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Processed food classification: Conceptualisation and challenges

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A R T I C L E I N F O

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A B S T R A C T

Background: Processed foods are typically praised/revered for their convenience, palatability, and novelty; however, their healthfulness has increasingly come under scrutiny. Classification systems that categorise foods according to their "level of processing" have been used to predict diet quality and health outcomes and inform dietary guidelines and product development. However, the classification criteria used are ambiguous, inconsistent and often give less weight to existing scientific evidence on nutrition and food processing effects; critical analysis of these criteria creates conflict amongst researchers.
Scope and approach: We examine the underlying basis of food classification systems and provide a critical analysis of their purpose, scientific basis, and distinguishing features by thematic analysis of the category definitions.
Key findings and conclusions: These classification systems were mostly created to study the relationship between industrial products and health. There is no consensus on what factors determine the level of food processing. We identified four defining themes underlying the classification systems: 1. Extent of change (from natural state); 2. Nature of change (properties, adding ingredients); 3. Place of processing (where/by whom); and 4. Purpose of processing (why, essential/cosmetic). The classification systems embody socio-cultural elements and subjective terms, including home cooking and naturalness. Hence, "processing" is a chaotic conception, not only concerned with technical processes. Most classification systems do not include quantitative measures but, instead, imply correlation between "processing" and nutrition. The concept of "whole food" and the role of the food matrix in relation to healthy diets needs further clarification; the risk assessment/management of food additives also needs debate.

1. Introduction

Food processing plays an essential role in providing edible, safe and nutritious foods to the population, and in food preservation. However, the topic is complex, with many different types of processes that may bring both risks and benefits depending on the context (van Boekel et al., 2010). For example, heat treatment reduces microbial activity which may increase shelf life and reduce food-borne illness, and can also improve digestibility, as well as bioavailability of nutrients or bioactives. To illustrate, it was found that unpasteurised (raw) milk was responsible for 96% of illnesses caused by contaminated dairy products in the US (Costard, Espejo, Groenendaal, & Zagmutt, 2017). Meanwhile, sometimes thermal processing can also have undesirable consequences such as loss of certain nutrients, for example pasteurisation of milk also reduces vitamin C content by 20% (Moltó-Puigmartí, Permanyer, Castellote, & López-Sabater, 2011). Processing can also lead to the formation of toxic compounds, for example heterocyclic amines and polycyclic aromatic hydrocarbons in processed meat, and acrylamide, a by-product of the Maillard reaction, while also resulting in browning and other desirable sensorial changes (van Boekel et al., 2010).

There is reportedly negativity and misconceptions regarding processed foods in the media and by consumers (Dwyer, Fulgoni, Clemens, Schmidt, & Freedman, 2012; Fox, 2012). Furthermore, concerns about the health risks of industrial processing, diet quality and chronic diseases, have led to the development of food classification systems which distinguish between different categories of processed foods (Moubarac, Parra, Cannon, & Monteiro, 2014). Notably, the NOVA classification system introduced the term "ultra-processed" food, and has subsequently influenced dietary guidelines in Brazil (Ministry of Health of Brazil, 2014), Uruguay (Ministry of Public Health of Uruguay, 2016),

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Ecuador (Ministry of Public Health of Ecuador, 2018), Peru (Peruvian State, 2019), Belgium (Flemish; Flemish Institute for Healthy Living, 2019) and France (Haut Conseil de la Santé Publique, 2017) (for English summaries, see Food and Agriculture Organization of the United Nations (FAO), 2019). The NOVA classification system has been extensively applied in studies of food availability, diet quality, and health outcomes, particularly obesity (Monteiro et al., 2018a; Moubarac et al., 2014). This novel approach is recognised by reports commissioned by the Pan American Health Organization (Pan American Health Organization of the World Health Organization, 2015) and by the Food and Agriculture Organization of the United Nations (FAO, 2015), although the latter also endorses an alternative system created by the International Agency for Research on Cancer (IARC). The paradigm shift towards classification of foods based on processing disregards established nutrient-based methods ("nutritionism") and moves away from traditional food groupings (e.g. "cereals and cereal products" and "meat and meat products"), which has led to heightened debate about the concepts and terminology surrounding processed foods.

Given the variability in criteria employed to classify foods according to their processing level, debate has arisen regarding their relative merits (Bleiweiss-sande et al., 2019; Crino, Barakat, Trevena, & Neal, 2017; Jones, 2019; Moubarac et al., 2014). A systematic review, carried out by NOVA authors, rated their own classification most highly, based on their own criteria and judgment (Moubarac et al., 2014). Yet, other authors have criticised this classification for being inconsistent and flawed, and based on broad and ambiguous definitions which are not backed by scientific evidence (Gibney, 2019; Gibney, Forde, Mullally, & Gibney, 2017). Meanwhile, proponents of NOVA counter-propose that the relationships these critics have with the food industry pose a conflict of interest (Mialon, Sêrodio, & Baeza Scagliusi, 2018).

