenges that food manufacturers are facing that need to be addressed. Recommendations are needed for the intake of whole grain cereals for infants and young children, including product-labeling guidelines for whole grain foods targeting these age stages. Another challenge is minimizing the higher contaminant content in whole grains, as well as those formed during processing. Yet, the greatest challenge may be to drive consumers' acceptance, including taste. The complementary feeding period is absolutely key in shaping the infant's food preferences and habits; therefore, it is the appropriate stage in life at which to introduce whole grain cereals for the acceptance of whole grains across the entire lifespan.

5.1 Introduction

Cereals, also called grains, refer to the crops that are harvested for dry grain only (FAO, 1994) and belong to the Gramineae family of grasses (Serna-Saldivar, 2016). They include maize, rye, sorghum, millets, wheat, rice, barley, oats, and teff. Pseudocereals as amaranth, quinoa, and buckwheat are often included within the true cereals, because of their similar nutritional profiles and uses (Van Der Kamp et al., 2014). Cereal grains represent the most important source of the world's total food (Lathman, 1997; Serna-Saldivar, 2016). Infant cereals are defined as "processed cereal-based foods" that are divided into "simple cereals which are or have to be reconstituted with milk or other appropriate nutritious liquids"; or "cereals with an added high protein food which are or have to be reconstituted with water or another protein-free liquid" (Codex Alimentarius, 2006; Commission Directive 2006/125/EC, 2006).

In many countries, infant cereals are among the first foods that are introduced at the beginning of the complementary feeding period (Butte et al., 2010; Freeman et al., 2000; Lange et al., 2013; Siega-Riz et al., 2010). The choice to provide infant cereals as the first food during weaning can be explained for several reasons (see **Figure 5.1**). (1) Cereals are an excellent source of energy, which is very important at the age of six months when exclusively breastfeeding is no longer sufficient to cover the nutritional requirements

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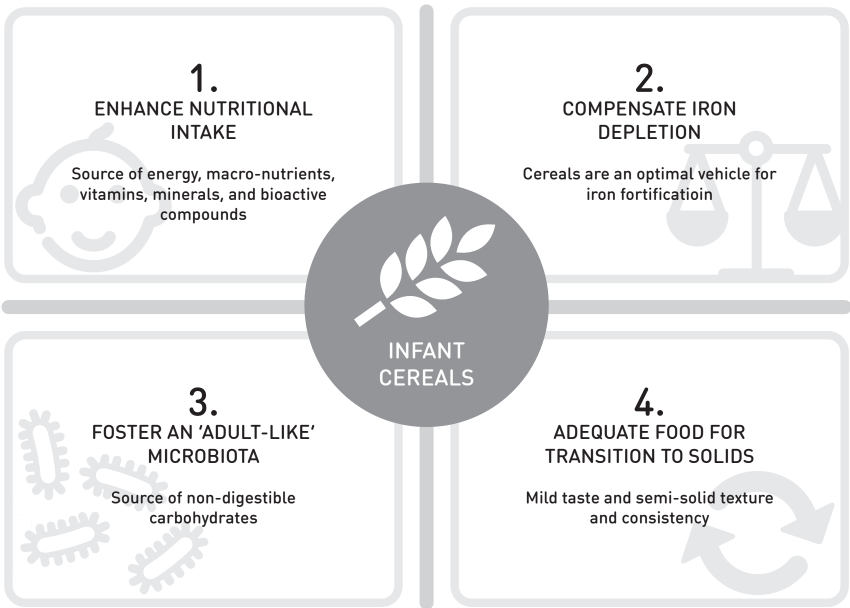

Figure 5.1. *Four reasons to provide infant cereals as one of the first foods during the complementary feeding period.*

of the infant (Agostoni et al., 2008). Moreover, cereals provide a substantial amount of carbohydrates (starch and fiber) and proteins, but are also a source of vitamins, minerals, and bioactive compounds (Fardet, 2010). (2) Cereals are an optimal vehicle for iron fortification (Finn et al., 2017; Grimes et al., 2015). Therefore, the provision of infant cereals is effective at the beginning of complementary feeding, when the infant's iron stores are depleting (Domellöf et al., 2014). (3) Cereals provide non-digestible carbohydrates, which are mainly responsible for the development of an 'adult-like' microbiota by increasing the Bacteroides population (Fallani et al., 2011). During weaning, clear changes in the infant's gut microbiota have been observed upon the addition of either wheat, sorghum, rice, or oats into a large intestine in vitro (Gamage et al., 2017), and a higher proportion of complex carbohydrates in infant cereals has been shown to lead to a higher fermentative activity of the intestinal microbiota of infants aged six to 10 months in vivo (Bernal et al., 2013). (4) Cereals have a mild taste and a semi-solid texture and consistency, which is adequate for the transition from milk toward the acceptation of solid foods at the beginning of complementary feeding (Nicklaus et al., 2015; Sakashita et al., 2003).

Despite the important role of cereals in infants and young children, still no consensus has been reached among pediatric organizations regarding adequate cereal intake, type of cereals, and degree of cereal processing (whole grain versus refined cereals). Our objective is to shed more light on these issues by reviewing existing research regarding the quantity, type, and degree of cereal processing. Even though we acknowledge the literature on cereals for adults, the focus of this article is on infant cereals, with special emphasis on whole grain infant cereals. Indeed, this paper is organized as follows. First, we review existing recommendations for infant cereal intake. Then, we focus on whole grain cereals and compare them to refined cereals in terms of their impact on infant nutrition and health. Finally, challenges for the food retailers, manufacturers, and policy makers are discussed, and future opportunities that can be derived from these challenges are proposed for infant cereals.

5.2 Recommendations for infant cereal intake

Nutritionists' advice for complementary feeding has changed dramatically over the last decade, as nutrition science has progressed and demonstrated the importance of good nutrition during the months following the period of exclusive breastfeeding. For example, while in the past the avoidance of allergens was the standard recommendation, today, one would rather recommend early introduction in small steps, while still breastfeeding. In many areas, no consensus has been reached yet. Likewise, recommendations for cereal intake in infant and young children vary across countries, and they often remain vague. There seems to be only one consensus: the intake of cereals is not recommended before the age of four months. Examples of existing recommendations for cereal intake in infants and young children are provided in **Table 5.1**. In Europe, the European Society for Paediatric Gastroenterology, Hepatology and Nutrition (ESPGHAN) recommends introducing iron-rich complementary foods such as cereals from four months alongside breastfeeding (Domellöf et al., 2014; Fewtrell et al., 2017). Similarly, The European Food Safety Authority (EFSA) recommends introducing iron-rich food after four to six months of age (EFSA, 2013). However, in the United States (US) and New Zealand, cereal intake before the age of six months is discouraged (American Academy of Pediatrics (AAP), 2012, 2020; Ministry of Health New-Zealand, 2008, 2010). Furthermore, countries communicate their cereal intake advice via the number of servings (Ministry of Health New-Zealand, 2008, 2010; National Health and Medical Research Council (NHMRC), 2011), tablespoons (Food and Nutrition Service U.S. Department of Agriculture (USDA), 2016), or exact grams (Asociación Española de Pediatría (AEP), 2007; Quintana et al., 2010), while in Europe and the US, there are also organizations that do not define specific amounts (American Academy of Pediatrics (AAP), 2012, 2020; Domellöf et al., 2014; EFSA, 2013; Fewtrell et al., 2017; Manger Bouger & Ministère des Solidarités et de la Santé, n.d.).

Some countries only provide recommendations about whether to introduce cereals with or without gluten, yet no general agreement has been reached about this issue. For example, France and Spain advise providing gluten-free cereals before five to six months of age (Dalmau Serra & Moreno Villares, 2017; Manger Bouger & Ministère des Solidarités et de la Santé, n.d.), whereas the ESPGHAN indicate that gluten may be introduced between four and 12 months of age (Fewtrell et al., 2017) (**Table 5.1**). Generally, information about the type of cereals is not incorporated within a country's recommendations. It seems that the type of cereals given to infants might be influenced by cultural beliefs. In the United Kingdom (UK) and Ireland, infant rice cereals are the most popular first complementary food (McAndrew et al., 2012; O'Donovan et al., 2015; Tarrant et al., 2010). In the Nordics and Baltics, in many instances, oats are the infant's first solid introduction (Nwaru et al., 2013; Sahlstrøm & Knutsen, 2010), except for Norway, where maize/rice infant cereals are the most common weaning foods (Lund-Blix et al., 2015). In Spain, wheat or rice are the most consumed infant cereals (AECOSAN, n.d.). According to the Feeding Infants and Toddlers Study (FITS) in the US, the most common food sources of starch in infants and young children are iron-fortified infant cereals, which are primarily made of rice or oats (Finn et al., 2017; Quann & Carvalho, 2018). Likewise, infant cereal intake in Canada is mainly rice-based (Friel et al., 2009), but mothers seem to start with maize porridges in African countries (Burns et al., 2016; Kimani-Murage et al., 2011; Vaahtera et al., 2001). On a final note, it is often unclear to which extent the cereals used for the formulation of infant cereals are recommended to

Table 5.1. *Examples of cereal recommendations for infants and young children.*

Country/Region and Organization	Wording, Recommendation or Guideline
Australia (National Health and Medical Research Council (NHMRC), 2011)	Infant cereals, dry, mixed grain, fortified Six to 12 months: seven serves per week, one serve weighs 20 g
Europe (EFSA, 2013)	"It should be noted that for formula-fed infants and some breast-fed infants after four to six months of age, an intake equivalent to this value (0.3 mg per day iron from breast milk) is not sufficient to maintain iron status within the normal range."
Europe, on behalf of the European Society for Paediatric Gastroenterology, Hepatology and Nutrition (ESPGHAN) (Domellöf et al., 2014; Fewtrell et al., 2017)	"There may be some beneficial effects on iron stores of introducing complementary food alongside breast-feeding from four months. Iron-rich complementary foods are recommended, these include iron-fortified foods such as cereals. Gluten may be introduced between four and 12 months."
France (Manger Bouger & Ministère des Solidarités et de la Santé, n.d.)	0–4 months: no cereal intake 5–6 months: cereals without gluten >7 months: cereals with gluten
New Zealand (Ministry of Health New-Zealand, 2008, 2010)	0–6 months: no cereal intake 6–7 months: iron-fortified cereals, puréed plain rice 7–8 months: age-appropriate infant cereals 8–12 months: breakfast cereals such as porridge, wheat biscuits (iron-fortified), infant muesli 12–24 months: all previously listed cereals 2–5 years: "At least four servings of cereals per day. Increasing whole grain options as children age."
Spain (Asociación Española de Pediatría (AEP), 2007; Dalmau Serra & Moreno Villares, 2017; Quintana et al., 2010)	< 5–6 months: cereals without gluten > 5–6 months: cereals with gluten 12 months: 57 g of cereals per day 24–36 months: 86 g of cereals per day "Fortified or whole grain (preferred) cereals, bread and pastas are suggested."
US (American Academy of Pediatrics (AAP), 2012, 2020)	"A baby's digestive system is not thought to be well prepared to process cereals until about six months of age. When he is old enough to digest cereal, he should also be ready to eat it from a spoon." "Baby cereals are available premixed in individual containers or dry, to which you can add breast milk, formula, or water. Whichever type of cereal you use, make sure that it is made for babies and iron fortified."
US (Food and Nutrition Service U.S. Department of Agriculture (USDA), 2016)	Breakfast, lunch, supper, or snack 6–11 months: 0–4 tablespoons of iron-fortified infant cereals or iron-fortified ready-to-eat breakfast cereals (in case of a snack) "A serving of this component is required when the infant is developmentally ready to accept it. A serving of grains must be whole grain rich, enriched meal, or enriched flour. Breakfast cereals must contain no more than 6 g of sugar per dry ounce (no more than 21 g sucrose and other sugars per 100 g of dry cereal)."

be processed (refined or whole grain). The 2015–2020 Dietary Guidelines for Americans encourages the consumption of nutrient-dense foods such as whole grains in children aged between one and 18 years (1.5 to four ounce-equivalents) to increase dietary fiber, ensure normal gastrointestinal function, and prevent chronic diseases (U.S. Department of Health and Human Services and U.S. Department of Agriculture (USDA), 2015). In the next section, we will describe the reasons in favor of the use of whole grains in infant cereals.

5.3 Reasons to believe in the use of whole grains in infant cereals

According to the American Association of Cereal Chemistry International (AACCI) (American Association of Cereal Chemists (AACCI), 2013b): "Whole grains shall consist of the intact, ground, cracked, or flaked caryopsis, whose principal anatomical components—the starchy endosperm, germ, and bran—are present in the same relative proportions as they exist in the intact caryopsis". The HEALTHGRAIN Consortium of the European Union added in 2010 to this definition that cover removal and small grain component losses are allowed, but they should be less than 2% of the grain or less than 10% of the bran (Van Der Kamp et al., 2014).

This chapter discusses why the use of whole grains for infant cereals would be better from a nutritional, health, and consumer point of view, compared to the use of refined cereals.

5.3.1 Nutritional differences between whole grains and refined cereals

All grains are made up of three parts: the multi-layered outer fiber-rich bran, the micronutrient-rich and lipid-rich germ, and the starchy endosperm. While in whole grains, all components of the grain are still present (80–85% endosperm, 10–14% bran, and 2.5–3% germ), refined cereals consist only of the endosperm (Fardet, 2010).

The highest proportions of compounds such as fibers, vitamins, minerals, and other phytochemicals are found in the bran and germ of the grain. Several biological compounds have been described in whole grain cereals with interesting physiological functions (e.g., immune system stimulation, cell signaling and/or gene regulation, antioxidant, anti-inflammatory) and potential protective mechanisms (e.g., diabetes, cancers, cardiovascular diseases) (Fardet, 2010). The major bioactive compounds in whole grain are vitamins, minerals, and phytochemicals including phenolics, carotenoids, vitamin E, lignans, β-glucans, inulin, resistant starch, sterols, and phytates (Liu, 2007). Although these bioactive compounds are present in whole grains in general, some bioactive compounds are specific to certain cereals such as γ-oryzanol in rice, avenanthramide, avenacosides, and saponins in oats, β-glucans in oats and barley, and alkylresorcinol in rye (Fardet, 2010). Therefore, processing whole grain cereals to refined cereal products leads to major losses of these protective compounds, as they lack the bran and germ fractions (Fardet, 2010). For example, it has been shown that after refining wholemeal flour into white flour, only 42% of fiber, 17% of magnesium, 21% of zinc, 8% of selenium, and 21% of vitamin E were retained (Truswell, 2002). Also, a large drop in phenolic compounds (an important group of the phytochemicals) has been observed after milling the whole kernel of maize (Butts-Wilmsmeyer et al., 2018), and a review by Ktenioudaki et al. (2015) indicated that milling caused a decrease of phenolic compounds, flavonoids, tocols, carotenoids, and sterols in several cereals (Ktenioudaki et al., 2015). Results reported by Adom et al. (2005) revealed that the majority of phytochemicals in whole wheat grain are present in the bran and germ. The content was found to be 15 to 18-fold higher in the bran and the germ compared to the content in the endosperm (Adom et al., 2005). Accordingly, it has been shown that analyzed phenolic compounds were enriched in the bran of the rye kernel (Pihlava et al., 2015), relatively higher in the bran of wheat (Žilić et al., 2012), and more abundant in whole wheat compared to refined samples of wheat (Lu et al., 2014). It seems that especially the aleurone layer of the bran contains a high level of bioactive compounds (Van der Kamp, 2012) that have a high antioxidant and anti-inflammatory capacity (Mateo Anson et al., 2010). It can be concluded that whole grains are more nutrient-dense compared to refined cereals (Papanikolaou & Fulgoni, 2017). To illustrate, the nutritional differences between whole wheat flour and refined wheat flour are shown in **Table 5.2**.

One main compound that is removed during the refining of cereals is dietary fiber. Dietary fibers (e.g., β-glucans, arabinoxylans, resistant starch, and inulin) are a major contributor to several health benefits (Foschia et al., 2013; Gill et al., 2018). Fiber, defined by the EFSA as "non-digestible carbohydrates plus lignin" (EFSA, 2010), has according to Directive 2008/100/EC "beneficial physiological effects such as: decreasing intestinal transit time, increasing stool bulk, fermentable by colonic microflora, reducing blood total cholesterol levels, reducing post-prandial blood glucose, or reducing blood insulin levels" (Commission Directive 2008/100/EC, 2008). The health effects of fibers depend on the degree of fermentation. Traditionally, fibers can be classified into insoluble and soluble fibers. Soluble fibers are highly and rapidly fermented by the microbiota, while insoluble fibers are poorly and slowly fermented. Soluble fibers increase viscosity, bile acid excretion, serum lipids, and short-chain fatty acids, which benefit post-prandial glucose response, among others. Insoluble fibers are capable of absorbing water, and favor laxation and intestinal regulation (Fardet, 2010; Slavin et al., 2013). The ratio of soluble to insoluble fiber is different depending on the type of cereals (e.g., wheat 1:5, oats 1:1.5) (Fardet, 2010; Manthey et al., 1999).

Table 5.2. *Nutritional composition differences between whole and refined wheat flour, per 100 g (Dutch Food Composition Database, 2016).*

Nutrient	Whole Wheat Flour	Refined Wheat Flour (75% Extraction)
Carbohydrates, g (% of energy)	62 (75.6)	71 (80.6)
Protein, g (% of energy)	10 (12.2)	12.6 (14.3)
Fat, g (% of energy)	2 (5.5)	1.1 (2.8)
Dietary fiber, g	11	4
Vitamin B1, mg	0.4	0.07
Vitamin B2, mg	0.15	0.04
Vitamin B3, mg	5.7	1
Vitamin B6, mg	0.35	0.12
Vitamin B9, mg	0.037	0.022
Vitamin E, mg	1.4	0.4
Vitamin K, mg	0.019	0.008
Iron, mg	4	0.8
Zinc, mg	2.9	0.64
Magnesium, mg	124	20
Sodium, mg	5	2
Potassium, mg	250	156
Phosphorus, mg	370	103

Whole grains, as a rich source of dietary fibers and other bioactive compounds, may modulate the gut microbiota, and therefore impact consumers' health. While extant research has focused on the contribution of whole grains to health, little research has been conducted on how their dietary fibers and other constituents from whole grain matrices affect the gut microbiota. Oats may have particular effects on the gut microbiota in comparison with other grains, due to their high levels of soluble fiber (mainly of β-glucan) (Rose, 2014). In fact, there is controversy regarding how different types of whole grains can affect gut microbiota. On one hand, it has been shown that whole grain wheat breakfast cereal has a prebiotic effect on the human gut microbiota compared with wheat bran (Costabile et al., 2008). However, the intake of whole grain and fiber-rich rye bread versus refined wheat bread did not differentiate intestinal microbiota composition in adults with metabolic syndrome (Lappi et al., 2013). Moreover, short-term consumption of whole grains (six weeks) increased stool weight and the frequency of bowel movements, but had modest positive effects on gut microbiota compared with refined grains (Vanegas et al., 2017). Similarly, a six-week intervention with whole-grain rye and wheat in healthy overweight adults affected some markers of gut health without altering the fecal microbiota (Vuholm et al., 2017). Nevertheless, soluble feruloylated arabinoxylan oligosaccharides and polyphenols isolated from rice bran have been shown to have positive impacts on human gut microbiota through a prebiotic function (Pham et al., 2017).

However, the proposed health benefits of whole grains go beyond the effects from dietary fiber only. Considering the huge number of components that are involved in whole grains, it is likely that they have synergistic effects in contributing to the potential health benefits according to the holistic approach described by Fardet (2014). The author reported that the effects of nutrients depend on a whole food or matrix, meaning that the effects of food as a whole are different than the sum of its individual compounds (Fardet, 2014).

5.3.2 Benefits of whole grain consumption

Accumulating evidence demonstrates that the consumption of whole grain foods has several benefits for human health (Fardet, 2010). More specifically, whole grain consumption has extensively been shown to reduce weight gain and the risk of obesity (Albertson et al., 2016; Roager et al., 2019; Thielecke & Jonnalagadda, 2014), type 2 diabetes (Aune et al., 2013; Della Pepa et al., 2018; Kyrø et al., 2018; Malin et al., 2018; Schwingshackl et al., 2017), (colon/colorectal) cancer (Aune et al., 2011, 2016; Kyrø et al., 2014; Makarem et al., 2016), and cardiovascular diseases (Aune et al., 2016; Temple, 2018). Furthermore, whole grain consumption reduces the risk of respiratory diseases, infectious diseases, and all-cause and cause-specific mortality (Aune et al., 2016; Benisi-Kohansal et al., 2016; Johnsen et al., 2015; B. Zhang et al., 2018; Zong et al., 2016). Recently, whole grain intake has also been linked to an improved cognitive function in adults (Edwards et al., 2017). Several mechanisms that are induced by the intake of whole grains could explain these protective effects. These mechanisms comprise the reduction of inflammatory processes (Masters et al., 2010; Roager et al., 2019; Vitaglione et al., 2015), the enhancement of insulin response (Giacco et al., 2014; Malin et al., 2018; Marventano et al., 2017), the modification of blood lipid profiles (Cooper et al., 2017; Giacco et al., 2014; Ye et al., 2012), and improvement and maintenance of the gut health (Foerster et al., 2014; Gong et al., 2018; Langkamp-Henken et al., 2012; Vanegas et al., 2017; Vuholm et al., 2017). Observational evidence showing the health benefits of whole grain consumption is consistent; however, results from randomized controlled trials have not been as convincing as those from observational ones yet (Della Pepa et al., 2018; Kelly et al., 2017).

