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

Fatma Boukid[1], Michelle Klerks[2,3,4], Nicoletta Pellegrini[4,5], Vincenzo Fogliano[4], Luisma Sanchez-Siles[2,3], Sergio Roman[6], Elena Vittadini[7#]

[1]Institute of Agriculture and Food Research and Technology (IRTA), Food Safety and Functionality Programme, Food Industry Area, Finca Camps i Armet s/n, 17121, Monells, Catalonia, Spain
[2]Institute for Research and Nutrition, Hero Group, 5600 Lenzburg, Switzerland
[3]Department of Research and Nutrition Hero Group, 30820 Alcantarilla, Murcia, Spain
[4]Food Quality Design Group, Wageningen University, PO Box 8129, Wageningen, The Netherlands
[5]Department of Agricultural, Food, Environmental and Animal Sciences, University of Udine, via Sondrio 2/A, Udine, 33100, Italy
[6]Marketing Department, Facultad de Economía y Empresa, University of Murcia, 30100 Murcia, Spain
[7]School of Biosciences and Veterinary Medicine, University of Camerino, via Gentile da Varano III, 62032 Camerino (MC), Italy

corresponding author

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.

Keywords: snacking, cereal bars, healthiness, naturalness, sustainability, innovation

1. Introduction

Snacking has been generally defined either as “all foods and drinks with calories consumed between or outside the three main meals” (Chaplin and 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 and 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; B. Bloom 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; B. Bloom 2019a). Furthermore, childhood snacking is moving toward three snacks per day, covering more than a quarter of children's daily calories (Piernas and 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, Cleveland, and Goldman 2008), and to contribute significantly into intakes of whole grains and fiber (McGill, III, and Devareddy 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; A. Walji 2020).

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. 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 and Conti-Silva 2018). The term CBs is sometimes interchangeably used in scientific literature with “granola bars” or “muesli bars” (Curtain and Grafenauer 2019).

CBs are versatile vehicles of components including cereals, dried fruit, nuts, honey, and chocolate (Granato et al. 2011; Carvalho and Conti-Silva 2018) 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 (Padmashree et al. 2012; IRI 2018). 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 (G. 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 and 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 and 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 and Slavin 2017; Slavin 2013a). 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 (WHO 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.

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.

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 and Aramouni

2013), as they are a good source of energy, complex carbohydrates (including fiber), protein, and bioactive components (Silva de Paula et al. 2013; Padmashree et al. 2012).

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 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 of minerals, vitamins, omega 3 fatty acids and fiber as well as to give versatile taste and flavor (S. P. Heenan et al. 2010; Potter, Stojceska, and Plunkett 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 (Caporgno and Mathys 2018; Ballard and Morrow 2013; Corrochano et al. 2018; F Boukid 2021; F Boukid and Rosene 2020; Nascimento et al. 2012; Fatma Boukid and Castellari 2021; F Boukid, Rosell, and Castellari 2021).

****Table 1****

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.

****Table 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 and 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 (Srebernich et al. 2016; Pallavi et al. 2015).

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 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 (Pongsawatmanit, Chantaro, and Nishinari 2013; Molina-Rubio, Casas-Alencáster, and Martínez-Padilla 2010). 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.

3.3. Production phase

A general diagram for CB production is illustrated in Fig. 1. Through this section, each step is discussed to enable a better understanding of the progress and the limitations in the CB processing.

****Figure 1****

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).

3.3.2. Mixing and processing

Mixing (Fig. 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 (Fig. 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 (Fig. 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%.

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 (Tunnarut and Pongsawatmanit 2018; Pavithra et al. 2013). 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.

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, Pechey, and Marteau 2015). However, as CBs are a versatile product and available with a wide variety of ingredients, the nutritional composition and quality can differ largely (Sharma et al. 2014; Aleksejeva, Siksna, and Rinkule 2017; Curtain and Grafenauer 2019). In general, CBs are often a great source of fiber, but also have a high sugar content (Curtain and Grafenauer 2019; Aleksejeva, Siksna, and Rinkule 2017). An overview of the nutritional composition of CBs launched between 2018-2020 in the European and North American markets is shown in Table 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.

****Table 3****

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 Fig. 2, we look at the newest, emerging trends for CBs: chilled and frozen, functional formulations and new flavors.

Figure 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.