Although the health benefits of whole grains in adults are broadly acknowledged, the question arises of whether whole grain consumption could have the same or even larger benefits in infancy and early childhood. Unfortunately, only a limited number of empirical studies have been conducted in infants and children.

In a crossover clinical trial, systemic inflammatory biomarkers were evaluated of 44 overweight or obese Iranian girls aged between eight and 15 years old when half of their cereal intake consisted of whole grains. Changes in biomarkers such as C-reactive protein, soluble intercellular adhesion molecule-1, serum amyloid A, and leptin were found after six weeks of whole grain consumption. However, no significant effects of whole grain intake on the subjects' weight and body mass index (BMI) were found (Hajihashemi et al., 2014). A recent Danish cross-sectional study conducted by Damsgaard et al. (2017) on 713 children aged between eight and 11 years investigated the association between the amount of ingested whole grain and the type of whole grain with fat mass and biomarkers related with cardiometabolic risk profile (Damsgaard et al., 2017). The total intake of whole grains (median intake 52 g/day) was not correlated with fat mass index, but it was associated with serum insulin. The intake of whole grain oats specifically was inversely associated with fat mass index, systolic blood pressure, low-density lipoprotein (LDL) cholesterol, and insulin (Damsgaard et al., 2017). Another study by Koo et al. (2018) with 63 Malaysian children aged between nine and 11 years showed that an intervention of six 30-minute nutrition education classes emphasizing the consumption of whole grains and the substitution of whole grain foods on a daily basis during school break time over a 12-week period significantly resulted in lower BMI z-scores, lower body fat percentage, and a lower waist circumference compared to the children that did not received the intervention (control group). However, the exact amount of whole grains consumed per day that caused the achieved effects in this study was not reported (H.-C. Koo et al., 2018). Furthermore, in the prospective, randomized Special Turku Coronary Risk Factor Intervention Project (STRIP) with a sample of 941 children, dietary counseling was given biannually based on the Nordic Nutrition Recommendations, and one of the major aims was to promote the intake of vegetables, fruits, and whole-grain products, among other measures. Achieving the dietary targets during the 20-year dietary intervention was associated with better insulin sensitivity and serum lipid profile throughout the early life course (Laitinen et al., 2018). Lastly, a clinical trial of 28 infants and children (median age 7.2 years) with chronic functional constipation showed that an intervention of dietician's advice to follow a diet oriented according to the Food Guide Pyramid with an emphasis on fruits with peel, pulses, vegetables, seeds, nuts, and whole grain cereals resulted in improved bowel habits for 75% of the subjects. The authors concluded that a diet high in dietary fiber and bran is feasible in constipated children, and that it will ameliorate constipation (Maffei & Vicentini, 2011), but more controlled clinical trials are needed in order to demonstrate the benefits of whole grain consumption for childhood constipation (Stewart & Schroeder, 2013). In summary, results from these studies conducted on children indicate that whole grain consumption might be beneficial for health at this age stage, as shown by e.g., the biomarkers related to obesity and cardiovascular diseases. This evidence is promising, but still, more research is needed to analyze the effects of whole grain intake in infants and young children.

Although the few randomized controlled trials have shown that whole grains might be beneficial in childhood, it seems that there is an urgent need to improve whole grain intake. Findings from several studies investigating the dietary patterns of children demonstrate that the consumption of whole grains in children across the globe (young children of 18 months up to adolescents of 18 years) is infrequent and poor (Alexy et al., 2010; Bellisle et al., 2014; Mann et al., 2015; Neo et al., 2016; Welker et al., 2018). However, this pattern seems to be stronger in Europe and Asia as compared to the US (Welker et al., 2018). For example, three-day dietary records from 821 German children aged between two and 18 years showed that only about 4% of their total grain consumption consisted of whole grains (mean intake ranged from 20–33 g/day). No whole grain intake was observed in nearly 20% of all dietary records. This means that the German Food Guide Pyramid's aim of 50% of total grain intake should consist of whole grains was by far not reached (Alexy et al., 2010). Another seven-day dietary survey was held among 1171 French children aged between three and 17 years old. More than half of these children reported to never consume any whole grains. Of those children who did, mean whole grain intake was between six and eight g/day and 13 g/day in children aged between three and 12 years and 13–17 years, respectively (Bellisle et al., 2014). In the UK, based on four-day diet diaries of 1502 children between 1.5–17 years, it was found that 15% did not consume any whole grains. In this age range, a mean of roughly 18 g/day of whole grains was consumed, which is below the country's recommendations of 32 g/day (Mann et al., 2015). Lastly, whole grain intake of 561 Singaporean children aged between six and 12 years was assessed by 24-h recalls. Results showed that only 38% of the respondents indicated consuming whole grains during the data collection days, meaning that 62% did not. Median intake of whole grains was approximately 15 g/day. Six percent of all the children reached the set 48 g/day of whole grains, which is an amount that is most commonly associated with improved health outcomes (Neo et al., 2016).

5.3.3 Consumer perspectives on whole grains

From a consumer perspective, the term "whole grains" is frequently linked to words such as "wholesome" (Thielecke & Nugent, 2018), "healthy" (Kuznesof et al., 2012; McMackin et al., 2013), "with minimal processing" (Kuznesof et al., 2012) and "natural" (Kuznesof et al., 2012; McMackin et al., 2013; Thielecke & Nugent, 2018). This is particularly relevant as a recent systematic review concluded that: "Food products that are not perceived as natural may not be accepted by the majority of consumers in most countries" (Román et al., 2017) (p. 50). Also, young people perceive whole grain foods as healthy and somehow related to healthiness (Kamar et al., 2016; Magalis et al., 2016).

Jones and Sheats (2016) indicated that many new trend drivers are exerting more influence on consumer behavior and the consumption of food and grains than before. These trend drivers involve issues such as concerns about the environment, misconceptions of technologies and practices used in food manufacturing, and worries about the rising obesity rates (Jones & Sheats, 2015) (p. 29). Sustainability issues are particularly relevant. For example, evidence from a systematic review by Nelson et al. (2016) showed that a dietary pattern higher in plant-based foods (e.g., vegetables, seeds, whole grains) and lower in animal-based foods is significantly associated with a minor impact on the environment (Nelson et al., 2016). Furthermore, recent findings from Román and Sánchez-Siles (2018) showed that environmental protection, and organic and sustainable food production play a major role in explaining infant cereal brand choice (Román & Sánchez-Siles, 2018). In this vein, it is important to consider that whole grain food products are less processed than refined grains, and more sustainable from an environmental point of view (Fardet, 2014). Next, we will focus on the challenges and future opportunities derived from the research reviewed earlier in this manuscript.

5.4 Challenges and future opportunities

A low intake of whole grains in adult populations might be explained by a number of reasons such as the difficulty of identifying whole grain foods (McMackin et al., 2013), a lack of knowledge of how to prepare them (Kuznesof et al., 2012; Magalis et al., 2016), higher prices (Kuznesof et al., 2012; Magalis et al., 2016; McMackin et al., 2013), unfamiliarity with whole grain products (McMackin et al., 2013), limited availability, and poorer perceived taste and texture (Kuznesof et al., 2012; McMackin et al., 2013). Similar evidence was found with younger consumers (11–16 years) (Kamar et al., 2016). Accordingly, food manufacturers face many challenges that need to be addressed, including a lack of unified recommendations for whole grain intake, consumer confusion when identifying whole grain food products, and the need to ensure the highest health and safety standards for whole grain infant cereals while retaining sensory appeal. In what follows, we elaborate on these challenges and discuss future opportunities derived from them, both for the food industry and policy makers.

5.4.1 Lack of unified recommendations for whole grain intake

Emerging evidence of the health benefits of whole grain consumption emphasizes the need for recommendations to incorporate whole grain foods into the diet. Such recommendations have been increasingly added to the already existing dietary guidelines in several countries lately, and are strongly focused on the general population (Slavin et al., 2013). The recommended whole grain consumption for the general population is inconsistent, and varies from country to country. Where some organizations provide specific daily doses targets, others advise increasing whole grain consumption in general (European Food Information Council (EUFIC), 2015; Seal et al., 2016; World Health Organization, 2004). For example, the World Health Organization (WHO) recommends an "increase consumption of whole grains", but also states that "appropriate intake levels shall be determined in accordance with national dietary guidelines and considering cultural traditions and national dietary habits and practices" (World Health Organization, 2004). Another non-specific recommendation is given in the UK, where the National Health Service (NHS) states: "Where you can, choose whole grain varieties." (NHS, 2020). In Spain, it is generally recommended to choose whole grain bread, pasta, rice, and flour, as shown in their food pyramid (Sociedad Española de Nutrición Comunitaria (SENC), 2015). Interestingly, in the US, it is recommended to increase whole grain intake by replacing refined grains with whole grains, but also "to consume at least half of all grains as whole grains" (U.S. Department of Health and Human Services and U.S. Department of Agriculture (USDA), 2015). In Denmark, Sweden, and Norway, it is more specifically recommended to consume at least four portions/day, which is equal to 75 g of whole grains/day for a 2400-kcal diet, or 90 g/day for men and 70 g/day for women (Danish Veterinary and Food Administration (DVFA), 2014; Johnsen et al., 2015; Norwegian Nutrition Council (NNC), 2011). However, many countries across the globe, such as those located in Southeast Asia, do not have any whole grain recommendations in their dietary guidelines (Brownlee et al., 2018).

Detailed whole grain recommendations in terms of quantity for infants and young children were also absent until recently. Yet, the current ongoing debate has led to the intention of some organizations to carefully integrate whole grain recommendations for children under two years of age (**Table 5.3**). Currently, Spain recommends that half of the cereal intake should be whole grains in infants and young children younger than 24 months (Varea Calderón et al., 2013). In Australia, recommendations are more amount-specific, and include recommending 16 servings/week and 19 servings/week of whole grains for young children aged between 13–23 months and 24–36 months, respectively. The National Health and Medical Research Council (NHMRC) defines one serving as 40 g of bread, which is equal to one slice, so the daily Australian recommendation for whole grain consumption can also be calculated as 90 g (two slices) and 110 g (three slices) of whole grain bread/day (National Health and Medical Research Council (NHMRC), 2011). Multiple organizations in the US are recommending whole grain intake. From the ages of six to 12 months, it is recommended by Healthy Eating Research to offer the infant a variety of whole grain products, such as brown rice or whole grain cereals (Pérez-Escamilla et al., 2017). For infants and young children between 12–36 months old, it is recommended to start with two ounces cereals/day, starting with one ounce of whole grains at 12 months (American Heart Association, 2013), and increasing intake to at least 1.5–2.5 ounces of whole grains/day at 36 months of age (U.S. Department of Health and

Human Services and U.S. Department of Agriculture (USDA), 2015). It is specified that in general, one ounce is equal to one slice of bread, one cup of ready-to-eat cereals, or half a cup of cooked rice, pasta, or cereals (U.S. Department of Health and Human Services and U.S. Department of Agriculture (USDA), 2015) (**Table 5.3**).

To increase whole grain intake, future strategies need to be explored and incorporated. In general, it seems that individuals around the world are confused about the amount of whole grains that should be consumed daily (Cereal Partners Worldwide (CPW), 2017). Also, the development of whole grain infant cereals within the food industry is hindered by a lack of clear regulations on whole grains. Clear global recommendations regarding daily whole grain intake, especially for infants and young children below two years of age, would provide a solid basis for the industry, healthcare professionals, and consumers to make accurate choices in processing, advising, and purchasing whole grain foods.

5.4.2 Consumer difficulty identifying whole grains

Although whole grains have been defined by several organizations as discussed earlier and the whole grain stamp has been used on more than 9000 products in 41 countries (Whole Grains Council, 2014), until now, a consistent global definition for whole grain foods has not yet been developed. Without a standard definition for whole grain foods, packaged whole grain food products might provide different amounts of whole grains per serving. To ensure that consumers can easily identify foods with high whole grain content, accurate and credible labeling is needed. In fact, a roundtable's expert panel represented by individuals from Europe and the US proposed, aligning with both the Dietary Guidelines for Americans 2010 (DGA) and the approved AACCI whole grain characterization (American Association of Cereal Chemists (AACCI), 2013a), that a food providing at least eight grams of whole grains per 30 g (27 g/100 g) is nutritionally meaningful, and can be considered a whole grain food (Ferruzzi et al., 2014).

However, the US Whole Grains Council (2014) was not convinced about this definition, because it does not refer to wet or dry weight, and thus it can be misleading to label a food as whole grain when the product might contain more refined grain ingredients than whole grain ingredients (Whole Grains Council, 2014). Therefore, Ross et al. (2017) offered, on behalf of the HEALTHGRAIN Forum, a new definition, namely: "A whole grain food is one for which the product is made with ≥30% whole grain ingredients on a dry-weight basis and contains more whole grain ingredients than refined grain ingredients". When a product meets these requirements, it can be labeled as a whole grain food, and display the whole grain stamp with the accurate proportion of whole grain content. The authors acknowledged that, "This 30% is selected as a starting point for whole grain food labeling. There is insufficient evidence to state that 30% of a product

Table 5.3. *Examples of whole grain recommendations for infants and young children.*

Country/region and organization	Wording, recommendation, or guideline
Australia (National Health and Medical Research Council (NHMRC), 2011)	13–23 months: - Whole grain or higher fiber cereals/grains: 16 serves[*] per week - Refined or lower fiber cereals/grains[**]: 8.5 serves[*] per week 24–36 months: - Whole grain or higher fiber cereals/grains: 19 serves[*] per week - Refined or lower fiber cereals/grains[**]: Nine serves[*] per week
Spain (Varea Calderón et al., 2013)	<24 months: "It is necessary to consume four to six servings of cereals per day to meet the dietary requirements; moreover, half of these servings should be whole grain to meet the fiber requirements."
US (American Academy of Pediatrics (AAP), 2012, 2020; American Heart Association, 2013; Gidding et al., 2006)	12 months: - Two ounces of cereals per day - Make sure half of the amount is whole grain 12–24 months: - Three ounces of cereals per day - Make sure half of the amount is whole grain "Serve whole grain breads and cereals rather than refined grain products. Look for *whole grain* as the first ingredient on the food label."
US (Food and Nutrition Service U.S. Department of Agriculture (USDA), 2016)	"At least one serving per day, across all eating occasions, must be whole grain or whole grain-rich. Grain-based desserts do not count towards meeting the grains requirement." 12–24 months: *Breakfast (minimum amount to be served)* - ½ slice of whole grain-rich or enriched bread or; - ½ serving of whole grain-rich or enriched bread product, such as biscuit, roll, or muffin, or; - ¼ cup of whole grain-rich, enriched, or fortified cooked breakfast cereal, cereal grain, and/or pasta *Lunch and supper (minimum amount to be served)* - ½ slice of whole grain-rich or enriched bread or; - ½ serving of whole grain-rich or enriched bread product, such as biscuit, roll, or muffin or; - ¼ cup of whole grain-rich, enriched, or fortified cereal, cereal grain, and/or pasta *Optional best practices that providers may choose to implement to make further nutritional improvements to the meals they serve:* "The Institute of Medicine (IOM) recommended that at least half of all grains served are whole grain-rich. To meet this goal, providers are encouraged to prepare at least two servings of whole grain-rich grains each day. This is an increase from the required one serving of whole grain-rich grains per day."

Table 5.3. *Continued*

Country/region and organization	Wording, recommendation, or guideline
US (Pérez-Escamilla et al., 2017)	Six to 12 months: "What your baby eats at around nine months is indicative of what she/he will like to eat when school-aged. Offer your baby a variety of vegetables and fruits and whole grain products (e.g., brown rice, whole grain cereals)." 12–24 months: "Offer your toddler whole grain food, such as whole wheat bread, whole wheat pasta, maize tortillas, or brown rice. These food items are rich in fiber, which is often missing from children's diets. Offer ½ to one slice of whole grain bread, or ¼ to ½ cup of whole grain cereal or pasta at most meals and snacks."
US (U.S. Department of Health and Human Services and U.S. Department of Agriculture (USDA), 2015)	12–36 months: - Whole grain: 1.5 to 2.5-ounce equivalents*** or above - At least half of total grain consumption is whole grain

**One serve is equivalent to 40 g of bread.*

***Refined or lower fiber cereals were included as a group for cultural reasons; whole grain or higher fiber can replace these if preferred.*

****In general, one slice of bread, one cup of ready-to-eat cereal, or ½ cup of cooked rice, cooked pasta, or cooked cereal can be considered as a one-ounce equivalent.*

is the significant amount for health and this definition does not aim to set thresholds for health claims" (Ross et al., 2017) (pp. 528-529).

Consumer knowledge about nutrition and the ability to understand product labels are important factors to consider. For example, findings from Violette et al. (2016) showed that 63% and 66% of older adults (aged >65 years) correctly identified whole grain cereals and crackers, respectively; however, refined bread was incorrectly identified by 46% of the respondents as being whole grain (Violette et al., 2016). Accordingly, more transparent and clear labels would make it easier for the consumer to identify and understand whole grain foods (Chien et al., 2018). Furthermore, knowledge education regarding the health benefits in later life and the use of whole grain infant cereals in early life may cause consciousness and a change in consumer purchase behavior (Ferruzzi et al., 2014).

5.4.3 Safety and health concerns of whole grains and infant cereal processing

Historically, mothers prepared cereals for infants themselves at home. These cereals were finely ground, toasted, boiled, and mixed with water or milk. This mode of preparation is still possible, but nowadays, it is easier if a blender or a food processor is used to improve the texture. Today, commercial infant cereals are commonly used. These cereals do not need to be ground nor cooked before consumption, and are, in most countries, produced according to strict safety regulations.

Since infants are a vulnerable group, safety and health challenges are of particular concern in the manufacturing of infant cereals. In this subsection, we will describe some examples of safety and health concerns regarding the content of arsenic and mycotoxins in whole grain raw materials, the production of contaminants such as acrylamide during processing, and how some processes applied in infant cereals will increase the levels of free sugars.

5.4.3.1 Safety concerns of whole grain infant cereals

The use of whole grains in infant cereals may come with some safety issues, because whole grains usually contain more contaminants than refined cereals. Two main reasons are described in a recent review published in this journal by Thielecke and Nugent (2018). Firstly, the outer layers of the cereal grain are more likely to be exposed to contaminants such as heavy metals and mycotoxins from the soil, such as arsenic or pesticides. Secondly, the germ and the bran contain higher concentrations of asparagine, which is an amino acid that leads to the formation of acrylamide during the processing of cereals (Thielecke & Nugent, 2018).

Arsenic is a heavy metal with neurotoxic and carcinogenic effects. It can be present in high concentrations in rice, which is a common cereal used in the manufacturing of infant cereals. Since arsenic is accumulated in the outer layer of rice, the concentrations in whole grain rice cereals are higher compared to their refined counterparts (Hojsak et al., 2015; Thielecke & Nugent, 2018).

The US Food and Drug Administration (FDA) and the European Commission Regulation established a maximum level of 100 μg/kg or 100 ppb of inorganic arsenic in rice used for foods targeted at infants and young children (European Commission, 2015; U.S. Food and Drug Administration (FDA), 2020), and companies are striving to achieve lower values in infant cereals. Manufacturers select sources of rice and rice-derived ingredients with lower inorganic arsenic levels (U.S. Food and Drug Administration (FDA), 2020). However, values of arsenic in infant cereals are sometimes still too high. This finding follows from a survey conducted in the US by Healthy Babies Bright Futures (HBBF) that analysed the inorganic arsenic content in 105 infant cereals of leading brands. The results indicated an average arsenic content of 73 ppb in rice infant cereals and 96 ppb in whole grain rice (brown rice) infant cereals. The authors concluded that arsenic content in rice infant cereals is still excessive, and therefore infant cereals manufacturers need clearer strategies to reduce the arsenic in their products. The authors requested that the FDA recommendations limit the intake of rice infant cereals until mitigation of arsenic level has been reached. They proposed increasing the intake of multigrain or other cereals instead of decreasing the consumption of rice infant cereals (Healthy Babies Bright Futures, 2017).

Mycotoxins are toxic secondary metabolites produced by certain filamentous fungi (molds). Mycotoxins can accumulate in maturing cereals and other food and feed crops in the field and in grain during transportation (Alshannaq & Yu, 2017). In a recent study conducted in the US retail market, one or more mycotoxins were found in 69% (101/147) of the infant and toddler foods, and 50% (34/68) of the breakfast cereals. However, the concentrations of detected mycotoxins were lower than the current FDA action, and guidance levels and rice-based cereals appeared to be less susceptible to mycotoxin contamination than other cereal types (K. Zhang et al., 2018). Mycotoxins can be present in the outer layers of grains, but cleaning of the grain ensures a decrease of mycotoxins (Thielecke & Nugent, 2018). Furthermore, the bioactive compounds found in whole grains can protect against the negative impact that mycotoxins might have (Thielecke & Nugent, 2018). Manufacturers must carry out controls to limit the levels of mycotoxins according to the maximum levels for commercial infant cereals established by the European Commission 1881/2006 (aflatoxin B1: 0.10 μg/kg, ochratoxin A: 0.50 μg/kg, patulin: 10 μg/kg, deoxynivalenol: 200 μg/kg, zearalenone: 20 μg/kg and fumonisins: 200 μg/kg) (Commission Regulation (EC) No 1881/2006, 2006).

Acrylamide, which is formed when toasting raw material, is another contaminant to consider in infant cereals due to its carcinogenic effects. The toasting of raw material is carried out to remove possible contaminants such as fungi, yeasts, bacteria, insect eggs, and the inactivation of the lipoxidases that are responsible for fat rancidity and improve the sensory characteristics of the final product. When the temperature and exposure time of toasting are high (usually above 120 °C) and the moisture content is low, toasting can stimulate the formation of acrylamide (European Food Safety Authority (EFSA), 2015). Although the asparagine (and thus acrylamide) content is higher in whole grains than in refined products, the overall higher health benefits of whole grains may outweigh this disadvantage (Food and Drug Administration, 2016; Food Drink Europe, 2013; Seal et al., 2008). In this sense, companies decrease the temperature and time of toasting, or use an enzymatic treatment with asparaginase for the mitigation of acrylamide formation during infant cereal processing to maintain levels below the established thresholds by the European Commission (2017) (Commission Regulation (EU) 2017/2158, 2017).

5.4.3.2 Sugar-related concern in infant cereals

During the processing of infant cereals, more specifically when the infant cereals are enzymatically hydrolyzed, free sugars are produced. This should be considered, because the recommendations for infants and young children under the age of two are strict with regards to the intake of free sugars. The ESPGHAN states that no sugar should be added to complementary foods, and free sugars should be minimized or avoided (Fewtrell et al., 2017).

However, many manufacturers, depending on the country, choose to enzymatically hydrolyze the cereals after toasting. The enzymatic hydrolysis of infant cereals is carried out for some reasons, including the technological aim to stabilize the viscosity of the infant cereals after preparation and the physiological aim to increase the starch digestibility. For a long time, there has been an incorrect belief that infants and young children are not able to digest or hydrolyze starch due to a low presence and activity of pancreatic α-amylase, which is the main enzyme that is responsible for starch digestion (Hadorn et al., 1968; Lilibridge & Townes, 1973; Zoppi et al., 1972). On the contrary, infants are able to digest starch even more efficiently than adults. There are two facts that contradict the old belief that infants are not able to digest starch. Firstly, other enzymes such as glucoamylase–maltase and salivary α-amylase make up for the physiological lower activity of pancreatic α-amylase (Auricchio et al., 1965; Lee et al., 2004; Lin et al., 2012; Lin & Nichols, 2017). Secondly, infants have a higher capacity to ferment the non-digested starch (resistant starch) that reaches the colon, which is also called energy salvage, compared to adults (Christian et al., 1999, 2003). Therefore, it could be assumed that hydrolysis is an unnecessary step in the manufacturing of infant cereals.

5.4.4 Sensory acceptability of whole grain cereals

One of the potential advantages of refined cereals, compared to whole grains, is the improved sensory characteristics that are highly accepted by consumers (Cordain et al., 2005; Heiniö et al., 2016). Findings from a study conducted in Singapore among 21 to 26-year-olds largely confirmed the characterized barriers from studies carried out in Europe and North America that were discussed earlier in this article, indicating categories such as “sensory” and “habitual” as the most common barriers for whole grain consumption (Neo & Brownlee, 2017).

Interestingly, research has shown that acceptability increases with repeated consumption. For example, a noteworthy outcome of an intervention by Kuznesof et al. (2012) revealed that many participants “surprisingly” liked the taste of the whole grain foods when they were introduced to it, as they prejudged disliking the taste due to negative experiences from years ago. Frequent consumption resulted in participants that learned to like the whole grain foods (Kuznesof et al., 2012). This result was also found in two other studies, which showed that direct exposure to whole grains by including them in the diet tended to increase acceptability and consumption (Brownlee et al., 2013; Neo

& Brownlee, 2017). In other words, familiarization with whole grain foods is likely to reduce negative thoughts about the expected taste.

In either way, sensory appeal remains a key factor in food choice and (whole grain) intake (Kamar et al., 2016; McMackin et al., 2013). In this light, the sensory liking of grain products seems to depend on the type of food product. A preference for refined pasta and rice was found over their whole grain counterparts, but both types of tortillas and bread were equally liked among college students (Magalis et al., 2016). Other studies indicated that the gradual and/or unknown replacement of refined grain ingredients with whole grain ingredients does not affect acceptability or consumption in young adults (Mellette et al., 2018) and schoolchildren (Chan et al., 2008; Rosen et al., 2008; Toma et al., 2009). Recent findings from the qualitative and quantitative study by Román and Sánchez-Siles (2018), on a sample of parents of infants and young children under 18 months, highlight the importance placed on the sensory properties (with special emphasis on taste and texture) when buying infant cereals (Román & Sánchez-Siles, 2018). In this regard, a study by Haro-Vicente et al. (2017) tested whether infant cereals containing 30% whole grains would be similarly accepted by both parents and infants/young children aged between four and 24 months compared to the same cereal with only refined grains. Other attributes such as color, smell, and taste were also evaluated by the parents. Importantly, results of the eight-day experimental trial showed that among infants, young children, and their parents, the sensory acceptability of infant cereals with added and without added whole grains was found to be the same. Furthermore, there were no significant differences experienced between the two infant cereals for any of the other attributes (Haro-Vicente et al., 2017). All of the main findings of studies evaluating the sensory acceptability of whole grains are summarized in **Table 5.4**.

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The eating behaviors of infants and young children eating behavior is influenced by both intrinsic (e.g., genetics/predisposed biological tendencies, age) and environmental (e.g., parents, demographics) factors (Cosmi et al., 2017). Reflecting their basic biology, infants have an innate preference for sweet taste and a dislike for bitter taste (Mennella & Bobowski, 2015). The substitution or addition of whole grains might cause an adverse taste (Heiniö et al., 2016) due to for example phenolic compounds (Heiniö et al., 2008) and oxidation changes of linoleic acid (Bin & Peterson, 2016), which will possibly be rejected by infants. Therefore, parents and caregivers play a critical role in shaping infants' and young children's dietary patterns during complementary feeding, which is the time when food preferences, eating skills, and habits are grounded (Harris & Coulthard, 2016; Maier-Nöth et al., 2016; Murray, 2017; Nicklaus, 2016a). Importantly, the eating habits that are established during this stage might become a potential barrier for future consumption (Neo & Brownlee, 2017). Even the foods that might be rejected primarily may be learned to be liked and consumed by children through repeated exposure, as-

Table 5.4. *Main findings of studies evaluating consumers' sensory acceptability of whole grain foods.*

Author, Year	Country	Age	Main Results
Brownlee et al., 2013	UK	+18 years	"Whole grain consumption was significantly higher in participants who were provided with whole grain foods throughout the intervention period compared with the control group that was not provided with whole grain foods (approximately doubled, $P<0.001$) and compared to baseline."
Chan et al., 2008	US	6–11 years	"There was no difference in children's consumption of the 50:50 blend pizza (50% whole grain and 50% refined grain) compared to the 100% refined counterpart (mean consumption 106 ± 4 g of 50:50 pizza compared to 100 ± 2 g of refined pizza)."
Haro-Vicente et al., 2017	Spain	4–24 months	"Overall acceptability for infant cereals with whole grain and refined cereals was very similar both for infants (2.30 ± 0.12 and 2.32 ± 0.11, $P=0.606$) and parents (6.1 ± 0.8 and 6.0 ± 0.9, $P=0.494$). Sensory evaluation of the color, aroma, taste, and texture by parents indicated no significant difference between both types of infant cereals (all $P>0.05$)."
Kuznesof et al., 2012	UK	18–65 years	"Many participants expressed surprise at liking the taste of whole grain foods that they had either prejudged to be 'tasteless' or recalled (on the basis of a previous eating experience) to taste inferior to alternatives. A preference for certain whole grain foods was established over time."
Magalis et al., 2016	UK	18–19 years	"Both refined rice and refined pasta were significantly more well-liked than their whole grain counterparts for all sensory attributes ($p \leq 0.05$). For tortillas and bread, the whole wheat and refined wheat samples were similarly well-liked ($P>0.05$)."
Mellette et al., 2018	US	18–24 years	"Respondents liked all muffin formulations (muffins containing 50%, 75%, and 100% whole wheat flour) similarly for appearance, taste, texture, and overall liking. After the whole grain content of each muffin was revealed, 66% of students increased their liking of the muffin containing 100% whole wheat flour."
Neo & Brownlee, 2017	Singapore	21–26 years	"The whole grain familiarization period did not alter the taste expectations of the consumers, but it did manage to increase acceptance for four of the whole grain products tested ($P<0.001$ for oatmeal cookie, granola bar, and muesli, $P<0.05$ for wheat biscuit breakfast cereal."
Rosen et al., 2008	US	Kinder-garten–6th grade children	"Mean consumption of buns and rolls at the baseline for both schools (0% whole wheat) was ~75%. Intake of bread products did not differ significantly from the baseline level up to the 59% level of red whole wheat and 45% of the white whole wheat. The range of consumption for dinner rolls made with red whole wheat flour was 57% to 77%, while white whole wheat flour was 50% to 78%, indicating that grain bread products may be more acceptable, with a total whole grain flour content approaching 75%."
Toma et al., 2009	US	Kinder-garten–6th grade children	"No significant differences ($P>0.05$) in consumption between control products (products with refined flour) and test products (burritos and cookies containing 51% and 100% whole grain, respectively) were found."

sociative conditioning, or in interaction with contextual signals from the eating environment. Infants and young children have the ability to learn to like foods between roughly four months and two years of age, and this is likely to be stable across childhood and adulthood (Nicklaus, 2016b).

Thus, the introduction of whole grains in infancy offers a great opportunity for the acceptance of whole grains across the entire lifespan. Also, this period generates a favorable circumstance to introduce less sweet non-hydrolyzed infant cereals instead of their hydrolyzed counterparts. Sensory learning techniques that parents or caregivers can use to encourage familiarity include starting with small bites (preferably without any added flavors), aiming for at least 10 exposures, and encouraging repeated tasting at a regular interval (Nekitsing et al., 2018). Taste preferences often form the greatest challenge in the development of whole grain food products (Saleh et al., 2019).

5.5 Conclusions

Infant cereals are one of the first foods given during complementary feeding. They play an important role in the early stage of life by providing the infant with energy, macronutrients, vitamins, minerals, bioactive compounds, and non-digestible carbohydrates that stimulate the gut microbiota. The existing evidence reviewed in this article suggests that whole grains are more beneficial for health compared to refined cereals. Whole grains are rich in compounds that induce several mechanisms that aid in reducing the risk of non-communicable diseases. With respect to the beneficial impact of whole grains in adults, the low intake in children and adolescents, and the consumers' healthy perception of whole grains, it can be concluded that the incorporation of whole grains in infant cereals is a great opportunity for the future. However, there are some important issues that retailers, manufacturers, researchers, and policy makers need to address. Consistent and unified whole grain recommendations for infants and young children under two years of age are still lacking, which is probably due the scarcity of research that has been done in this vulnerable age group. Another barrier is the inconsistent product labeling and the difficulty that consumers have identifying whole grain foods. Manufacturers also need to deal with natural and process contaminants in whole grains. However, the hardest challenge that comes along with the production of whole grain food products and its ultimate acceptance by consumers is sensory appeal. Although people often prefer refined cereals, the gradual or unknown replacement of refined whole grains does not seem to negatively influence sensory acceptability, even in infants. The complementary feeding period is an important time for shaping the infant's food preferences, eating skills, and habits, and therefore, it is the right time to introduce whole grain infant cereals for the acceptance of whole grains across the entire lifespan.

CHAPTER 6

6

Healthier and more natural reformulated baby food pouches: Will toddlers and their parents sensory accept them?

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Abstract

Consumer demand of commercial baby food packaged in squeezable pouches has increased in the last few years. However, pouches have been criticized for having excessive levels of sugar and too many processed ingredients. This study examined how reformulations towards healthier (lower sugar levels) and more natural (fewer processed ingredients) products influenced toddlers' and parents' sensory acceptability. Three pairs of baby yogurt pouches (old versus reformulated recipes) were tested. In the reformulated recipes, fruit concentrates were replaced by fruit purees, and added sugar was eliminated. 150 parent-toddler (1-4 years) dyads were included in a 4-day double-blind randomized cross-over study in Spain. Each parent-toddler dyad tested one of the three yogurt pairs (A-B, C-D, E-F). Toddler's acceptability was measured by the toddler's reaction and by the estimated and relative intake. Parent's overall liking and sensory evaluation was measured on a 7-point hedonic scale. Although the reformulated recipes of two yogurt pairs scored significantly lower on acceptability in toddlers (pair A-B: 3.39 ± 0.49 and 3.12 ± 0.70; pair C-D: 3.54 ± 0.61 and 3.30 ± 0.65, $P<0.05$) and their parents (pair A-B: 5.73 ± 0.97 and 5.04 ± 1.43; pair C-D: 5.84 ± 1.27 and 5.04 ± 1.51, $P<0.05$), all reformulated recipes were highly accepted. The reformulation of food products represents a huge challenge for food manufacturers. Our findings suggest that a reduction of sugar content up to 30% along with a reduction in the number of processed ingredients is acceptable by toddlers and their parents.

6.1 Introduction

Infancy and early childhood are the most critical stages for the development of food preferences and dietary patterns (Nicklaus & Remy, 2013; Schwartz, Scholtens, et al., 2011). Unfortunately, childhood overweight currently represents a global public-health problem which affects high as well as middle-and-low-income countries (Caprio et al., 2020; Narzisi & Simons, 2021). In 2019, more than 38.2 million children under the age of 5 years were overweight or obese (World Health Organization, 2021). Under this situation, despite their relatively recent introduction in the market a few years ago, commercial baby food packaged in squeezable pouches has become the market leader category in many developed countries. For example, in 2019 pouches were the most common type of packaging in the UK, representing 54% of packaged wet spoonable baby foods (Garcia et al., 2020). Similarly, flexible stand-up pouches are currently the most popular type of packaging in baby fruit products in Europe (Mintel, 2021b).

Despite their market success and competitive advantages compared to other types of packaging (e.g., convenience, mess-free, shelf stability), several consumer groups, public health authorities and scholars have argued that baby food pouches (particularly those based on fruits) contain too much sugar and induce a preference for sweet taste in children, which in turn is likely to result in excessive weight gain (Beauregard et al., 2019; Hutchinson et al., 2021; Katiforis et al., 2021; Koletzko et al., 2018, 2019; Moding et al., 2019; The New York Times, 2018; Theurich, 2018, 2019; Westland & Crawley, 2018). For example, Moding et al. (2019) evidenced that infant and toddler pouches contained more sugars per serving compared to infant and toddler foods in other packaging types. Baby food pouches have also been criticized for having ingredients lists which are "far from simple" and contain too many processed ingredients (Moding et al., 2019; Westland & Crawley, 2018).

Based on the entire body of evidence showing the negative impact of high levels of sugar on health, the World Health Organization recommended to limit the intake of free sugars[2], especially in early life, below 5% of total energy intake (World Health Organization, 2015). It is worth mentioning that different definitions for what comprises free sugars exist. The WHO does not include sugars derived from fruit purees in its definition of free sugars (World Health Organization, 2015), whereas the further advice on the definition of the SACN does (Scientific Advisory Committee on Nutrition, 2015, 2016).

2 Free sugars include monosaccharides and disaccharides added to foods and beverages by the manufacturer, cook or consumer, and sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates.

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Importantly, product reformulation represents one of the most efficient strategies for improving the nutritional characteristics of sugar-containing commercially available processed foods (Belc et al., 2019), and baby food pouches are no exception. However, food manufacturers face a major challenge as product reformulations can alter product sensory characteristics and consumers' acceptance (Deliza et al., 2021; Hutchings et al., 2019; Román et al., 2021). This is even more problematic for the food industry today, given the current and expected market dominance of baby food pouches.

In view of these considerations, this study aims to examine how product reformulations of baby food pouches in terms of a reduction in sugar content and number of processed ingredients (i.e., healthier and more natural products) influence consumers' (toddlers and their parents) sensory acceptability as well as parents' evaluation of the ingredient list and purchase intentions. The analysis of a reduction in the number of processed ingredients along with consumers' evaluations of the ingredient list are particularly relevant in the light of the latest market trends of "food naturalness" and "clean label" (Asioli et al., 2017; Román et al., 2017).

Notably, most previous studies analyzing sensory acceptability of sugar-reduced food products have been conducted with adult consumers (Biguzzi et al., 2014, 2015; de Oliveira Pineli et al., 2016; Markey et al., 2015; Romagny et al., 2017; Wise et al., 2016), and to a minor extent with children aged 6-12 years (Lima et al., 2018, 2019) and 8-12 years (Velazquez et al., 2020). Only recently Sanchez-Siles et al., (2020) focused their attention on sugar reductions of complementary infant cereals. Their findings are inspiring as drastic reductions of sugar are well accepted by infants and their parents, but authors acknowledge that their results are restricted to infant cereals and call for further research to test other baby food product categories. In fact, more research is needed on infants and toddlers because (a) they have a stronger preference for sweetness compared to adults (Mura Paroche et al., 2017), and (b) feeding habits at this stage of life will determine the development of food preferences and eating habits later in life (Klerks et al., 2021). Furthermore, prior research has shown that the influence of sugar reduction on the sensory aspects of products depends not only on the level of reduction, but also on the type of product (Biguzzi et al., 2014). Baby food pouches market introduction is so recent that published empirical evidence in this category is absent. Finally, the current study is, to the best of our knowledge, the first one conducted with toddlers (1-4 years old).

6.2 Materials and methods

6.2.1 Sample characteristics and recruitment

150 parent-toddler dyads were recruited by an independent market research firm in June 2019 from four major cities in Spain (Barcelona, Madrid, Sevilla, Valencia). Eligible parents were main responsible for feeding their toddlers. Eligible healthy toddlers were 1-4 years old (12-48 months) and were already familiar with drink or fruit pouches. Toddlers with food allergies, food intolerances, or any other illnesses that determine a special care of the diet were excluded from the study. The study was conducted according to the guidelines established in the Declaration of Helsinki (2013) (World Medical Association, 2013) as well as the International Conference on Harmonization Good Clinical Practice guideline (Dixon, 1999). Written informed consent was obtained from all participants.

6.2.2 Baby yogurt pouches

The baby yogurt/fruit pouches (in this paper referred to as yogurt, or yogurt pouch) used in this experiment were designed and produced by Hero España, S. A. (Murcia, Spain) and in full compliance with European Directives and Regulations (Commission Directive 2006/125/EC, 2006; Commission Regulation (EC) No 1881/2006, 2006). Three yogurt pairs (old versus reformulated recipes) differing in flavors were tested. The product names[3] and ingredient lists of the six yogurt pouches can be found in **Table 6.1**, and their nutritional composition is shown on **Table 6.2**.

The main changes between the old and reformulated recipes were: 1) elimination of added sugar, 2) replacement of fruit concentrates by fruit purees, and 3) decrease in sweetness. These changes affected the nutritional composition (i.e., total sugar content, and following the WHO definition of free sugars (World Health Organization, 2015), the quantity of free sugars in the formulations were reduced by substituting fruit juice concentrates with fruit purees), the number of processed and total ingredients, and the Food Naturalness Index (FNI)[4] (Michel et al., 2021; Sanchez-Siles et al., 2019) of the yogurt pouches. Main differences between the old and reformulated recipes are shown in **Table 6.3**.

For the sensory evaluation, all yogurt pouches were labelled equally and provided with three-digit randomization codes. For the ingredient and purchase intention evaluation, the yogurt pouches were not blinded: packages, including product names, characters, and ingredient lists (except nutritional information), were visible. All yogurt pouches

3 The old and reformulated recipes of two yogurt pairs (A-B and E-F) differed in product name due to a shift in (the order of) ingredients.