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 (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; Leidy et al. 2013; Sung et al. 2014; Shang, Chaplot, and Wu 2018; Samakradhamrongthai, Jannu, and Renaldi 2021). 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 (Peuhkuri, Sihvola, and Korpela 2011; Leidy et al. 2013). 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; H. Jarocka 2019a). 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, Gu, and Ryu 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 (Ryland et al. 2010; Mendes et al. 2013; da Silva et al. 2014). 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, Singh, and Barnwal 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, Jannu, and Renaldi 2021).

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 (Marques et al. 2015; Garcia et al. 2012; Hess and Slavin 2017). 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; H. Jarocka 2019b). Particularly high viscous fibers have been associated with a greater satiety as compared to those snack bars low in viscous fibers (Possinger 2014; P. 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; H. Jarocka 2019b).

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 and 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 (Slavin 2013b; Makki et al. 2018). 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 (News 2019).

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, Wanasundara, and Scanlin 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.

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; A. Walji 2019). 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 (Pinto et al. 2017; Miraballes et al. 2014). 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.

Sugar

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, Soumya, and Indrani 2012; Thorup, Gregersen, and Jeppesen 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, Rajwa, and Mauer 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, Smith, and Tokuda 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).

Fat

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.

Sodium

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

422 sodium per 100 g) and “sodium-free” (<0.005 g of sodium per 100 g) (Regulation (EC) No
423 1924/2006). In a list of the most consumed CBs, the content of sodium ranged from 20 to 230 mg
424 in commercial CBs (Possinger 2014). This suggests the urgent need for public health efforts to
425 reduce the content of sodium in food products, particularly in bars for kids (Maalouf et al. 2017).
426 One of the best strategies recommended to lower sodium intake is the gradual reduction to enable
427 consumers' taste buds to become accustomed to less salt (Scourboutakos, Murphy, and L’Abbé
428 2018). The use of contrasting salt level (use of larger encapsulates which increases the salt
429 perception at lower concentrations) is very promising in different bakery products, but it has not
430 yet been tested in CBs.

431 In order to have a better, deeper understanding of this major trend of health and wellbeing in CBs,
432 and to conclude this section, the most common claims of CBs related to body functions (Table
433 4) and to nutrients and bioactive compounds (Table 5) launched between 2018-2020 in Europe,
434 USA, and Canada have been summarized. Our analysis, based on Mintel’s data on more than
435 1100 commercially available CBs, shows that health claims related to energy, slimming, satiety
436 and weight and muscle gain were the most popular. This reflects a clear response from the food
437 industry to consumers’ interest in weight management. In addition, there has been a substantial
438 interest products having claims related to antioxidant and probiotic effects. This suggests that
439 consumers have fundamentally changed their lifestyle to include snacks with health benefits
440 relying on functional claims declared on the package.

441 ****Table 4****

442 As evidenced in Table 5, nutrition claims involving added benefits such as added protein and fiber
443 are more popular than those representing low/reduced ingredients or even absence from
444 ingredients such as sugar.

445 ****Table 5****

446 **4.2. Naturalness**

447 Consumers have a strong preference for foods that are free from additives and preservatives and
448 that are grown and produced with respect to nature (Román, Sánchez-Siles, and Siegrist 2017a).
449 Preferences for naturalness are reflected in the snack category too, as over half of consumers in
450 2018 in the US let their snack purchase drive by claims such as “made with natural ingredients”,
451 “organic” or “free-from” (IRI 2018). Similarly, 60% of German, Italian and Spanish snack bar
452 consumers indicate that bars made with natural ingredients are worth paying more for (Mintel; A.
453 Walji 2020). Many mothers, especially Polish mothers, indicated to value the level of naturality

of snacks they buy for their children (Damen et al. 2020). In what follows, we focus on several key aspects of CBs naturalness, namely: clean label, minimal processing, local and organic production.

4.2.1. Clean label and minimal processing

CB manufacturers are embracing simplicity and naturalness via "clean label" formulations and transparent brand communication (Mintel; O. Buchet 2019). 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, Sánchez-Siles, and Siegrist 2017a). 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 and Chambers 2019). Under this scenario, many CB brands are focusing on eliminating unwanted artificial ingredients (Mintel; A. Walji 2019), 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; O. Buchet 2019). 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; O. Buchet 2019).

Manufacturing processes also influence the consumer's perception on naturalness (Román, Sánchez-Siles, and Siegrist 2017b). 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; O. Buchet 2019). 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; A. Walji 2020).

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; 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; A. Walji 2020).

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, Sánchez-Siles, and Siegrist 2017a). 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, Ramankutty, and Foley 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; K. Formanski 2019). CB manufacturers are therefore encouraged to use organic raw materials as much as possible.