4 FNI is a comprehensive index based on insights from consumer, legal and technical perspectives that predicts perceived naturalness.

Table 6.1. *Product names and ingredient lists of tested products (old and reformulated recipes[*]).*

Yogurt pair	Product name (no. of ingredients)	Old (longer) ingredient list	Product name (no. of ingredients)	Reformulated (shorter) ingredient list
A-B	Yogurt with strawberry (11)	Pasteurized yogurt after fermentation (42%), fruit purees and juices from concentrates (40%) (strawberry puree (10%), pear, grape and apple juices), sugar, starches (corn and rice), lemon juice from concentrate, concentrate of carrot, apple and blackcurrant, and natural flavors	Yogurt with apple and strawberry (8)	Pasteurized yogurt after fermentation (43%), apple puree (43%), strawberry puree (7%), starches (corn and rice), lemon juice from concentrate, natural flavors, and concentrate of carrot, apple and blackcurrant
C-D	Yogurt with banana and strawberry (11)	Pasteurized yogurt after fermentation (42%), purees and fruit juices from concentrates (40%) (banana puree (11%), strawberry puree (10%), pear and grape juices), sugar, starches (corn and rice), lemon juice from concentrate, concentrate of carrot, apple and blackcurrant, and natural flavors	Yogurt with banana and strawberry (8)	Pasteurized yogurt after fermentation (46%), fruit purees (banana (28%) and strawberry (15%)), starches (corn and rice), concentrate of carrot, apple and blackcurrant, lemon juice from concentrate, and natural flavors
E-F	Yogurt multifruit with biscuit (16)	Pear and grape juices from concentrates (29%), banana puree (11%), pasteurized yogurt after fermentation (30%), water, partially hydrolyzed flours (7%) (wheat (4.7%), rice, corn, oats, barley, rye, sorghum, and millet), sugar, lemon juice from concentrate, and natural flavors	Yogurt multifruit with cereals (15)	Fruit purees (44%) (apple, banana, and pear in a variable proportion), pasteurized yogurt after fermentation (30%), water, hydrolyzed flours (7%) (wheat, rice, corn, oats, barley, rye, sorghum and millet), lemon juice from concentrate, and natural flavors

[*]Note: Lemon juice from concentrate and concentrate of carrot, apple, and blackcurrant are added in very small quantities (less than 1%) to the reformulated products for technological reasons (i.e., acidifying, improve color), not for sweetening purposes.

Table 6.2. *Nutritional composition of tested products.*

Per 100g	Yogurt pair A-B		Yogurt pair C-D		Yogurt pair E-F	
	Yogurt with strawberry (old recipe)	Yogurt with apple and strawberry (reformulated recipe)	Yogurt with banana and strawberry (old recipe)	Yogurt with banana and strawberry (reformulated recipe)	Yogurt multifruit with biscuit (old recipe)	Yogurt multifruit with cereals (reformulated recipe)
Energy (Kcal)	79	70	85	75	83	77
Energy (kJ)	331	294	356	317	349	323
Fat (g)	1.6	1.8	1.6	1.7	1.4	1.4
Saturated fat (g)	1.0	1.1	1.0	1.1	0.8	0.8
Carbohydrates (g)	13.9	11.2	15.1	12.4	15.0	13.4
Total sugar (g)	11.3	7.9	12.4	8.9	9.6	7.4
Protein (g)	2.0	1.8	2.4	2.2	2.3	2.1
Fiber (g)	0.5	0.8	0.4	0.9	0.8	1.0
Salt (g)	0.08	0.08	0.05	0.06	0.05	0.05
Sodium (mg)	32	32	20	24	20	20

Table 6.3. *Main differences between old and reformulated recipes.*

Yogurt pair	Total sugar (g/100g)			No. of processed ingredients			Food Naturalness Index		
	Old recipe	Reform* recipe	*% Reduction*	Old recipe	Reform* recipe	*% Reduction*	Old recipe	Reform* recipe	*% Increase*
A-B	11.3	7.9	*30%*	9	5	*44%*	2.5	3.0	*20%*
C-D	12.4	8.9	*28%*	8	5	*37%*	2.5	3.0	*20%*
E-F	9.6	7.4	*23%*	6	3	*50%*	2.8	3.5	*25%*

**Reform=Reformulated*

were manufactured at the same time (1-2 weeks of difference) to ensure that all samples were equally fresh.

6.2.3 Experimental procedure and measurements

The study had a double-blind randomized[5] cross-over design. The study took place at home and lasted for four days. Parents were responsible for conducting the experiment and reporting on their children reactions and food intake. In-home studies present two advantages: they can be performed with few constraints on the participants, and children are in their usual environment with their usual feeder (Madrelle et al., 2017). Feed-

5 All parent-toddler dyads were randomized to one of the yogurt pair groups (A-B, C-D, or E-F), and were later again randomized and counterbalanced into the feeding sequence (i.e., A-B or B-A). The randomization schedule was done in blocks of 4 for each study site (city). There were no statistically significant differences between the product groups and between the different feeding sequences groups in terms of age of toddlers and parents.

ers (parents) know their child's reactions towards foods best and therefore are likely to be more sensitive to subtle differences in their reactions. In fact, extant research has validated the use of subjective measurement (through parent's evaluations) of infants' and toddlers' reactions (Gerrish & Mennella, 2001; Haro-Vicente et al., 2017; Lange et al., 2013; Maier et al., 2007; Remy et al., 2013; Sanchez-Siles et al., 2020). Moreover, prior research has shown that parents' and external observers' (i.e., researchers) assessments of infants' and toddlers' sensory reactions are very similar (Demonteil et al., 2019).

Parent-toddler dyads (1-4 years) were equally allocated to test one of the three yogurt pairs, resulting in 50 parent-toddler dyads per yogurt pair. Prior to testing (day 1), to ensure accurate recording, trained interviewers visited parents at their homes and gave them the food samples, as well as detailed instructions[6] as to how to conduct the study and report on their children reactions and intake of the samples. Importantly, findings from Madrelle et al. (2017, p.282) show that parents who have been trained (even briefly) are able to accurately assess "the presence or absence of specific eating behaviours of their child while eating".

On day 2 and 3, parent-toddler dyads tested the two yogurt pouches (the old and the reformulated recipe) of the corresponding yogurt pair in random order. It was required that on both days the same parent was involved in feeding the child. Following standard procedures parents were instructed not to feed their toddler with beverages or solid foods for one hour before the testing (Forestell & Mennella, 2007; Lange et al., 2013). Parents were first asked to evaluate the toddler's reaction, only after that, they evaluated the yogurt themselves to ensure no interference with their toddler's reactions. The feeding session was finished when either the child rejected the yogurt three or more times, or when the child finished the yogurt entirely. On the fourth day, trained interviewers collected the sensory records and conducted debrief interviews with parents at their home (**Figure 6.1**).

6.2.3.1 Participant characteristics and yogurt pouches feeding habits

At the start of the questionnaire, parents were asked questions with regards to who was involved in the study (father, mother, or other), the age of the parent, the age of the toddler, and the gender of the toddler. Furthermore, parents needed to indicate of which brand they usually would buy yogurt pouches, the frequency with which they usually would give such a product ("every day", "almost every day", "3-4 days per week",

6 No particular instructions were given to parents regarding the way of feeding their toddlers (e.g., using a spoon or letting toddlers to suck straight from the pouch). The aim was that toddlers were fed the very same way as they had been fed before the study took place so as not to bias the results. Parents also received instructions as to how to report intake through the variables estimated intake and relative intake. For instance, they were told not to indicate that toddlers had had the entire portion if food was considerably spit out.

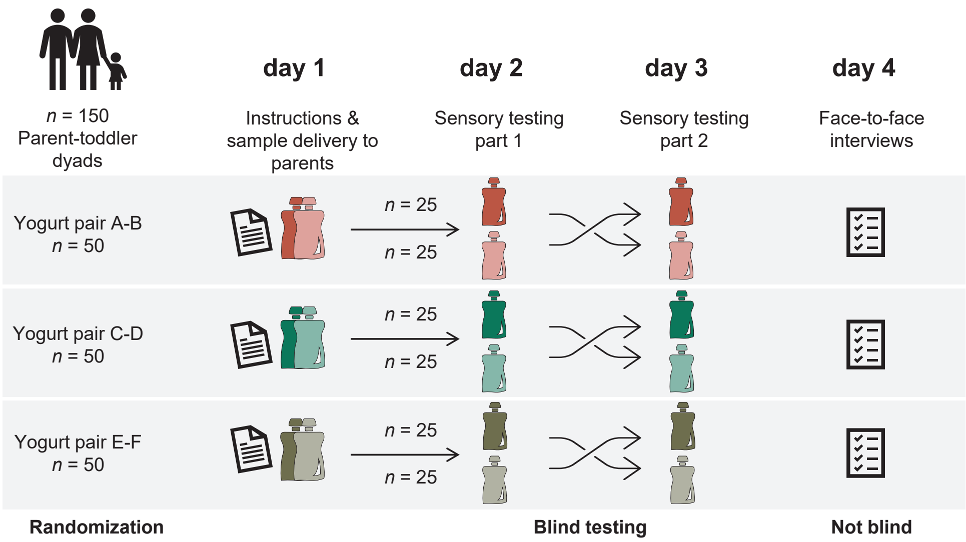


***Figure 6.1**. Study overview.*

"1-2 days per week", "with less frequency"), and the moment(s) of the day they usually would give it ("breakfast, "mid-morning", "lunch", "mid-afternoon", "dinner").

6.2.3.2 Sensory evaluation

The toddler's overall acceptability of the yogurts was assessed through three different, yet related measures: the toddler's reaction towards the pouches as perceived by parents, the estimated intake, and the relative intake of yogurt pouches compared to usual intake.

The toddler's reaction was measured by means of a 4-point hedonic scale (Haro-Vicente et al., 2017; Lange et al., 2013; Sanchez-Siles et al., 2020; Schwartz, Chabanet, et al., 2011). The scale ranges from: "1 = very negative" if the toddler spit out the food, frowned, removed the pouch, or stopped eating; "2 = negative" if the toddler only ate a little bit, grimaced and stopped eating; "3 = positive" if the toddler ate some of the food without a specific reaction; "4 = very positive" if the toddler accepted the food immediately and displayed signs of content, such as a relaxed face or a smile. All scores on the scale were accompanied with a corresponding smiley-face to guide the parents.

The ingested amount (estimated intake) and the relative intake compared to usual intake were measured via a 5-point scale with scores ranging from: "1 = less than 1/4" to "5 = the entire portion" and "1 = a lot less than usual" to 5 = a lot more than usual" from Madrelle et al. (2017).

Parent's overall liking was measured using a one-item 7-point hedonic scale ranging from "1 = dislike very much" to "7 = like very much" (Haro-Vicente et al., 2017; Sanchez-Siles et al., 2020). Parents were also asked to evaluate key sensory attributes: sweetness, color, taste, texture, and aroma on the same 7-point hedonic scale (Kuang et al., 2020).

6.2.3.3 Evaluation of the ingredient list and purchase intention

After sensory testing, face-to-face interviews were carried out. First, parents were asked to carefully evaluate the ingredient list of the product and indicate how much they agreed with the following statement "All in all, I find this an acceptable ingredient list", referring to the list as a whole, on a 5-point Likert scale ranging from 1 = "totally disagree" to 5 = "totally agree". To better understand the parent's perception, they were then asked to explain why they thought the ingredient list was either acceptable or not acceptable (open question). Lastly, purchase intention was assessed by asking them: "If this product with these ingredients was available in your usual store, at a price similar to that of the competition, would you buy it?". Parents indicated their answer on a 5-point scale ranging from 1 = "definitely wouldn't buy it" to 5 = "definitely would buy it". No information was provided regarding nutritional profile (and sugar content) of each recipe.

6.2.4 Data analysis

Paired t-tests were used to test for significant differences between the old and reformulated recipes in terms of the toddler's reaction, the toddler's estimated and relative intake, the parent's overall acceptability and evaluation of key sensory attributes, as well as ingredient list acceptability and purchase intention. Significance was considered at $P<0.05$. Data is expressed in mean ± standard deviation (SD). All statistical analyses were performed using Microsoft Office Excel (Microsoft Corporation, Redmond, WA) and IBM SPSS version 27 (SPSS Inc., Chicago, IL).

6.3 Results

6.3.1 Participant characteristics and usual feeding habits

The final sample included 149[7] parents and their toddlers. Participants' characteristics are presented in **Table 6.4**. The mean age of toddlers was 30.2 ± 11.0 months, roughly equally divided between the age ranges 12 – 30 months (51.2%) and 31 – 48 months (48.3%). More mothers were involved in the study (83.9%) compared to fathers (16.1%). As shown in **Figure 6.2a**, most of the toddlers were usually fed a yogurt pouch or a similar product 1-2 days per week (51.7%). Yogurt pouches were mostly given during mid-afternoon (66.4%) (**Figure 6.2b**).

7 Data of one parent-toddler dyad in Group A-B was not fully completed and therefore it was excluded from the analysis.

Table 6.4. *Participants' characteristics.*

Variable	Total (n=149)	Group A-B (n=49)	Group C-D (n=50)	Group E-F (n=50)
Toddlers				
Boys, *n* (%)	74 (49.7)	25 (51.0)	25 (50.0)	24 (48.0)
Girls, *n* (%)	75 (50.3)	24 (49.0)	25 (50.0)	26 (52.0)
Age in months (mean ± SD)	30.2 ± 11.0	29.2 ± 10.1	30.4 ± 11.0	30.8 ± 11.9
Age 12-30m, *n* (%)	77 (51.2)	26 (53.1)	26 (52.0)	25 (50.0
Age 31-48m, *n* (%)	72 (48.3)	23 (46.9)	24 (48.0)	25 (50.0)
Parents				
Mother, *n* (%)	125 (83.9)	41 (83.7)	45 (90.0)	39 (78.0)
Father, *n* (%)	24 (16.1)	8 (16.3)	5 (10.0)	11 (22.0)
Other, *n* (%)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Age in years (mean ± SD)	35.7 ± 5.4	35.1 ± 4.4	35.1 ± 6.7	36.8 ± 5.2
Age 20-35y, *n* (%)	67 (45.0)	22 (44.9)	25 (50.0	20 (40.0)
Age 36-50y, *n* (%)	82 (55.0)	27 (55.1)	25 (50.0)	30 (60.0)
Barcelona, *n* (%)	37 (24.8)	12 (24.5)	12 (24.0)	13 (26.0)
Madrid, *n* (%)	37 (24.8)	12 (24.5)	13 (26.0)	12 (24.0)
Sevilla, *n* (%)	38 (25.5)	13 (26.5)	12 (24.0)	13 (26.0)
Valencia, *n* (%)	37 (24.8)	12 (24.5)	13 (26.0)	12 (24.0)

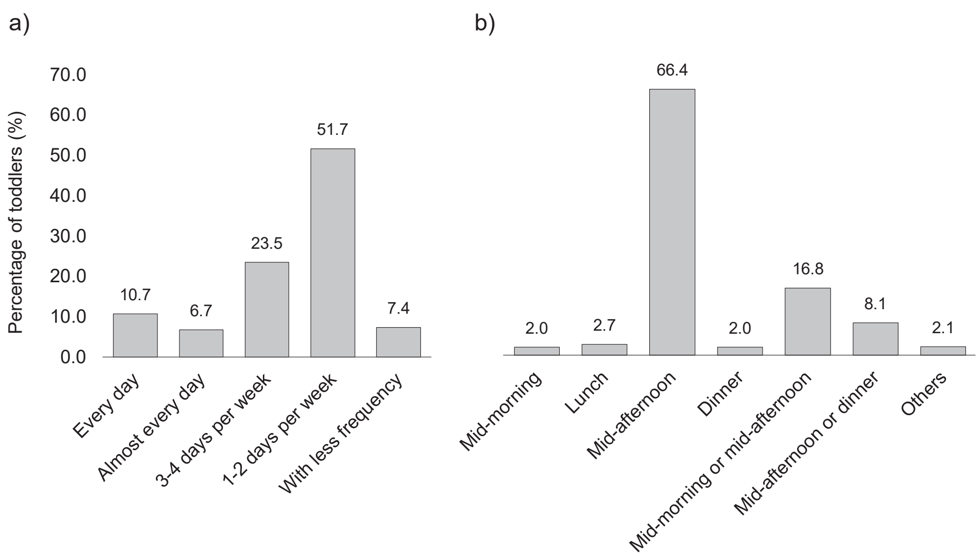


Figure 6.2. *a) Usual frequency of consumption yogurt pouch or a similar product, and b) Moment of the day at which such product is mostly provided. Multiple answers were possible. "Others" included "Breakfast or mid-afternoon", "Breakfast or lunch or mid-afternoon or dinner", and "Lunch or dinner". Exclusively "Breakfast" was not mentioned.*

6.3.2 Sensory evaluation

The reformulated recipes of two yogurt pairs (A-B and C-D) scored slightly, but significantly, lower on acceptability both in toddlers and their parents (**Figure 6.3**).

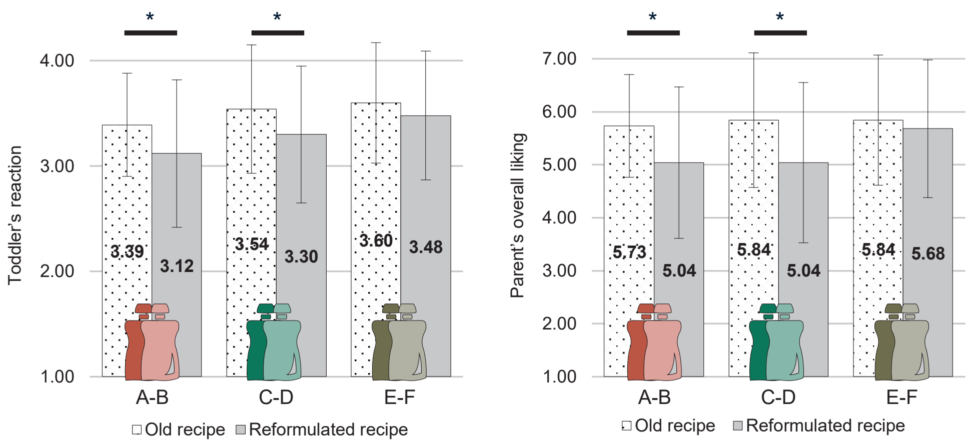


***Figure 6.3.** Toddler's reaction and parent's overall liking. *significant at $P<0.05$.*

The estimated and relative intake in toddlers were also found to be significantly different between the old and reformulated recipes of yogurt pair A-B, but not for the other two yogurt pairs (**Table 6.5**).

Taste and sweetness of the reformulated recipe of yogurt pair A-B were liked less by parents, as well as taste, sweetness, sourness and texture of the reformulated recipe of yogurt pair C-D. No significant differences in acceptability were found for yogurt pair E-F. Although small differences in acceptability between old and reformulated recipes were found, all reformulated recipes were highly accepted by toddlers and their parents with mean scores for each of the recipes of >3 and >5, respectively.

In addition, as shown in **Figure 6.4a**, >90% of toddlers had either a positive or very positive reaction to all recipes. The estimated intake was high (>68% of toddlers consumed the yogurt pouches entirely, see **Figure 6.4b**), and the relative intake was most often similar to usual intake (**Figure 6.4c**).

6.3.3 Evaluation of the ingredient list and purchase intention

Ingredient lists were perceived very positive as the mean rating was >4 for all recipes as depicted in **Table 6.6**, meaning that in general parents agreed with the statement that ingredient lists were acceptable. No significant differences between the old and refor-

Table 6.5. *Toddler's overall acceptability (toddler's reaction, estimated intake, and relative intake) and parent's overall liking and evaluation of key sensory attributes of the three yoghurt pairs.*

Yogurt pair	Variable	Old recipe	Reformulated recipe	*P*-value
Toddlers				
A-B	Toddler's reaction	3.39 ± 0.49	3.12 ± 0.70	**0.026**
	Estimated intake	4.76 ± 0.52	4.45 ± 0.96	**0.010**
	Relative intake	3.04 ± 0.29	2.84 ± 0.59	**0.040**
C-D	Toddler's reaction	3.54 ± 0.61	3.30 ± 0.65	**0.009**
	Estimated intake	4.62 ± 0.90	4.42 ± 0.99	0.151
	Relative intake	3.04 ± 0.53	2.86 ± 0.53	0.083
E-F	Toddler's reaction	3.60 ± 0.57	3.48 ± 0.61	0.182
	Estimated intake	4.60 ± 0.86	4.56 ± 0.86	0.659
	Relative intake	3.24 ± 0.74	3.08 ± 0.67	0.185
Parents				
A-B	Overall liking	5.73 ± 0.97	5.04 ± 1.43	**0.002**
	Aroma	5.63 ± 1.25	5.48 ± 1.17	0.459
	Taste	5.96 ± 1.21	5.20 ± 1.61	**0.002**
	Sweetness	5.88 ± 1.25	5.35 ± 1.60	**0.023**
	Sourness	5.49 ± 1.23	5.16 ± 1.60	0.191
	Texture	6.00 ± 1.24	5.78 ± 1.25	0.094
C-D	Overall liking	5.84 ± 1.27	5.04 ± 1.51	**0.003**
	Aroma	5.90 ± 0.95	5.74 ± 1.08	0.344
	Taste	6.12 ± 1.10	5.38 ± 1.50	**0.002**
	Sweetness	5.92 ± 1.29	5.16 ± 1.66	**0.002**
	Sourness	5.84 ± 1.28	4.90 ± 1.88	**0.001**
	Texture	6.06 ± 1.38	5.52 ± 1.68	**0.029**
E-F	Overall liking	5.84 ± 1.23	5.68 ± 1.30	0.290
	Aroma	6.26 ± 0.99	6.16 ± 1.08	0.341
	Taste	6.12 ± 1.06	6.04 ± 1.16	0.542
	Sweetness	5.92 ± 1.41	5.74 ± 1.32	0.322
	Sourness	5.76 ± 1.24	5.64 ± 1.44	0.402
	Texture	6.14 ± 1.25	5.88 ± 1.49	0.156

P-values in bold are significant; Toddler's reaction on a 4-point hedonic scale: 1 = "very negative" to 4 = "very positive"; Estimated intake on a 5-point scale: 1 = "less than ¼" to 5 = "the entire portion"; Relative intake on a 5-point scale: 1 = "a lot less than usual", to 5 = "a lot more than usual"; Parent's overall liking and key sensory attributes on a 7-point Likert scale: 1 = "dislike very much" to 7 = "like very much".

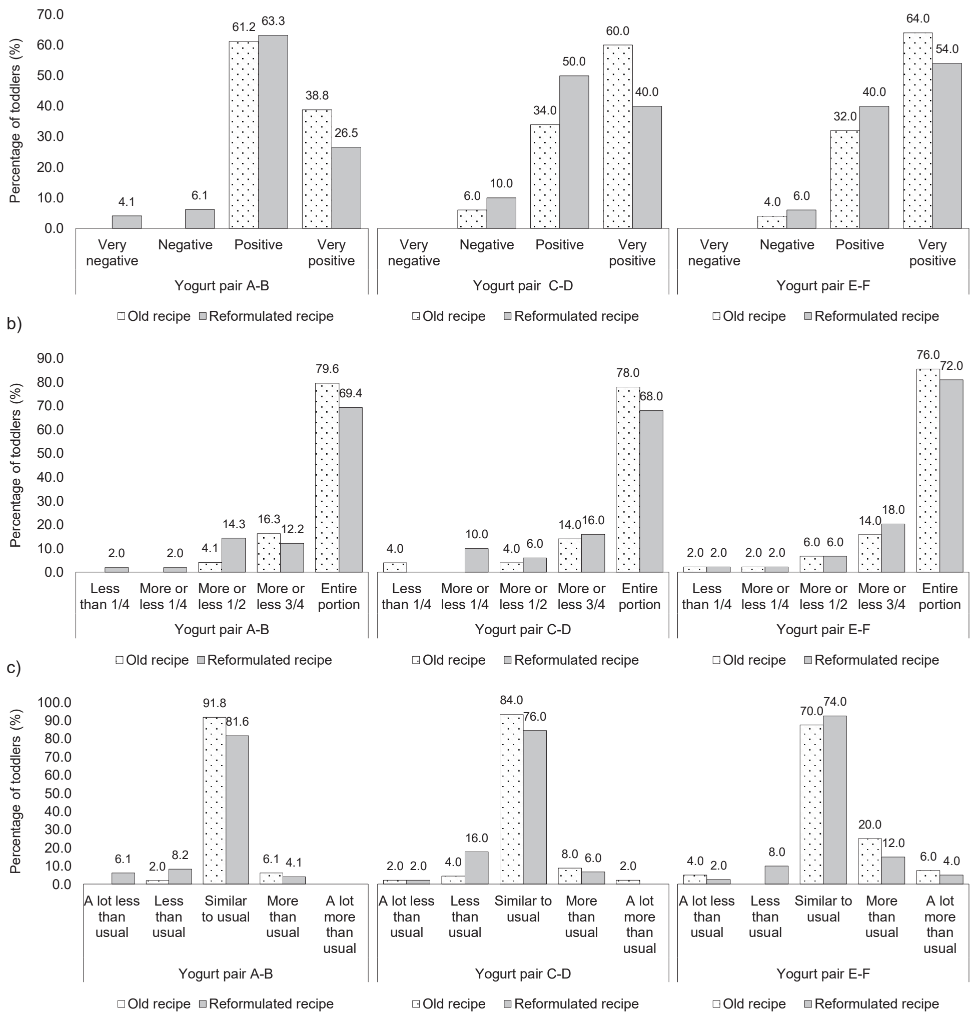


***Figure 6.4**. Toddler's overall acceptability expressed in frequencies (%); a) Toddler's reaction; b) Estimated intake; c) Relative intake.*

mulated recipes were found. Neither were significant differences found on purchase intention ratings, which were high for all recipes (ranging from 3.90 to 4.66).

We analyzed the reasons provided by parents to justify their numerical evaluation (from 1 to 5) of the acceptability of the ingredient list (**Table 6.7** shows a summary of the findings). We found that lower levels of acceptability (1 and 2 scores) of the old ingredient lists were mainly motivated by the addition of sugar. For example, one subject argued that the ingredient list was not acceptable at all because "it has sugar and I just don't like

Table 6.6. *Ingredient list acceptability and purchase intention.*

Yogurt pair	Variable	Old recipe	Reformulated recipe	*P*-value
A-B	Ingredient list	4.20 ± 0.76	4.08 ± 1.06	0.485
	Purchase intention	4.37 ± 0.70	4.08 ± 1.08	0.109
C-D	Ingredient list	4.16 ± 0.91	4.18 ± 0.85	0.896
	Purchase intention	4.14 ± 1.08	3.90 ± 1.16	0.219
E-F	Ingredient list	4.46 ± 0.76	4.50 ± 0.76	0.755
	Purchase intention	4.52 ± 0.84	4.66 ± 0.69	0.322

Ingredient list: "All in all, I find this an acceptable ingredient list", referring to the list as a whole, on a 5-point scale ranging from 1 = "totally disagree" to 5 = "totally agree". Purchase intention: "If this product with these ingredients was available in your usual store, at a price similar to that of the competition, would you buy it?", on a 5-point scale ranging from 1 = "definitely wouldn't buy it" to 5 = "definitely would buy it".

my child's diet containing sugar". Interestingly, one mother argued: "It has a lot of sugar and little fruit". Others also noted that the old recipes had non-natural ingredients (e.g., "Some ingredients are unnatural and not acceptable for the age the product is targeted to". On the contrary, high levels of acceptability of the reformulated recipe (4 and 5 scores) were found among parents who positively valued the naturalness of the product and the elimination of sugar. Some examples follow: "The best thing is that it does not have preservatives or additives, it is a natural product", "It is a natural product, with no sugar". Parents providing high acceptability of the old recipes (4 and 5 scores) noted their greater variability and complete list of ingredients and good flavor. However, some parents considered the reformulated recipes (particularly B[8]) as not acceptable because of the high percentage of apple which is likely to lead to acid taste. In addition, a few parents highlighted that both old and reformulated ingredient lists were appropriate as they did not contain palm oil or gluten.

6

Table 6.7. *Reasons to justify high and low acceptability of old and reformulated ingredient lists.*

	Old (longer) ingredient list	Reformulated (shorter) ingredient list
High acceptability (4 and 5 scores)	(+) Good flavor (+) Varied ingredients	(+) Natural ingredients (+) No added sugar
Low acceptability (1 and 2 scores)	(-) Presence of added sugar (-) Presence of preservatives and additives	(-) Acid taste due to high apple content (only in recipe B)

8 In fact, upon further examination, as shown in Table 6.6, recipe B is the only reformulated recipe whose acceptability of the ingredient list (4.08) is lower than its old counterpart (4.20).

6.4 Discussion

This study examined the extent to which reformulated yogurt pouches with a better nutritional profile (i.e., lower sugar content) and less processed ingredients were sensory accepted by toddlers and their parents in comparison to the previous/old recipes. Three pairs of pouches (old versus reformulated recipes) with different ingredient lists were tested. In the reformulated recipes, fruit concentrates were replaced by fruit purees, and added sugar was eliminated. 150 parent-toddler (1-4 years) dyads, from four major cities in Spain were included in a 4-day double-blind randomized cross-over study. Several research, social and practical implications can be derived from the current study.

6.4.1 Research implications

Our results offer new insights which substantially add to the literature on consumer sensory evaluation of food product reformulations. In particular, we found that all reformulated recipes were highly accepted by toddlers and their parents. Nevertheless, reformulated recipes B and D (which implied a sugar reduction of 30 and 28%, respectively) scored significantly lower in toddler's reaction, parent's overall liking and in other sensory attributes evaluated by parents (i.e., taste, sweetness). Reformulated recipe B also scored significantly lower in toddler's estimate and relative intake. On the contrary, reformulated recipe F (which implied a sugar reduction of 23%) was equally accepted as compared to the old recipe, both in toddlers and their parents, in all measures included in the study. Interestingly, prior evidence with adult samples shows that sugar reductions higher than 28% are not well accepted by consumers (Biguzzi et al., 2015; Markey et al., 2015; Oliveira et al., 2015), while our findings indicate that sugar reduction up to 30% is well accepted by toddlers.

We also contribute to the existing literature by testing how the simultaneous reduction in sugar content and number of processed ingredients influence consumers' evaluation of the ingredient list and purchase intentions. Our results proved to be meaningful and quite interesting. More specifically, ingredient list evaluation and purchase intentions of reformulated recipe F and its old counterpart E were not significantly different (in fact, both consumer's measures were higher in the reformulated yogurt pouch). This is reasonable given that sensory acceptability was not different between them (E and F). Surprisingly, despite the lower sensory scores of reformulated recipes B and D (in comparison to their old versions A and C, respectively), there were no significant differences between old and reformulated yogurt pouches in terms of ingredient list acceptability and purchase intention. This can probably be explained by a pattern where hedonic liking of foods interacts with credence attributes (i.e., healthiness, naturalness), which cannot be objectively evaluated by consumers, to influence consumers' attitudes and purchase intentions (Fernqvist & Ekelund, 2014). But more importantly, our results are consistent to previous research which evidences that even though taste is a major driver of consumer food choice (Grunert, 2002), consumers (and in our case parents) are willing to compromise on hedonic and sensory characteristics of food products as long as they are healthier and more natural (Hjelmar, 2011; Román & Sánchez-Siles, 2018). This seems to be particularly the case for infant and toddler food, given its importance for children's future development and growth. For example, one mother interviewed in Hjelmar's (2011, p.340) qualitative study argued that: "Before we had children we just bought the cheapest. Now we need to take health considerations, we also bought less organic products before". In addition, our findings are in line with the "clean label" trend which emphasizes the consumer's preference for simple ingredient listing and the absence of processed, artificial, unnatural or chemically perceived ingredients (Aschemann-Witzel et al., 2019; Asioli et al., 2017; Bearth et al., 2014; Román et al., 2017).

Finally, our study further adds to the literature on sensory reactions to food product reformulations by focusing on a highly vulnerable segment of the population (toddlers) which has received hardly any attention from scholars in the past.

6.4.2 Social and practical implications

Infants' and toddlers' innate preference for sweet taste is likely to be strengthened with repeated intake and exposure. Given the current market success of baby food pouches, it is imperative that food manufacturers significantly reduce their sugar content. Our results indicate that a reduction in the sugar content of baby yogurt pouches is well-accepted by consumers. Also, these sugar reductions are more effective in terms of consumers' purchase intentions if they are simultaneously implemented with a reduction in the number of processed ingredients. In addition, in their reformulations towards healthier and more natural pouches, food manufacturers could consider reducing the number of additives and unnecessary/unexpected ingredients as well as prioritizing the use of organic raw materials, minimal processing technologies and sustainable packaging (Michel et al., 2021; Sanchez-Siles et al., 2019).

Furthermore, our study shows that yogurt pouches are mostly given during mid-afternoon, also known as "merienda" (snack) time in Spain. Reformulation of baby snacks towards healthier products is thus especially important in view of the current "snackification" trend, where snacking is increasing and boundaries between snacks and meals have been blurred (Mintel, 2018). In any case, we encourage moderate pouch consumption which has not been associated with excess weight in prior research (Lundkvist et al., 2021). Food pouches have to be understood as an addition to the child's diet rather than their primary form of nutrition (Pérez-Escamilla et al., 2017). It is important that smooth foods such as pouches are balanced with lumpy foods or finger foods, and when possible, the content of the pouch should be squeezed into a bowl or straight onto a spoon to facilitate the development of eating skills (Cichero, 2016, 2017) and to minimize the risk of dental caries (Koletzko et al., 2019). This is in line with the draft Nutrient Profile Model for infants and young children between 6-36 months from the WHO, where it is proposed that food packaging with a spout should state clearly "Infants and young children must not be allowed to suck directly from the pouch/pack/container" (World Health Organization, 2019b, p.9).

On a final note, we encourage the food industry to be completely transparent in their labeling of foods aimed at infants and young children in order to avoid confusion among parents. This implies to use product names which correspond to the main ingredients of the product. Unfortunately, there is evidence of misleading labeling in baby food in many countries (Ferrante et al., 2021; Katiforis et al., 2021; Tedstone et al., 2019; World Health Organization, 2019a). For instance, Katiforis et al. (2021, p.14) analyzed food pouches sold in New Zealand and found one "containing less than 5% spinach, spinach appeared first in the product name, implying that the largest quantity ingredient was spinach when it was in fact apple". In line with these findings, another study found that dark green vegetables were more likely to be included in the product's name, in comparison to other vegetables, even though quantities were not representative (Ferrante et al., 2021).

6.4.3 Limitations and future research opportunities

We tested three different sugar reductions (23%, 28% and 30%) on yogurt pouches. Given the scarcity of research conducted on infants and toddlers and the importance of feeding at this stage of life, further research is needed on other commercially available food products addressed to young children such as jars, biscuits, bars and other snacks. Additionally, higher levels of sugar reduction could be tested to determine the maximum threshold of reduction before negative reactions are generated. Following previous extant research, toddlers' reactions were subjectively evaluated by their parents through a 4-point hedonic scale which might be subject to bias. Future research could explore further methodologies which may reduce bias in sensory research with infants and toddlers. Also, we have not recorded how parents fed their child (directly from pouch or by spoon). Given that the use of a spoon is highly recommended, it would be interesting to investigate the extent to which parents actually use it. This would provide valuable insights as to when (in which occasions) and where the spoon is being used (e.g., indoors versus outdoors). Furthermore, there are limitations in comparing results across the three yogurt pair groups that need to be addressed.

It is worth noting that the draft Nutrient Profile Model report from the WHO recommends a limited use of fruit purees as an ingredient in commercial baby foods, particularly in savory foods, yogurts, and other desserts. The report also recommends that an age restriction of 6-12 months should apply to fruit puree with or without addition of vegetables, cereals, or milk (World Health Organization, 2019b). Hence, further studies on these types of products should focus on 6-12 month-old infants. We have conducted the study in toddlers 12+ months of age following the Spanish recommendations to introduce yogurt from the age of 12 months (small quantities can be given from 9 or 10 months and onwards) (Gómez, 2018).

Lastly, we measured consumers' purchase intentions which may not correspond to their final behavior. Thus, further studies would benefit from including actual purchases. Several interesting insights were obtained when asking parents about the acceptability of the ingredient lists. However, these findings were restricted by the use of a single open question. Further qualitative studies with consumers thorough in-depth interviews and/or focus groups on this topic could prove fruitful.

6.5 Conclusions

Contemporary packaging such as pouches represent a departure from traditional baby foods (e.g., jars) and given their current and expected market penetration, they have the potential to dramatically change how solid foods are eaten in infancy and early childhood. Pouches have been criticized, among other things, for their high sugar contents and ingredient list. This study examined how product reformulations towards healthier (lower sugar levels) and more natural (fewer processed ingredients) influenced toddlers and parents' sensory acceptability. Parents' evaluation of the ingredient list and purchase intentions were also assessed. The reformulation of food products represents a huge challenge for food manufacturers. Our findings suggest that a reduction of sugar content up to 30% along with a reduction in the number of processed ingredients can be a realistic approach which might not jeopardize market acceptance.

CHAPTER 7

General Discussion

This thesis aimed to gain a better understanding of healthiness and naturalness in the formulation of snacking products – a growing and trending product category that resonates with the increasing trend known as "Snackification". The first part of the thesis explored trends in snacking and focused on (cereal) snack bars. The second part of the thesis focused on snacks and cereals for babies and children. In this chapter I will provide a summary of the main findings presented in this thesis and put them in context of previous research. Also, I will reflect on the implications for practice and the research methodologies, and provide directions for future research.

7.1 Summary of the main findings

In **Chapter 2**, production methods, current and emerging market trends, and practical implications for the development of cereal bars were investigated. Cereal bars were shown to be a versatile type of snack, that besides cereals, may contain a wide variety of different ingredients. Health and well-being, naturalness, sustainability, and convenience are current trends that are here to stay, with many implications for new product development. In a nutshell, nutritionally well-designed cereal bars with few but recognizable ingredients, coinciding with the Planetary Health Diet, and with a desired texture and taste, are the way to go for manufacturers to meet consumer demands. Yet, there is no one size fitting all, and product customisation and personalised nutrition will be essential in the future of nutrition. That cereal bars have been shown to be a versatile type of snack was confirmed in **Chapter 3**, in which cereal bars were compared to chocolate bars. Although cereal bars varied greatly in terms of healthiness and naturalness, they were a healthier and more natural alternative to chocolate bars. Still, cereal bars were notably high in sugar and saturated fat, and they contained long lists of ingredients, of which many were processed – making them quite unnatural snack items. In cereal and chocolate bars, healthiness and naturalness were only weakly correlated, implying they are different aspects of food in this category.

Complementary to Chapter 3, in **Chapter 4** we evaluated healthiness and naturalness in another snack category (biscuits) and compared this type of snack between three different target populations (i.e., babies, children, and adults). Baby biscuits were a healthier and more natural alternative to children and adult biscuits, although energy density and sugar levels need improvement. Children biscuits were nutritionally poor and the least natural of the three target populations, mainly due to the presence of a higher number of additives. As nutrition in childhood is of paramount importance for health, we reviewed the type, quantity, degree of processing, and health benefits of whole grain infant cereals in **Chapter 5**. Whole grains are full of fibre, vitamins, minerals, and other bioactive components that exert many health-promoting effects. Whole grains should be incorporated in the diet as early as possible, however, a lack of unified intake recommendations in infancy, high natural and process contaminants, and sensory appeal are challenges that need to be addressed. Sensory acceptance of consumers is key, hence, in **Chapter 6** we examined how product reformulations of baby yoghurt pouches in terms of a reduction in sugar content and number of processed ingredients (i.e., healthier and more natural products) influenced toddlers' and their parents' sensory acceptability. Two of three reformulated yogurt recipes scored slightly lower on acceptability, while there was no observed difference in acceptability for one yogurt pair. Even though acceptability was found to be lower for two recipes, the results showed that all reformulated recipes were still highly accepted by both toddlers and their parents.

The observed results of this thesis can be divided in two main areas of Snackification: 1) trending snacks – the case of (cereal) snack bars, and 2) baby and children's snacks and cereals. The findings in each of these areas will be discussed below and an overview is presented in **Figure 7.1**.

Chapter 2: Current and emerging trends in cereal snack bars	▪ Cereal are a versatile snack with a wide variety of different ingredients. ▪ Nutritionally well-designed cereal bars with few but recognizable ingredients, coinciding with the Planetary Health Diet, and with a desired texture and taste, are the way to go for manufacturers to meet consumer demands.
Chapter 3: Healthiness and naturalness of cereal and chocolate bars	▪ Cereal bars varied greatly in terms of healthiness and naturalness. ▪ Cereal bars were a healthier and more natural alternative to chocolate bars, but both aspects need improvement. ▪ In these bars, healthiness and naturalness were only weakly correlated.
Chapter 4: Healthiness and naturalness of baby, children, and adult biscuits	▪ Baby biscuits had the best nutritional quality and were the most natural as compared to children and adult biscuits. ▪ Energy density and sugar levels of baby biscuits need improvement. ▪ Nutritional quality of children biscuits was low and comparable to that of adult biscuits. ▪ Children biscuits were the least natural, mainly due to their higher number of additives.
Chapter 5: Current status, challenges, and future opportunities for whole grains	▪ Whole grains are full of fibre, vitamins, minerals, and other bioactive components that exert many health-promoting effects. ▪ Whole grains should be incorporated in the diet as early as possible. ▪ Challenges for manufacturers are the lack of unified intake recommendations in infancy, high natural and process contaminants, and sensory appeal.
Chapter 6: Acceptance of healthier and more natural reformulated baby food pouches	▪ All healthier and more natural reformulated yogurt recipes were highly accepted by toddlers and their parents. ▪ Two of three reformulated yogurt recipes scored slightly lower on acceptability. ▪ There was no observed difference in acceptability for one yogurt pair.