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; B. Bloom 2019b). 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; A. Walji 2020). 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.

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 (Ohr 2019; F Boukid et al. 2021). 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.

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 and 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

555 technological quality. This underlines that CB production chain aligns with Sustainable
556 Development Goal number 2 of the 2030 Agenda aiming to reduce agri-food ingredients waste
557 and give value to by-products (United Nations 2015). Importantly, CBs can be produced with
558 mildly refined ingredients without thermal processing. They have a relatively low water activity
559 and a shelf life of 12 months or longer and can be distributed at ambient temperature (Corrigan,
560 Hedderley, and Harvey 2012). All these features typically lead to a lower carbon footprint
561 allowing CBs manufacturers to support sustainability-related statements.

562 *4.3.3. Packaging*

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

570 **4.4. Convenience**

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

584 *4.4.1 Meal replacement bars*

585 Meal replacement bars are designed to replace one or two meals per day for consumers following
586 a low-calorie diet (400-800 kcal/day). Meal replacement bars do not require meal preparation,

587 they are relatively inexpensive, convenient, palatable and versatile (Sung et al. 2014). These bars
588 are commercialized as a nutritionally balanced meal with a specific focus on hunger control and
589 weight reduction. However, none of these bars can entirely replace a properly-balanced meal
590 (Reents 2019). Numerous studies have attempted to formulate CBs for meal replacement (Suhem
591 et al. 2013; Suhem et al. 2017; Sung et al. 2014; Pinto et al. 2017). In a randomly controlled study,
592 the consumption of replacement bars used for replacing lunch for 10 days in 17 subjects resulted
593 in an average reduction in energy intake of 250 calories per day (from 2057 to 1812 kcal)
594 (Levitsky and Pacanowski 2011). Another study investigated the partial replacement of dinner
595 (night snacking) using two types of bars (cereal based and non-cereal based) in randomized 25
596 adults (Waller et al. 2004). After 4 weeks, the cereal group had an important reduction of total
597 daily caloric intake (-396.5 ± 641.6 kcal/ day) with respect to the other group (-23.2 ± 889.6
598 kcal/day). This evidence suggests that the partial replacement of meals by these bars can be useful
599 in reducing daily energy intake and promoting weight loss.

600 **4.5. Emerging trends**

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

603 *4.5.1. Chilled and frozen CBs*

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

618 *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; H. Jarocka 2019a). 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; H. Jarocka 2019a).

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 (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, Greve, and Lee 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 (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; H. Jarocka 2019a). 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 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.

****Table 6****

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 modulating matrix structure can open up new opportunities for the design of healthier foods (Capuano and 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 (Suhem et al. 2013; Suhem et al. 2017; Pinto et al. 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.

686 CBs are food items that can be well combined with the modern and multiple consumers' needs
687 such as healthy, natural, and sustainable nutrition.

688 **Disclosure statement**

689 Michelle Klerks and Luisma Sanchez-Siles are members of the Research & Nutrition department
690 of the Hero Group. All other authors do not declare potential conflict of interest.

691 **Data availability statement**

692 Not applicable.

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1180 **Table 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.	(S. Heenan et al. 2012; Potter, Stojceska, and Plunkett 2013)
Seeds	Flaxseed	- enhance the sensory characteristics - excellent source of fiber and omega 3 fatty acids. - rich in antioxidants	(Colussi et al. 2014; Khouryieh and 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; Ryland et al. 2010; Ramírez-Jiménez et al. 2018)
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 and Aramouni 2013)

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1182 **Table 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 (S. P. Heenan et al. 2010; S. Heenan et al. 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; (Padmashree et al. 2012; Mendes et al. 2013)
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	(Salgado, Giraldo, and Orrego 2017; Niu et al. 2019; Lira-Ortiz et al. 2014)

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Table 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).

Abbreviation: IQR: interquartile range.

Table 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.

Table 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.

Table 6: Practical implications of current and emerging trends for CB new product development.

Trend	*Subtrend*	*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.