Figure 7.1. *Overview of key findings per Chapter.*

7.2 Healthiness and naturalness in trending snacks – the case of (cereal) snack bars

Mega-trends such as the rapid urbanisation shape the need for convenience food solutions (Nielsen, 2018), which in turn emphasize the trend towards snacking of ready-to-eat food products. Cereal bars are such common ready-to-eat snack foods, that also respond to consumers' growing health and natural consciousness (Pallavi et al., 2015). Indeed, as shown in **Chapter 2**, health and well-being, naturalness, sustainability, and convenience are the main trends in new product development of cereal bars. A study by Crofton et al. (2013) showed that consumers expect a healthy snack to be low in calories, (saturated) fat, salt, and sugar and to be free from artificial colours, sweeteners, and flavours. Snacks, including cereal bars, that contained ingredients such as whole grains, fruit, oats, bran, nuts, seeds, raisins, legumes, or flaxseed, were perceived as healthy. In line with these consumer expectations and perceptions, cereal bars were shown in **Chapter 3** to be a healthier and more natural alternative to chocolate bars (**Table 7.1**). Nevertheless, healthiness of cereal bars varied greatly with Nutri-Scores ranging from B to E and a predominant Nutri-Score D, which is consistent with previous findings (Curtain & Grafenauer, 2019; Dréano-Trécant et al., 2020). Likewise, the degree of naturalness of cereal bars was quite diverse, ranging from a Food Naturalness Index of 1.3 to 4.0 but with a low average of 2.0 (slightly natural). Similar findings to ours were also found in a recent study by Sanchez-Siles et al. (2022). In their case study on snack bars, wherein healthiness and naturalness were also measured through Nutri-Score and the Food Naturalness Index, cereal bars scored divergent on both aspects. Compared to protein bars, fruit bars, and nut/seed bars, cereal bars scored the weakest nutritional quality, and after protein bars, worst on naturalness (Sanchez-Siles, Román, Fogliano, et al., 2022). Cereal bars may be manufacturers' answer to the changing consumer demand for food products with health-promoting ingredients in the confectionery market (Kosicka-Gębska et al., 2022), but manufacturers can only stay successful and competi-

Table 7.1. *A comparison of healthiness and naturalness between cereal and chocolate bars (Chapter 3). ↓: significant lower value, ↑: significant higher value, ↔: no significant difference.*

		Cereal bars (*n*=50)	**Chocolate bars (*n*=50)**
Healthiness	Nutri-Score	0% A 12% B 22% C 50% D 16% E	0% A 0% B 0% C 0% D 100% E
	FSAm-NPS score	↓	↑
	Energy	↓	↑
	Saturated fat	↓	↑
	Sugars	↓	↑
	Fibre	↑	↓
	Protein	↔	↔
	Sodium	↔	↔
Naturalness	Food Naturalness Index	↑	↓
	Farming practice	96% conventional 4% organic	100% conventional 0% organic
	Number of Additives	↔	↔
	Number of Unnecessary/unexpected ingredients	↓	↑
	Number of Processed ingredients	↔	↔
	Total number of Ingredients	↑	↓

tive if product reformulation or innovation is applied (Crofton et al., 2013) to improve the health, natural, and sustainable aspects of cereal bar formulations in line with the current and emerging trends.

So, how can these trends be addressed in the formulation of cereal bars? The discussed trends may have many practical implications for manufacturers (**Figure 7.2**). Considering that two phases (the solid phase and binding phase) can be distinguished in the composition of cereal bars, there may be several ways to improve their healthiness and naturalness.

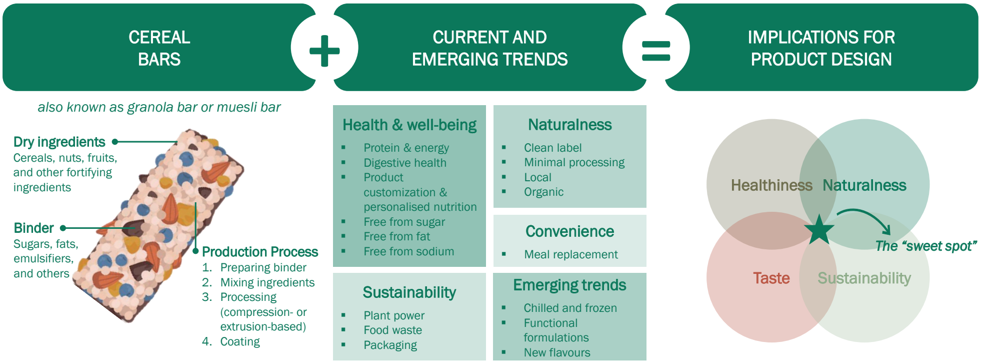


Figure 7.2. *Overview of main findings Chapter 2. A cereal bar consists of a solid phase (dry ingredients), a binding phase, and production phase. To meet market trends and consumer demand, future formulations should be improved by balancing healthiness (i.e., nutritional quality), naturalness, sustainability, and sensory aspects.*

7.2.1 Addition of functional ingredients

First, the basic cereal matrix and fortifying ingredients can be addressed. This part of the cereal bar could be improved by the addition of whole grain cereals such as oat, rye, or barley instead of refined cereals. Using whole grains would foster nutritional quality and the degree of naturalness (Sanchez-Siles et al., 2019), and its consumption is in line with the Planetary Health Diet (Willett et al., 2019). To address both the sustainability and protein fortification trends, refined grains could also be partially substituted by legumes. Besides, the addition of legumes would be a good way to reduce the environmental impact enforced by reliance on animal-based protein sources, such as milk powder (Tas & Shah, 2021). Emerging trends could be captured by the addition of innovative and functional ingredients that are well documented in literature. For example, omega-3 or probiotics are feasible ways to enhance the functionality of a cereal bar. Omega-3 is known to exert many health benefits such as supporting cardiovascular, brain, and immune health (Shahidi & Ambigaipalan, 2018). In many regions of the world the population has very low EPA and DHA blood levels (Stark et al., 2016), so fortifying cereal bars with (microencapsulated) omega-3 oils from either flaxseed, fish, or microalgae, would be a great opportunity to increase omega-3 intake (Hernandez, 2013). Increasing evidence is also showing the positive effects of probiotics on digestive and immune health (Anaya-Loyola et al., 2019; Kalman et al., 2009). While vegetative probiotics are very fragile, spore-forming probiotics like *Bacillus coagulans* or *Bacillus subtilis* carry a natural protective outer layer which makes them highly stable during processing. Such probiotics would be suitable to add to the cereal matrix, as they can survive most manufacturing processes and do not require refrigeration (if water activity a_w<0.75) (Elshaghabee et al., 2017).

7.2.2 Alternative ingredients

Second, the binder is a crucial part of cereal bars. The analysis of the nutritional composition of cereal bars in the European and North American markets in 2018-2020 as well as the analysis of the top 50 best-selling cereal bars in the German market in 2019 (**Chapter 2 and 3**) indicated that levels of sugar and saturated fat were on the higher end. Following the World Health Organization that encouraged the industry to reduce these "unhealthy" nutrients to promote healthy diets (World Health Organization, 2020), and to be in line with the sub-trends "free from sugar" and "free from fat", strategies to reduce their contents in cereal bars need to be implemented. **Chapter 3** showed that many cereal bars contain highly processed sugars such as glucose or glucose-fructose syrups in their binder that not only contribute to the high sugar levels, but also reduce the degree of naturalness as they are regarded as unnecessary/unexpected and processed ingredients (Sanchez-Siles et al., 2019). Sugar alternatives that 1) reduce sugar content, 2) are perceived as natural, and 3) bind and aggregate the different ingredients, are desired but challenging to find. A common sugar alternative that complies with those requirements and which is currently already being applied in many cereal bars in the market is prebiotic fibre. Prebiotic fibres like oligofructose or inulin have low glycaemic indices, may reduce sugar, are extracted from nature (e.g., chicory root, agave), and have great texturizing properties (Franck, 2002; Schaafsma & Slavin, 2015). Digestive and cardiovascular health benefits of their consumption have been reported in literature, ranging from stimulating the growth of beneficial gut bacteria, to lowering blood cholesterol levels (Meyer & Stasse-Wolthuis, 2009; Teferra, 2021). However, the denomination of this ingredient in the ingredient list requires attention. "Oligofructose" or "fructo-oligosaccharides" may be perceived by consumers as less natural and less attractive as compared to "chicory root fibre" or "agave fibre". Furthermore, maltitol was found to be the most common sweetener in cereal bars, being the fourth most used additive. Although maltitol is a perfect replacer for sugar due to the similarity of the physicochemical features (Saraiva et al., 2020a), it is still recognized as an additive (E965) which decreases the naturalness of the bar. Promising sugar alternatives for cereal bars that might favour consumer naturalness appeal are rare sugars like monk fruit and allulose. However, these alternatives have not been approved in Europe yet (FoodNavigator, 2021; Mahato et al., 2021). Besides sugar, the saturated fat content in the binder's formulation needs attention. Coconut fat and palm oil were often used fats in cereal bars. However, consumers are increasingly demanding palm oil free products. Fats like coconut oil may have a perceived health advantage over palm oil but contain a similar or even higher level of saturated fatty acids (Hinrichsen, 2016). Rapeseed, sunflower, or soy bean oil are lower in saturated fats (Parsons et al., 2020), but have a lower stability in terms of oxidative degradation (Hinrichsen, 2016). So, depending on the matrix of the cereal bar, manufacturers need to choose the best solution taking into account technical feasibility (i.e., textural properties), healthiness (i.e., saturated fat content), sustainability, and costs.

Third, to increase perceived and objective naturalness of cereal bars, manufacturers should ask themselves first whether all ingredients in the current recipes are genuinely needed. Is a blend of three types of sugar syrups necessary? Could the number of additives be reduced, or even fully eliminated? A next step would be to find more natural alternatives for the essential ingredients, for example, dried fruits instead of fruit powders or concentrates, natural flavours instead of artificial ones, and natural sugars instead of highly processed sugars (Sanchez-Siles et al., 2019).

To conclude, cereal bars are an excellent vehicle to modulate the food matrix, where ingredients with different structures and functionalities can be included at different levels of processing. New product developments should take advantage of the versatility of cereal bars; there are so many opportunities to develop healthy, natural, and sustainable cereal bars with a great taste and texture that responds to the market trends and consumer demands. As compared to the development of new product, reformulation of existing recipes might pose a bigger challenge as sensory qualities need to be maintained and costs need to be controlled. For example, the 50 best-selling cereal bars in **Chapter 3** accounted for >50% of the total market share – with millions of bars sold per year. Habitual consumers of these bars might notice the difference of an altered product that is healthier and/or more natural but tastes worst or costs more (Drewnowski et al., 2022). However, a few cereal bars in our sample have shown that it is possible to design a healthier or more natural cereal bar that even belongs to the best-selling cereal bars in Germany. Those bars should function as clear examples, encouraging manufacturers to reformulate, even if it takes an investment in research, machinery and other production processes (Drewnowski et al., 2022).

7.3 Healthiness and naturalness in baby and children's snacks and cereals

Infancy and early childhood are the time periods where eating habits are formed (Nicklaus & Remy, 2013; Schwartz, Scholtens, et al., 2011). Thus, the provision of healthy and varied foods in this stage of life is of utmost importance. Prior research by Damen et al. (2019, 2020) showed in their studies on mother's values and considerations in snack providing, that healthiness was one of the most important drivers in mother's snack choice for their 2-7-year-old children. Nonetheless, all mothers in both studies mentioned that their child's preference played a key role in their snack choice too (Damen et al., 2020; Damen, Hofstede, et al., 2019). Biscuits have been shown to be frequently offered processed snacks to babies and children (Damen, Luning, et al., 2019; Demonteil et al., 2019; Moore et al., 2019). We therefore examined and compared the nutritional and natural profile of baby, children, and adult biscuits. Using data from 1280 biscuits sold in the German, Dutch, Spanish and UK markets, we observed that baby biscuits (<3 years) were the healthiest and most natural of the three target groups, although energy density and sugar levels were still quite high and should be improved (**Table 7.2**).

Table 7.2. *A comparison of healthiness and naturalness between baby, children, and adult biscuits (Chapter 4). ↓: significant lower value, ↓↓: significant lower value compared to ↓, ↑: significant higher value, ↑↑: significant higher value compared to ↑, ↔: no significant difference.*

		Baby biscuits (*n*=85)	**Children biscuits (*n*=97)**	**Adult biscuits (*n*=1098)**
Healthiness	Energy	↓	↑	↑
	Fat	↓	↑	↑↑
	Saturated fat	↓	↑	↑↑
	Carbohydrates	↓	↑↑	↑
	Sugars	↓	↑	↑↑
	Fibre	↔	↔	↔
	Protein	↑	↓	↓
	Salt	↓	↑↑	↑
Naturalness	Food Naturalness Index	↑	↓↓	↓
	Farming practice	50.6% pesticide controlled 49.4% organic pesticide controlled	93.8% conventional 6.2% organic	80.9% conventional 19.1% organic
	Number of Additives	↓	↑↑	↑
	Number of Unnecessary/ unexpected ingredients	↓	↑	↑
	Number of Processed ingredients	↓	↑↑	↑
	Total number of Ingredients	↓	↑	↑

Although **Chapter 5** emphasized that the introduction of whole grain infant cereals instead of refined infant cereals during the complementary feeding is imperative for short and longer-term health goals, three quarter of baby biscuits in **Chapter 4**'s sample were made from refined grains. To increase both healthiness and naturalness in a biscuit's formulation, manufacturers should step up their game and replace (part of) refined grains for whole grains. Furthermore, regarding the nutritional quality of commercially available baby foods, the sweet taste profile and high content of total and added sugars have been the most debated topics for years. Scholars express their concerns, and urgently demand a change in their formulations (Garcia et al., 2020; Hutchinson et al., 2021). In response, manufacturers attempt to reformulate their products. Previous research showed that compared to 2017, in 2021 baby snacks were significantly reduced in sugar and salt content (Curtis-Davis et al., 2022). Cutting out added sugar may be fairly easily to do in most baby foods, however, for baby biscuits it might be more challenging due to the structural and textural properties that sugar has (Buttriss, 2013; Mamat & Hill, 2018; van der Sman & Renzetti, 2019) and which according to legislation cannot be substituted by a sweetener (Commission Regulation (EC) No 1333/2008, 2008). We have shown that many manufacturers add a fruit juice concentrate to a biscuit's formulation instead of sugar. Although a fruit sugar (from concentrates) may be better perceived by consumers as compared to regular sugar (Sütterlin & Siegrist, 2015), it is equally considered as free sugar (EFSA Panel on Nutrition Novel Foods and Food Allergens (NDA) et al., 2022). Regardless of what type of sugar is being used, manufacturers should always be transparent about the use of sugars and most importantly, aim for the lowest levels possible.

Related to that, we tested how healthier and more natural reformulated recipes of baby yogurt pouches were perceived by toddlers and their parents as compared to the old recipes. The main changes between the old and reformulated recipes were the removal of added sugar, the replacement of fruit juice concentrates by fruit purees, and an overall decrease in sweetness. While previous literature showed that sugar reductions higher than 28% were not well-accepted by consumers (Biguzzi et al., 2015; Markey et al., 2015; Oliveira et al., 2015), our findings demonstrated that sugar reduction up to 30% was slightly less but still highly accepted (**Figure 7.3**). A reduction in sugar content of baby yogurt pouches is likely to result in minimal changes in their sensory characteristics and therefore still well-accepted by consumers. Such findings should encourage manufacturers to reformulate.

In the absence of standardised and up-to-date nutrition guidelines for commercially available baby foods, the World Health Organization's nutrient profile model for infants and young children 6–36 months in the European Region has been proposed (World Health Organization, 2022). This nutrient profile model is the result of a call-to-action

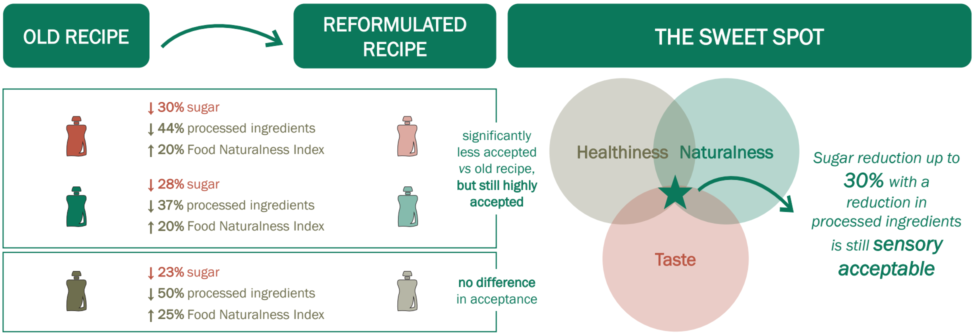


Figure 7.3. *The "sweet spot" between healthiness, naturalness, and taste. Reformulation towards healthier and more natural products without sacrificing sensory acceptance is achievable (Chapter 6).*

from all Member States to end the inappropriate promotion of foods for infants and young children. Indeed, existing guidelines and regulations for commercial baby foods are outdated and do not reflect the modern market (World Health Organization, 2019b), so updated mandatory legal regulations are undoubtedly needed to ensure extensive improvements in commercial baby foods. Nevertheless, some requirements of the nutrient profile model make it very difficult – if not impossible – to reformulate some of the existing product categories. For example, the strict prohibition of free sugars including 1) all mono- and disaccharides, 2) all syrups, nectars, and honey, and 3) fruit juices of concentrated/powdered fruit juice (excl. lemon or lime juice) would result in non-marketable biscuits. Such requirements are not motivating the industry to reformulate their products, and moreover, it may lead to a market gap that incites parents to purchase equivalent snacks designed for older children or adults that, as evidenced in **Chapter 4**, were of worse nutritional quality and were less natural.

Lastly, we found it quite alarming that those biscuits for older children (>3 years) were both from a nutrition and natural perspective poorly formulated (**Table 7.2**). Child-oriented biscuits were characterised by their high levels of sugar, saturated fat, and salt and long lists of ingredients, including many additives. This result may stem from the absence of legislation or nutrition guidelines for this specific age group. Unlike previous research that found clear associations between the presence of child-targeted cues (e.g., cartoons) and worse nutritional quality (Beltrá et al., 2020; Lapierre et al., 2016; Lythgoe et al., 2013; Machado et al., 2019), our study did not. Nonetheless, child-oriented biscuits were very similar to adult biscuits, and the substantial gap between baby and children biscuits warrants to be filled.

7.4 Implications for practice

Based on the findings of this thesis, there are several implications for practice. This paragraph describes the implications for the public health organizations, the industry, academia, governments, non-governmental organizations (NGOs) and consumers.

7.4.1 Public health organizations: recommendations and guidelines

Snacking recommendations are needed to guide the industry in their (re)formulation strategies to ultimately improve public health. However, clear and agreed upon science-based recommendations with regards to snacking do not exist. A review by Potter et al. (2018) on snacking recommendations worldwide acknowledged that existing guidelines varied a lot in nature both within and between countries. According to this elaborated review, guidelines are different in terms of the level of detail of food and drink products identified (e.g., “processed foods” or “cereal bar”), the focus on recommended foods *versus* discouraged foods, and the qualitative *versus* quantitative nature of the recommendations. To illustrate, in the Netherlands it is recommended to have maximum seven eating moments per day (of which three main meals) (Voedingscentrum, 2011), while in Brazil, for instance, it is discouraged to snack in between meals (Hess et al., 2016). Although snacking was found to be a prominent topic in many countries (Potter et al., 2018), the lack of agreed recommendations may be due to differences in cultures and eating habits between countries and regions. Even though an increase in snacking moments has been observed in France, the eating pattern is still centred around three traditional main meals commonly consumed at fixed hours every day (Saint Pol & Hébel, 2021). Similarly, Chinese adults seem to stick to eating three main meals and snack only occasionally (Mena et al., 2020). In other cultures, such as US and Australia, eating patterns are becoming less defined and snacking or “eating in-between meals” is gaining prominence (Kant & Graubard, 2015; Mena et al., 2020). While unravelling the reasoning for why snacking recommendations are so incoherent, we must acknowledge that they are heavily dependent on the definition used for snacks and snacking. Until now, such globally established definition is lacking, which impedes the interpretation of scientific literature (i.e., bias in research and incomparable research outcomes), and the development of practical recommendations for healthy snacking (Johnson & Anderson, 2010). Snacking is usually considered an impulsive and satisfying eating experience (Crofton et al., 2013). Nonetheless, it is evident that the concept of snacking has gradually shifted over the years. Previously, snacks were mainly associated with unhealthy “junk” foods (Hess et al., 2016), but research has shown that adequate, well-designed snacks may promote satiety and appetite control (Njike et al., 2016) and could fit perfectly within a healthy dietary pattern (Marangoni et al., 2019).