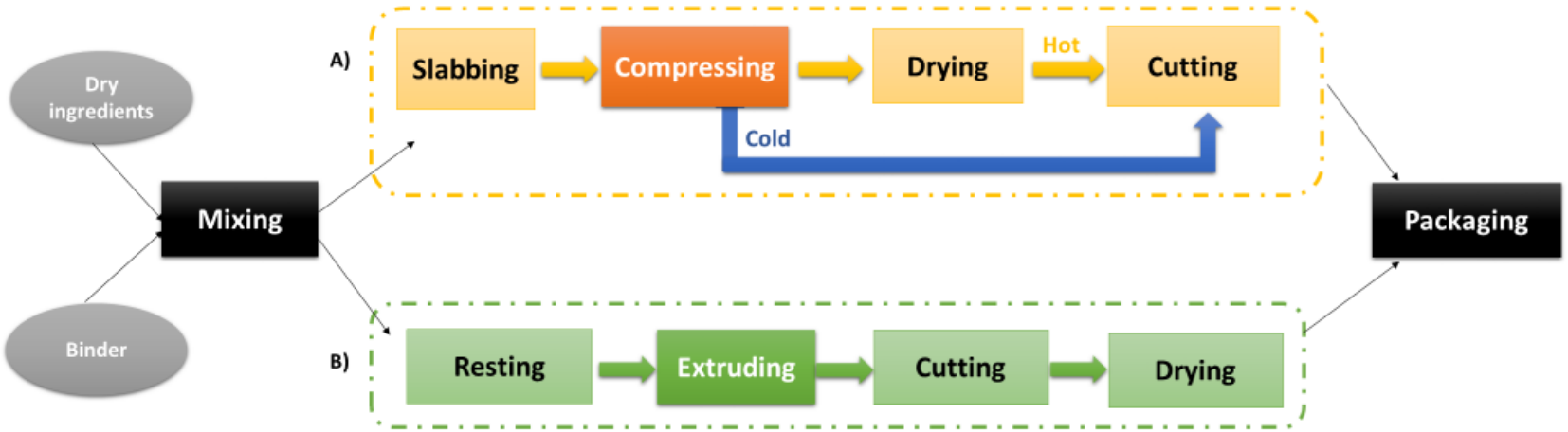

Figure 1: General diagram of CB production. A) Pressed CBs, where the mixture is slabbed and then gradually compressed through a series of rollers until it reaches the desired thickness. Then bars can be dried and then cut (hot processing) or directly cut (cold processing). B) Extruded CBs, where the mixed ingredients are left to rest to soften the texture of dry ingredients and then extruded, cut and dried.

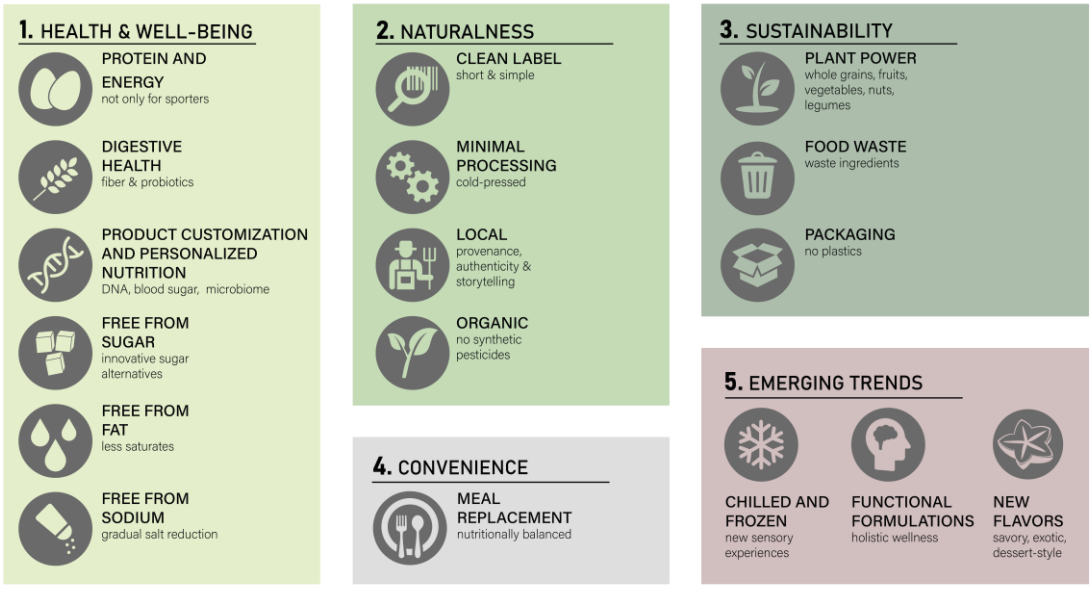

Figure 2: Summary of current and emerging trends in new product development of CBs.

Figure captions

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