In this thesis we observed big differences, in terms of healthiness and naturalness, between and within snack categories. This implies that not all snacks should be considered equally in the attempt of drawing global snack intake recommendations. Based on different dimensions (e.g., moment, purpose, type, duration, context, portion, etc.), criteria that a food or drink must meet in order to be considered a snack should be established and aligned recommendations can be drafted by public health organizations accordingly. Such recommendations should in nature be similar and have the same level of detail across countries, but cultural differences in terms of food availability and eating habits should always be taken into account. Similarly, consistent recommendations concerning whole grain intake in infancy are absent too. Our findings showed that whole grain intake in early life is important, but to encourage the industry to incorporate whole grains at a wide scale, more guidance from public health authorities as to what the optimum quantity in infancy is, is required. Clear and aligned intake recommendations could support the industry to make accurate choices in producing products that meet public health demand.

7.4.2 The industry: new product development of snacks and infant cereals

Results obtained from this thesis are also useful for the snack industry. There are many trends and sub-trends evolving, and those trends have many implications for new product development. Incorporation of innovative and health-boosting ingredients to enhance nutrient composition, elimination of unnatural ingredients, reduction or total removal of "unhealthy" nutrients, or rethinking packaging and waste are only a few examples of implications for manufacturers suggested in this thesis. Positive results on the effects of reformulation towards healthier and more natural food products on sensory appeal obtained in this thesis indicate that food manufacturers should embrace, not avoid, reformulation.

To get a better understanding of how results of this thesis could be used for the industry, I would like to highlight some real-life examples from the industry. Until recently, the Spanish infant cereals market consisted mainly of refined and hydrolysed (i.e., with free sugars produced during manufacturing) cereals. There was an urge to nutritionally improve the current market offer, especially given the fact that cereals are one of the first foods given in Spain during the complementary feeding period – a crucial phase for the infants' short and longer term health (Klerks et al., 2021). Our ambition was to reformulate the refined and hydrolysed cereals by substituting part of the refined grains with whole grains (33% and 50%) and eliminating the hydrolysis step in the production phase (i.e., no free sugars produced during manufacturing). Previous research on the sensory acceptance of whole grains and sugar-reduced cereals in infancy (Haro-Vicente et al., 2017; Sanchez-Siles et al., 2020; Sanchez-Siles, Román, Haro-Vicente, et al., 2022), together with the evidence-based health benefits of whole grains as described in **Chapter 5**, have provided a solid basis for our ambition. In fact, the results of our research have supported the reformulation and communication of healthier infant cereals, which led to a revolutionary shift in the total Spanish infant cereals market that went from mainly refined and hydrolysed to whole grain and non-hydrolysed.

Research findings from this thesis served as a basis for multiple internal strategies but can certainly be extrapolated to the rest of the industry. For instance, Hero launched its Sustainability Strategy in 2020. The Sustainability Strategy entails 4 pillars, of which one is "Pillar 3: Naturally healthy food". The purpose of Pillar 3 is *"Conserving nature's goodness via naturally healthy food"*. Within Pillar 3, several goals were set per food category to endorse the United Nations Sustainable Development Goals for 2030 (United Nations, 2015). Pillar 3 goals include, among others, the increase of whole grains in our cereal snack bars and cereal-based baby and toddler foods/snacks (supported by results from **Chapters 2–5**), the elimination of fruit juice concentrates in pureed baby foods (supported by results from **Chapter 6**), and a reduction of sugar, saturated fat, and salt in our snack bars (supported by results from **Chapter 2 and 3**). An overview of all goals, including an indication of which chapter supports which goal, is shown in **Table 7.3**.

Table 7.3. *Goals set for Pillar 3 Naturally Healthy Food of Hero's Sustainability Strategy. Given the relevance of this thesis, only the goals set for Hero's categories Baby and Toddler Foods and Healthy Snacks categories are shown.*

Food category	Goal	Supported by Chapter:
Baby and Toddler Food	1. 55% of our meals offering to use non-meat proteins by 2025	-
	2. 55% of our products to be organic by 2025	4
	3. 75% of our cereals and snacks to contain whole grains (min. 30%) or legumes (min. 20%)	4 and 5
	4. 90% of our pureed products to be free from 1) starch and from 2) fruit concentrates by 2025	6
	5. 0% palm oil in our products by 2025	4
Healthy Snacks	6. 55% of our cereal bars to contain whole grains (min. 30%) and/or nuts (min. 40%) by 2025	2, 3 and 5
	7. Establish a range of fruit- or vegetable-based products by 2025	2
	8. A further 20% reduction in the use of "unhealthy" nutrients (sugar, saturated fat, salt)	2 and 3
	9. 100% of our products to use cocoa by 2025 & nuts by 2023 are from certified sustainable sources	2
	10. Minimize the use of palm oil to 10% of our offerings and any use from certified segregated sources by 2025	2 and 3

7.4.3 Academia, governments, NGOs, and consumers: clarification of misunderstood concepts

Two concepts were at the centre of this thesis, namely "healthiness" (i.e., nutritional quality) and "naturalness". However, the concept "degree of processing" was involved too since processed snacks were the topic of interest. The holistic nature of this thesis allowed for clarification of these three concepts that are often misunderstood, confused, or interchangeably used by academia, governments, NGOs and consumers (Petrus et al., 2021; Sadler et al., 2021; Sarmiento-Santos et al., 2022). In fact, consumers' perceptions of healthiness and naturalness are often related (Hartmann et al., 2018; Román et al., 2017), and processed foods are perceived as less healthy (Ares et al., 2016) and less natural (Battacchi et al., 2020; Carfora et al., 2021; Evans et al., 2010) as compared to minimal or unprocessed foods. A recent study on consumers' knowledge, understanding, and preferences of healthiness and naturalness of processed foods concluded that "consumers perceive that the more natural products are those that are less processed and are also the healthier ones" (Saulais et al., 2023). In line with consumer perceptions, ultra-processed foods are considered intrinsically unhealthy and unnatural according to the NOVA classification system developed by Monteiro et al. (2019). The NOVA classification has been the most applied classification system in epidemiological studies, associating increased ultra-processed food consumption with a higher risk of several diseases (Pagliai et al., 2021). Hence, governments and NGOs discourage the consumption of ultra-processed foods (Monteiro, Cannon, Lawrence, et al., 2019). We found it therefore imperative to assess if foods that are by definition ultra-processed (in this thesis: snacks) (Monteiro, Cannon, Levy, et al., 2019) could potentially be formulated in a way that they are still healthy and natural.

In line with Sanchez-Siles et al. (2022), we have shown in **Chapter 3** that the level of processing is not necessarily related to the product's healthiness or naturalness. Within the product category of snack bars, and even among its sub-categories, products varied greatly in terms of healthiness and naturalness. Consistent with previous findings in snacks and snack bars (Michel et al., 2021; Sanchez-Siles, Román, Fogliano, et al., 2022), the same chapter also implied that in cereal and chocolate bars, a product's objective healthiness and naturalness are different concepts since they were only weakly correlated. **Chapter 4** added to these findings by incorporating another dimension: the target population. In this study, we demonstrated that even within the same product category of biscuits, healthiness and naturalness may differ substantially between the three target populations (i.e., babies, children, adults).

All in all, we showed in this thesis that healthiness, naturalness, and degree of processing are three different constructs that need to be untangled. Indeed, (ultra-)processed foods, including snacks, can be formulated with varying levels of healthiness and naturalness.

7.5 Methodological considerations

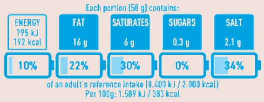
7.5.1 Food healthiness

In this thesis, the healthiness of snacking products was mainly assessed by evaluating nutrient composition (energy, fat, saturated fat, carbohydrates, sugar, protein, fibre, and salt). In **Chapter 3**, we have also examined the nutritional quality of cereal and chocolate bars using the front-of-pack logo Nutri-Score. For **Chapter 4**, we have chosen not to measure the Nutri-Score of biscuits since baby food is not eligible for the application of the Nutri-Score. To date, the algorithms of such schemes are based on the nutritional needs of healthy adults, and infants and young children have different nutritional needs as compared to adults (Santé Publique France, 2022). Instead, we have evaluated the compliance of baby biscuits with the World Health Organization's proposed nutrient profile model as discussed in paragraph 7.3.

The Nutri-Score has gained popularity in a growing number of EU countries. However, recently it became clear that criticism of the Nutri-Score system is rising in parallel with its increasing popularity. Concerns are mainly expressed by policy makers and scientists. Most of the criticism is rising from Mediterranean countries such as Greece and Italy. These countries believe that Nutri-Score is misleading and penalizes the acclaimed Mediterranean diet. For instance, Italy finds the Nutri-Score too simplistic, and they advocate for another enriched front-of-pack label – promoted by the Italian Ministry of Health – namely, the NutrInform Battery logo. Proponents of the NutrInform Battery argue that this logo is able to educate consumers and give valuable information on nutrition composition, helping consumers to balance good and bad nutrients and improve overall diet quality (Carruba et al., 2021). The logo shows the nutritional value (energy, fat, saturated fat, sugar, and salt content) in detail, and unlike the Nutri-Score, it separates saturated fat from total fat. The most critical difference as compared to the Nutri-Score is that NutrInform Battery is based on portion sizes, while Nutri-Score is based on 100g. Similarities and differences of the Nutri-Score and NutrInform Battery are shown in **Table 7.4**.

The advantage of considering the portion size, according to Carruba et al. (2021), is that some foods in the market are generally consumed in other quantities than 100g. Pizza, for example, is usually consumed in higher quantities than 100g and thus has a

***Table 7.4**. The similarities and differences between the algorithms of Nutri-Score and NutrInform Battery.*

	Nutri-Score 	**NutrInform Battery** 
Type	Summary	Nutrient-specific
Display	Graded indicators (A to E)	Numerical information
Per 100g or per portion	Per 100g	Per portion
Energy	✓	✓
Fat	×	✓
Saturated fat	✓	✓
Carbohydrates	×	×
Total sugar	✓	✓
Fibre	✓	×
Protein	✓	×
Salt	✓	✓
% fruits, vegetables, legumes, nuts, oils	✓	×

bigger impact on the overall diet. The contrary yields for olive oil, which is highly caloric, but usually consumed in smaller quantities than 100g. Proponents of the Nutri-Score counterargue in their open letter addressed to Carruba et al. (2021) that 1) defining portion sizes is challenging and depends heavily on individual requirements, 2) it is difficult for consumers to estimate the portion size, and 3) portion sizes are usually set by manufacturers, and sometimes such suggested portion sizes are not realistic. Hence, a standard quantity of 100g allows to objectively compare nutritional quality of foods (Touvier et al., 2021).

Following the critics on the Nutri-Score, changes to Nutri-Score's algorithm were recently proposed by the Scientific Committee, a committee which involves 11 researchers from pro Nutri-Score countries (Scientific Committee of the Nutri-Score, 2022). According to the committee, the algorithm performs overall well, but specific improvements were necessary to permit for a clearer differentiation between healthier and less healthy food items within a given food group, and to bring Nutri-Score more in line with food-based dietary guidelines in all member states. This resulted in stricter criteria in the point allocation system for unfavourable nutrients sugar and salt, and favourable nutrients fibre and protein. Also, the "fruit, vegetables, legumes, nuts and oils" component has been proposed to change into "fruit, vegetables, and legumes" (Scientific Committee of the Nutri-Score, 2022).

In this thesis, we have used the current algorithm of the Nutri-Score as a proxy for food healthiness. We found it a valuable tool to measure and compare the healthiness in snack bars, and to provide the industry with insights about how their products can be improved. However, it is likely that Nutri-Score's algorithm will be changed upon the proposed recommendations in the future. If so, these changes may have implications for the scores as calculated in **Chapter 3**. The stricter criteria for sugar and fibre will probably lead to some bars scoring a worse Nutri-Score as compared to the current algorithm and manufacturers will need to put a bigger effort to obtain a higher Nutri-Score. Even though the European Commission's decision on the adoption of a single nutrition label for all food products in the EU has been postponed, manufacturers should not wait to reformulate. It is a great opportunity to proactively improve food products to meet consumer demand, gain a competitive advantage, and contribute to public health concerns.

7.5.2 Food naturalness

The Food Naturalness Index has been developed to eliminate the misuse of "naturalness" claims by the industry and to create transparency in the marketplace. The index has been shown to accurately measure the degree of naturalness of snacks in line with consumers' perceived naturalness of those snacks (Michel et al., 2021). One of the major advantages of the Food Naturalness Index is that it addresses the complexity of the topic with an approach that incorporates different perspectives (consumer, technical, and legal/regulatory) and components (farming practice, additives, unnecessary/unexpected ingredients, and degree of processing). These four components are weighted equally, and therefore there is no single determining factor in the algorithm of the Food Naturalness Index. In **Chapter 3 and 4**, we used the Food Naturalness Index to objectively measure the degree of naturalness of cereal bars, chocolate bars, and biscuits. Employment of the index made it possible to easily compare the degree of food naturalness within and between different food groups. Furthermore, as the Food Naturalness Index considers the stricter limits of pesticides residues in baby food in the farming practice component, the index could be applied to baby foods, as well as to foods for children and the general population (i.e., adults)

Besides the many advantages that we experienced using the Food Naturalness Index, there were also several challenges that need attention. Although the Food Naturalness Index includes detailed lists of unnecessary/unexpected ingredients and processed ingredients – with in- and exclusion examples – the tool is in some cases still prone to subjectivity. One of the challenges we faced was the inability interpret the functionality of some ingredients from the product labels. As an example, in the Food Naturalness Index' algorithm, nutritional additives are excluded from a penalization (Regulation (EC) No 1169/2011, 2011), but for some products it was unclear whether minerals were added for fortification or technical purposes (e.g., calcium carbonate in a biscuit to increase calcium content, or to function as a raising agent). Another example of a challenging ingredient was fruit juice concentrate. Fruit juice concentrate may have various properties; besides being added for texture, it may also be added to sweeten and/or to flavour a product. Considering the rising concerns regarding fruit juice concentrates being identified as hidden sugars, we have decided that a fruit juice concentrate should only be considered expected when it was clear from the product name or label that it was added for flavouring purposes (i.e., apple juice concentrate in "apple biscuit"). In other cases (e.g., grape juice concentrate in a plain biscuit, or pineapple juice concentrate in "cranberry cereal bar") we concluded the function was primarily to sweeten the product, and hence the fruit juice concentrate was penalized for being unexpected.

While applying the Food Naturalness Index to different types of snacks, it became also evident that the index is product dependent. In the current list of unnecessary/unexpected ingredients, added sugar in infant food products is included. This should indeed be the case for most infant products such as fruit purees. However, in the case of baby biscuits, sugar should not be considered unnecessary/unexpected as it is needed to ensure a dissolvable texture. Also, milk-derived ingredients in cereal bars are now designated as unexpected ingredients, while in reality cereal bars often contain a chocolate coating with – not entirely unexpected – milk powder. Other issues that arose from applying the current Food Naturalness Index were how to deal with 1) the same ingredients that appear multiple times in the ingredient list, 2) a mix of refined and whole grain cereals, and 3) ingredients that we may not find in our kitchen cupboard but are not unexpected either (e.g., fructo-oligosaccharides in a cereal bar, collagen peptides in a protein bar).

In this thesis, to avoid inconsistencies and discrepancies in the results, agreed clarifications to the original lists were made and at least two or more researchers were involved in the calculations of the Food Naturalness Index. The challenges we faced still do not outweigh the potential the Food Naturalness Index holds for the future. The in- and exclusion criteria of the current Food Naturalness Index need to be adapted and/or elaborated according to our findings. An updated version could also include other relevant aspects of naturalness, such as sustainability and local production as they have been identified as important in the context of naturalness (Román et al., 2017).

7.5.3 Cross-sectional benchmark studies on product formulations

In **Chapter 3 and 4** we have carried out two cross-sectional comparative studies. In business, such types of comparative studies are also known as "benchmarks". A benchmark is a methodology whereby real-time product data is collected and analysed, to generate insights that aid in decision making for product design. Benchmarks are often used in food companies to 1) better understand the current market characteristics, 2) identify the market gaps and how to provide added value to consumers, 3) identify the weaknesses of own product portfolio that need improvement, and 4) identify the strengths of own product portfolio to build science-based communication materials. A benchmark may involve comparing the nutritional value, degree of naturalness, taste, texture, nutrition and health claims, or other attributes of food products. There are several important criteria to conduct a reliable benchmark. Examples of those criteria include setting clear objectives of the study, scoping the products of interest (e.g., type of products, country, and brands of interest), avoiding selection bias, ensuring a representative sample, and using high-quality data. Regarding the quality of data, it occurred that some studies in scientific literature use product data from databases such as OpenFoodFacts. Such databases lack rigor data, as consumers can enter data themselves and no peer-review is carried out. Using low-quality data may lead to incorrect comparisons and conclusions.

Therefore, we have chosen to use other product databases in this thesis. In **Chapter 3** we used The Nielsen Company database to retrieve the best sold cereal and chocolate bars in the German market. Instead of using OpenFoodFacts, product data was manually extracted from the brands' or retailers' websites as we found that most reliable. In **Chapter 4**, the sample size of biscuits was too big to manually search for product data, and thus we extracted data using the Global New Products Database (GNPD) tool from Mintel. Mintel is the world's leading Market Intelligence agency, and commonly used as data source in scientific studies investigating nutritional quality (e.g., Azzopardi et al., 2020; Grammatikaki et al., 2021; McCann et al., 2022). This tool was also used in **Chapter 2**, to explore the top claims and nutritional composition of cereal bars.

Product data in Mintel was found to be of better quality as compared to OpenFoodFacts, however, improvement of the accuracy of the data is still highly recommended. Scientific research on the nutritional quality of foods favours big datasets with reliable data in order to draw valid conclusions. Incorrect data, missing nutrient values, data entered per portion size instead of per 100g, and products with cartoons not being classified under "child products" are examples of encountered issues in this thesis that we have addressed case by case. Databases with millions of products will hardly ever be 100% accurate, however, data could certainly be improved by revising unlikely values (e.g., 150 g/100g of sugar instead of 15.0 g/100g), missing data points, and product packaging.

7.5.4 Sensory evaluation in early childhood

In **Chapter 6**, we have measured the sensory acceptance of baby yogurt pouches in toddlers (1-4 years) and their parents. Measuring sensory acceptance in early childhood (infants and toddlers) is known to be challenging. Considering previous research, we have assessed the toddlers' overall acceptability by means of three measures: 1) the toddler's reaction as perceived by the parents, 2) the estimated intake, and 3) the relative intake as compared to usual intake. Sensory evaluation was performed by non-trained subjects (parents). Research on toddler's reactions to new or modified foods is scarce in comparison with adult samples, mainly due to the inherent issues associated with data gathering (i.e., infants and toddlers are not able to fill in a survey). Some scholars have video-recorded infants' responses in laboratory settings and such recording were later coded and interpreted by coders (Moding et al., 2014). In a laboratory, conditions are well controlled and monitored, but this approach requires significant time and resource investment. A related alternative is the use of trained researchers as external observers who visit the infants/toddlers' home during each intake and report their reactions (Blossfeld et al., 2007). Given the complex characteristics of our experimental design (4-day double-blind randomized cross-over study with 150 toddler-parent dyads), we relied on parents to assess their children's reactions at home. This approach has two clear advantages: it can be performed with few constraints on the participants, and children are in their usual environment with their usual feeder (Madrelle et al., 2017). Feeders (parents) know their infant's reactions towards foods best and therefore are likely to be more sensitive to subtle differences in their reactions. In any case, in Demonteil et al.'s (2019, p.57) study, parents and researchers evaluated infants' sensory reactions to foods in the lab and their assessments "were found to be very similar between parents and investigators" (Demonteil et al., 2019).

A 4-point hedonic scale was used to evaluate the toddler's reaction as perceived by their parents. One of the major advantages of this scale is the accompanied description of each point, which helps parents to understand which option best describes their toddler's reaction and thus provides consistency among responses. In fact, extant research has validated the use of this subjective measurement (through parent's evaluations) of infants' and toddlers' reactions (Gerrish & Mennella, 2001; Haro-Vicente et al., 2017; Lange et al., 2013; Maier et al., 2007; Remy et al., 2013; Sanchez-Siles et al., 2020). For example, Lange et al. (2013, p.91) described in their methodology that: "the parents were asked to rate their infant's acceptance of each new food at the first introduction, using the following 4-point-scale: '--' (very negative) if the infant spit out the food, frowned, pushed the spoon away or stopped eating; '-' (negative) if the infant ate a couple of spoonfuls, grimaced and stopped eating; '+' (positive) if the infant ate some of the food without a specific reaction; '++' (very positive) if the infant accepted the first spoonful immediately and displayed signs of content, such as a relaxed face or a smile."

7.6 Future research perspectives

7.6.1 Improve and update the Food Naturalness Index

A first step for future research is to focus on improving and updating the current algorithm of the Food Naturalness Index. More research is needed on consumers' perceptions of unnecessary/unexpected ingredients in different types of foods. Results could aid in understanding and predicting which ingredients consumers perceive as unnecessary and/or unexpected. Consumer studies exploring differences in perceptions on natural and artificial additives are also desired to determine whether a distinction should be made in the component of additives. Second, further validation of the index is of importance. The Food Naturalness Index should be applied to food groups beyond the snacks studied in this thesis to examine which criteria set in Sanchez-Siles et al. (2019) should be elaborated in more detail. It would also be helpful to research whether the degree of naturalness of those products are in line with consumers' naturalness perceptions.

In **Chapter 6** we have investigated consumers' evaluations of the ingredient lists and purchase intentions of old recipes (longer ingredient lists, lower Food Naturalness Index) and reformulated recipes (shorter ingredient lists, higher Food Naturalness Index) of baby yogurt pouches. Some parents in our study mentioned aspects of naturalness as reasons for likeability and positive purchase intentions, but future research would also benefit from carrying out trials in a real-life setting (e.g., supermarket) where actual purchase intentions can be measured. Such research could be followed by a qualitative study with in-depth interviews or focus groups to better understand the drivers of consumer behaviour and purchasing patterns in this regard.

7.6.2 Product (re)formulations

Research should continue to focus on innovative ingredients in product formulations. For instance, in the case of cereal bars, more research is needed into finding a healthier (less sugar, less salt, less saturated fat) and more natural (no highly processed syrups, no palm oil, less/no additives) binder that enables the desired texture of the final cereal bars without compromising sensory appeal. For baby biscuits, solutions should be sought for decreasing sugar content as much as possible while keeping in mind safety (e.g., dissolvable texture) and natural (e.g., no addition of starch or other processed ingredients that are added to soften the texture) aspects. Innovative processing technologies such as nanotechnology or 3D-printing could be an area of potential future research too, as such technologies could offer benefits that include food safety, improved nutrition, or improved taste (Isaías et al., 2023).

The importance of health, natural, sustainability, and sensory attributes may differ for consumers depending on the type of product. The preferences revealed in the choice scenarios in the study of Saulais et al. (2023) seem to support market strategies as a response to consumers' willingness to give up sensory or functional properties in order to gain in naturalness (Saulais et al., 2023). It would be interesting if future research further investigates consumer choices and trade-offs in the snack category.

7.6.3 Research in infants, toddlers, and children

In general, more research should be conducted in infants, toddlers, and children. Research in infancy and (early) childhood is scarce mainly due to ethical considerations and technical limitations. Infants and toddlers are vulnerable population with incomplete cognitive development and limited or no abilities to communicate (Nicklaus, 2015). Further exploration of new and innovative ways to conduct sensory research in these populations that may reduce bias is suggested. Following the results obtained in **Chapter 5**, it would be fruitful if health benefits of whole grain intake in early childhood would be investigated. Results from such research could then be used as a basis for the development of clear recommendations of whole grain intake in early life.

7.6.4 Research to parents' purchase and feeding behaviour

Although extant research on parental feeding behaviour in many European (e.g., Carletti et al., 2017; Klerks et al., 2021; Lange et al., 2013) and non-European countries (e.g., Radwan, 2013; Siega-Riz et al., 2010b) exists, more details with regards to snacking behaviour in (early) childhood are needed. The frequency with which parents provide their babies foods that are not specifically designed for them, or the frequency with which they give their older children child-oriented snacks are topics of interest.

7.7 Main conclusions

The ever busy and demanding consumer of today has set the trend for "Snackification". This trend has had a significant impact on the food industry, leading to the development of new snack products. The focus of this thesis was understanding the healthiness and naturalness of snacking products. Several snacks (cereal bars, chocolate bars, biscuits, and yogurt pouches) and different target groups (infants, toddlers, children, and adults) were studied, and the benefits of an important ingredient in the formulation of snacks and cereals, whole grains, were investigated.

Snacking products, if well-formulated, are food items that can be well combined with the modern and multiple consumer needs such as healthy, natural, and sustainable nutrition. In snack bars, healthiness and naturalness were only weakly correlated, implying that from a technical perspective they are different concepts. Careful formulation is especially of great importance for younger consumers. Early childhood is an important period in life to introduce healthy foods that shape food preferences, eating skills, and habits. We showed that baby biscuits are a healthier and more natural alternative to adult biscuits, while biscuits targeted at older children were poorly formulated.

The findings of this thesis have increased our understanding of the healthiness and naturalness of several snacking products, and these insights can support new product development. Although product development towards healthier and more natural products represents a challenge for manufacturers, it can surely be done without sacrificing taste – the "sweet spot" simply needs to be found.

7

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Summary

Summary

Although a consistent definition of "snacks" and "snacking" is still absent, our traditional eating behaviour is clearly shifting from three substantial meals in a day to the frequent consumption of smaller amounts of food. This new way of eating is also known as "Snackification". Along with consumer's increasing snacking behaviour, their awareness and concerns about their own and the planet's health are rising too, resulting in a demand for healthy and natural snacks. Hence, manufacturers are driven to (re)formulate their snacks towards healthier and more natural products while maintaining an appealing taste. To better understand which approach manufacturers should take, the research in this thesis investigated the healthiness and naturalness in snacking products. The first part of this thesis (**Chapter 2 and 3**) explored trends in snacking and focused on (cereal) snack bars. The second part of this thesis focused on snacks and cereals for babies and children (**Chapter 4-6**).

Chapter 2 reviewed the composition, production methods, current and emerging trends, and practical implications for the development of new cereal bars. Cereal bars were shown to be a versatile type of snack that usually consist of three phases: 1) the solid phase including a variety of cereals, pulses, nuts and dried fruits, 2) a binding phase with sugar syrups, fats, and emulsifiers to "glue" the ingredients, and 3) a production phase that may be compression- or extrusion-based. Several current and emerging trends were discovered. Current trends included health and well-being, naturalness, sustainability, and convenience. Among these current trends, several sub-trends were distinguished, varying from digestive health to minimal processing and meal replacement. Emerging trends included chilled/frozen cereal bars, functional formulations, and new flavours. Such trends have many implications for the food industry. Nutritionally well-designed cereal bars with few but recognizable ingredients, coinciding with the Planetary Health Diet, and with a desired texture and taste, are the way to go for manufacturers to meet consumer demands. Yet, product customisation and personalised nutrition will be essential in the future of nutrition. **Chapter 3** built on this knowledge, by examining the healthiness (measured through Nutri-Score) and degree of naturalness (measured through the Food Naturalness Index) of cereal bars and comparing it to chocolate bars. The analysis relied on a dataset of the most consumed chocolate and cereal bars in Germany in 2019. Cereal bars varied greatly in terms of healthiness and naturalness, but were in general a healthier and slightly more natural alternative to chocolate bars. The high levels of sugar and saturated fat, and long lists of (processed) ingredients in cereal bars are points of improvement that should be addressed by manufacturers. In chocolate and cereal bars, healthiness and naturalness were only weakly correlated, suggesting that in this snack category they are different food attributes.

In **Chapter 4**, we examined and compared the healthiness and degree of naturalness between baby biscuits (<3 years), children biscuits (>3 years), and adult biscuits that were launched in the last three years in four European countries. Healthiness was measured by means of nutrient values per 100g, and baby biscuits were assessed for compliance with the World Health Organization's nutrient profile model. Again, the degree of naturalness was measured using the Food Naturalness Index. Although sweet snacks like biscuits are highly being criticised by policy makers, the study showed that they had the best nutritional quality and were the most natural as compared to children and adult biscuits that parents might occasionally offer to their offspring. However, baby food manufacturers need to continue their efforts in improving the nutritional composition of their products, especially focusing on energy density and sugar content. Additionally, we observed a big gap in terms of healthiness and naturalness between baby biscuits and biscuits marketed at older children. Quite worrisome, biscuits for older children were nutritionally poor and not natural, in fact, they were the least natural of the three target groups. That provision of adequate food in (early) childhood is important was underpinned in **Chapter 5**. This chapter reviewed existing research about the quantity, type, and degree of infant cereal processing, and focused specifically on whole grains. Whole grains were shown to be rich in fibre and bioactive components, and numerous health benefits of whole grain consumption were evidenced, including reducing the risk of obesity, type 2 diabetes, cancer, and cardiovascular diseases. We showed that incorporation of whole grains in the diet should already take place during the complementary feeding period as it is a key period for shaping the infant's food preferences, but several challenges were encountered that need to be addressed. Such challenges included the absence of unified whole grain intake recommendations in infancy, high natural and process contaminants, and sensory appeal. Indeed, sensory acceptance of consumers is a priority in product development, hence, in **Chapter 6** we examined how reformulations towards healthier and more natural products influenced toddlers' (1-4 years) and parents' sensory acceptability. Three pairs of baby yogurt pouches (old versus reformulated recipes) were tested. In the reformulated recipes, fruit concentrates were replaced by fruit purees, and added sugar was eliminated. This resulted in recipes with a lower sugar content and less processed ingredients. Toddler's acceptability was measured by the toddler's reaction and by the estimated and relative intake. Parent's overall liking and sensory evaluation was measured on a 7-point hedonic scale. All reformulated recipes were highly accepted by both toddlers and their parents. Two of three reformulated yogurt recipes scored slightly lower on acceptability, while there was no observed difference in acceptability for one yogurt pair. A reduction of sugar content up to 30% along with a reduction in the number of processed ingredients was sensory acceptable by toddlers and their parents.

In **Chapter 7**, the main findings were presented and put in broader context of previous research. I discussed how current and emerging trends could be incorporated in new product development of cereal bars and how snacks and cereals for babies and children can be optimised. Furthermore, I reflected on the implications of these findings for public health organizations, the industry, and other important stakeholders. I discussed that healthiness and naturalness are different constructs and that they both can exist in processed foods like snacks. Finally, I discussed how future research could focus on improving the Food Naturalness Index and on finding innovative ingredients for product formulations. From this thesis I conclude that snacking products, if well-formulated, are food items that can be well combined with the modern and multiple consumer needs such as healthy, natural, and sustainable nutrition. In snack bars, healthiness and naturalness were only weakly correlated, implying that from a technical perspective they are different concepts. Careful formulation is especially of great importance for younger consumers. Early childhood is a key period to introduce healthy foods that shape food preferences. We showed that baby biscuits are a healthier and more natural alternative to adult biscuits, while biscuits targeted at older children were poorly formulated. The findings of this thesis have increased our understanding of the healthiness and naturalness of several snacking products, and these insights can support new product development. Although product development towards healthier and more natural products represents a challenge for manufacturers, it can surely be done without sacrificing taste.

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Even though I was not present in Wageningen, I did feel part of the Food Quality and Design group. Dit gevoel kwam mede door jou **Corine**, bedankt dat je altijd voor mijn vragen klaar stond die je weliswaar altijd in no-time beantwoordde. **Shiksha**, we have spent such a good time together during the PhD week in Limburg (can you imagine we were 24/7 wearing masks?) and later during the PhD study trip. Also, thank you for teaching me everything about Nepal – now I finally understand that mountains higher than the Wageningse Berg do exist ;-). Lieve **Annelies**, guapa, jou wil ik ongelofelijk bedanken voor het feit dat je me er letterlijk doorheen hebt gesleept de laatste twee maanden voor de deadline. Mil mil mil gracias. De nodige pep-talks en geruststellende woorden waren zó fijn. Het is jammer dat we uiteindelijk niet samen hebben gewerkt hier in Spanje, maar hey, zeg nooit nooit! Je bent een topper en we moeten gewoon heel snel afspreken. **Fabiola,** we met online in a scientific writing course, and as the end of both our PhD adventures is approaching soon, we found each other again. It was nice to be able to share our stressful moments. Hope to see you soon in the Netherlands! Furthermore, I would like to thank all my fellow FQD PhDs that joined the PhD trip in 2022. The warm welcome of such a big group meant a lot to me. We had so much fun!

I would like to thank the students that have worked at the topic of Snackification: **Michelle**, **Anouk**, and **Joy**, and our interns at Hero: **Jisca**, **Marie**, **Annemiek**, **Olivier**, **Louise**, **Ilse**, **Mounira**, and **Lieke** – even though your topics were not always related to my PhD. Thank you all for your hard work! Lieve **Marjolein**, in eerste instantie was jij mijn inspiratie om toch de PhD te gaan doen. Heel fijn dat wij altijd contact hebben gehouden na onze master in Wageningen. En hoe leuk dat wij elkaar totaal onverwachts tegen kwamen bij het Planetary Health Diet event in Utrecht! Laten we snel een koffietje drinken!

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Cristal, preparing paella, having sleepovers, and playing with Sofía and Elena were so special to me in times of COVID and writing my thesis. Dear **Jaime** and **Corpus**, you are our friends that quickly became our family. You both know as no other how it is to do a PhD. Thanks for the good and deep talks, the parties, the travels. To many more please!

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About the author

About the author

Michelle Klerks was born on July 25th, 1993 in Schiedam, the Netherlands. After completing pre-university education at Sg. Spieringshoek in Schiedam, she started the BSc program Nutrition and Dietetics at The Hague University of Applied Sciences. During this program, she followed a minor course program in Psychiatry, Medication, and Food, and wrote her BSc thesis at the dietetics department of Erasmus MC Rotterdam. For this assignment, she created a diet manual with evidence-based dietary requirements of nearly 30 diets commonly used in the hospital. After obtaining her BSc degree in 2015, she enrolled in the MSc program Nutrition and Health at Wageningen University, where she followed the specialisation Nutritional Physiology and Health Status. She wrote her MSc thesis on the effects of oro-sensory exposure (i.e., mastication duration and sweet taste intensity) on the cephalic phase response of insulin, glucose levels, and subjective appetite feelings, which was part of the JellyHead Study. After finalizing her MSc thesis, she decided to pursue an internship abroad (Murcia, Spain) at the Innovation and Quality department of Hero Group, where she investigated complementary feeding practices and parental pressure to eat among Spanish infants and toddlers. After completing her studies in 2017 she travelled around the world for a couple of months, to finally return to Spain to kick-off her career as Innovation Technologist at Hero Group in 2018. Later she took on the role of Nutritionist for several product categories, including Baby and Toddler Food and Snacks, and Healthy Snacks. While working at Hero Group, Michelle started as a PhD Candidate at the Food Quality & Design group at Wageningen University early 2020. Her PhD project focused on understanding healthiness and naturalness in snacking products.

Michelle can be contacted by email at michelleklerks@hotmail.com.

List of publications

Manuscripts included in this thesis

Klerks, M., Bernal, M. J., Roman, S., Bodenstab, S., Gil, A., & Sanchez-Siles, L. M. (2019). Infant cereals: Current status, challenges, and future opportunities for whole grains. *Nutrients, 11*(2), 473. https://doi.org/10.3390/nu11020473

Boukid, F., **Klerks, M.**, Pellegrini, N., Fogliano, V., Sanchez-Siles, L., Roman, S., & Vittadini, E. (2022). Current and emerging trends in cereal snack bars: implications for new product development. *International Journal of Food Sciences and Nutrition, 73*(5), 610-629. https://doi.org/10.1080/09637486.2022.2042211

Klerks, M., Román, S., Verkerk, R., & Sanchez-Siles, L. (2022). Are cereal bars significantly healthier and more natural than chocolate bars? A preliminary assessment in the German market. *Journal of Functional Foods, 89*, 104940. https://doi.org/10.1016/j.jff.2022.104940

Klerks, M., Román, S., Haro-Vicente, J. F., Bernal, M. J., & Sanchez-Siles, L. M. (2022). Healthier and more natural reformulated baby food pouches: Will toddlers and their parents sensory accept them?. *Food Quality and Preference, 99*, 104577. https://doi.org/10.1016/j.foodqual.2022.104577

Klerks, M., Román, S., Sanchez-Siles, L. Baby, children, and adult biscuits. Differences in nutritional quality and naturalness. *Submitted to Food Science & Nutrition*.

Manuscripts not included in this thesis

Sanchez-Siles, L. M., Bernal, M. J., Gil, D., Bodenstab, S., Haro-Vicente, J. F., **Klerks, M**., ... & Gil, Á. (2020). Are sugar-reduced and whole grain infant cereals sensorially accepted at weaning? A randomized controlled cross-over trial. *Nutrients, 12*(6), 1883. https://doi.org/10.3390/nu12061883

Klerks, M., Roman, S., Bernal, M. J., Haro-Vicente, J. F., & Sanchez-Siles, L. M. (2021). Complementary feeding practices and parental pressure to eat among Spanish infants and toddlers: a cross-sectional study. *International Journal of Environmental Research and Public Health, 18*(4), 1982. https://doi.org/10.3390/ijerph18041982

Bernal, M. J., Roman, S., **Klerks, M.**, Haro-Vicente, J. F., & Sanchez-Siles, L. M. (2021). Are Homemade and Commercial Infant Foods Different? A Nutritional Profile and Food Variety Analysis in Spain. *Nutrients, 13*(3), 777. https://doi.org/10.3390/nu13030777

Sanchez-Siles, L., Román, S., Haro-Vicente, J. F., Bernal, M. J., **Klerks, M.**, Ros, G., & Gil, Á. (2022). Less Sugar and More Whole Grains in Infant Cereals: A Sensory Acceptability Experiment With Infants and Their Parents. *Frontiers in Nutrition, 9*, 855004. https://doi.org/10.3389/fnut.2022.855004

Overview of completed training activities

Discipline specific activities (* poster presentation)		
2020	6th World Congress of Pediatric Gastroenterology, Hepatology and Nutrition (WCPGHAN)*	Copenhagen, DK *[online]*
	Food Matters Live	London, UK *[online]*
	7th International Conference Nutrition & Growth (Kenes)	London, UK *[online]*
	34th EFFoST International Conference	Tel Aviv, IL *[online]*
	9th European Conference on Sensory and Consumer Research (Eurosense)*	Rotterdam, NL *[online]*
2021	DSM Expo (DSM)	*[online]*
	Food Matters Live	London, UK *[online]*
	Food Ingredients (Fi Europe)	Frankfurt, DE
	Course Healthy and Sustainable Diets (VLAG)	Wageningen, NL *[online]*
2022	Alimentaria	Barcelona, SP
	9th International Conference Nutrition & Growth (Kenes)	Vienna, AT *[online]*
2020-2023	*Symposia [online]:* Processed foods symposium – How to communicate about what we (don't) know? (EUFIC) The role of the intestinal microbiota in health and development of infants and children (ETH Zürich, NutriPaed) *Webinars [online]:* Postbiotics (Danone) ADM Future Food (ADM) The Future of Snacking (New Hope Network) Healthy Snacks (Bakery and Snacks) Trends Shaping the Future of Snacking (Future Bridge) Healthy Snacking Trends (Food Navigator) Parenting in 2030: How Gen-Z will shape the future of Early Life Nutrition (Friesland Campina) Mothers' preferences, attitudes, and decision making related to infant milk formula (Arla) Precision fermentation – Profiting the sustainable way (Future Bridge)	
General Courses		
2020	PhD week (VLAG)	Baarlo, NL *[online]*
2021	Scientific writing (WGS)	Wageningen, NL *[online]*
	Introduction to R (VLAG)	Wageningen, NL *[online]*
	Competence assessment (WGS)	Wageningen, NL *[online]*
	Scientific publishing (WGS)	Wageningen, NL *[online]*
	Brain friendly working (WGS)	Wageningen, NL *[online]*
	Reviewing a scientific manuscript (WGS)	Wageningen, NL *[online]*
	Research data management (WGS)	Wageningen, NL *[online]*
2023	The Foundations of Happiness at Work (edX)	Berkeley, US *[online]*
Assisting in Training and Supervision activities		
2021	Lecture ETH Master Students Food Science	Zürich, CH *[online]*
2022	FQD-24306 Case Studies Product Quality	Wageningen, NL *[online]*
2020-2023	Supervision of 11 students (BSc, MSc, and internships)	Wageningen, NL *[online]* Murcia, SP
Other activities		
2020	Preparation of research proposal	Wageningen, NL
2022	PhD study tour	Spain
2020-2023	Monthly multi-disciplinary scientific meeting "Snack Hub" Food Quality & Design Group WUR & Hero Weekly meeting with peer PhD Food Quality & Design WUR & Hero	Wageningen, NL *[online]* Murcia, SP *[online]*

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