Definitions give meaning to words, avoid multiple interpretations, and enable a common understanding. A good definition must describe all essential attributes, not be too wide or too narrow, avoid circularity, use terms with clear meanings and define what it is rather than what it is not (Aronson, 2009). Several publications have critically analysed definitions surrounding the term processed foods (and food processing), indicating confusion and dispute coming from different perspectives of public health, nutrition, dietetics and food science and technology (Botelho, Araújo, & Pineli, 2018; Fox, 2012; Gibney, 2019; Gibney et al., 2017; Jones, 2019; Jones & Clemens, 2017; Knorr & Watzke, 2019; Moubarac et al., 2014; Weaver et al., 2014). The definitions used by NOVA, popular press and websites, are distinctly different to legal and food science and technology definitions (Botelho et al., 2018; Jones, 2019; Jones & Clemens, 2017). For instance, according to the US Department of Agriculture's (USDA) definition, processed food "is any raw agricultural commodity that has been subject to … procedures that alter the food from its natural state" (as cited in Jones, 2019). Botelho asserts that in food science and technology, the level of processing is based on the intensity, duration and number of unit operations or steps [i.e. process], *in relation to* the changes in (physical, chemical or biological) properties which affect shelf life, food safety and quality, and bioavailability (Botelho et al., 2018). In contrast, according to the NOVA classification system the mere addition of sugar, salt, fat or additives, increases the processing level. This is disputed by Botelho and Jones who argue that the nutritional content largely depends on the recipe (ingredients) and not the process; ingredients and processing are regarded independently (Botelho et al., 2018; Jones, 2019).

Many critiques of the classification systems are negative, focusing on their flaws from a narrow perspective, without balanced consideration of the intentions (Botelho et al., 2018; Gibney, 2019; Gibney et al., 2017; Jones, 2019; Knorr & Watzke, 2019). Given the wide criticism and misunderstandings over the classification systems, and the definitions used, it is important to examine their basis comparatively and understand the distinctions. This warrants further review, to deepen understanding of the debates and make more meaningful conclusions, enabling collaborative progress towards healthier and more sustainable diets.

This review aims to critically examine constructs of processed food classification systems, through a qualitative analysis of definitions and the underlying intentions; to evaluate the findings in context of diverse perspectives; and to highlight the main areas of debate.

2. Followed approach

We conducted a critical literature review, via the following databases: Web of Science, Scopus, CAB Abstracts, ScienceDirect, PubMed, and Medline, using the search terms 'processed food(s)', 'define(s)', 'defined', 'definition(s)', 'ultra-processed' and 'ultraprocessed'. An additional proximity search using the term 'classification(s)' was performed in Medline. Additional references were retrieved through citations and conference proceedings (n = 11). Non-English language papers (n = 51) were excluded.

A total of 470 publications were screened for definitions of processed food(s), which were extracted. Definitions from non-peer reviewed papers (except textbooks) and extensional and contextual definitions were excluded. This resulted in 146 definitions (not all unique) which were grouped by categories of processed foods (e.g., "minimally processed food"), origin (created by) and whether they belong to a recognised classification. For the purposes of this review, we focused the analysis on the underlying constructs of the classification systems. There has been limited critical analysis of category definitions and the underlying rationale of the classification systems. Given the variety of classification systems that exist, the proposed critical analysis of definitions and rationales will bring greater clarity to future debates.

The major classification schemes, and the main papers defining these classification systems, were identified. The papers were examined for the stated intention behind the development of the classification, and the underlying basis of the classification. Descriptions of the classification systems and the themes of the definitions used were explored to further interpret the features distinguishing among the categories.

3. Major outcomes

3.1. Classification systems

The classification systems are outlined in Table 1. There are notable disagreements among experts about how level of processing should be classified. Several classification systems have been reproduced in multiple papers (with modifications). The NOVA classification system is the most widely published, 37 of the retrieved papers referenced NOVA when defining ultra-processed foods, with disparate definitions emphasizing different elements (combined in Table 1, citing the main references from the founding authors). Sometimes divergent definitions even appear within one paper (e.g., in the text vs. table/supplement; see Steele et al., 2016).

3.2. Reasons for development

Most of the classification systems are introduced by expressing concerns about the food transition to industrially-made products and a concomitant increase in chronic disease (Asfaw, 2011; Fardet, 2018; Monteiro, Levy, Claro, de Castro, & Cannon, 2011; Moubarac et al., 2014; Slimani et al., 2009). For example, Slimani et al. (2009) refer to the agricultural and the industrial revolutions leading to increased consumption of certain foods (e.g., refined sugars). The authors state that "a growing body of scientific evidence suggests that increased consumption of industrialized foods increases the risk of various chronic diseases" (Slimani et al., 2009). While Fardet (2018) describes "a fourth nutrition transition", the introduction of ultra-processed products in the 1980s, "the era of fractionated–recombined foods added with numerous ingredients and additives". Also, embedded in the rationale for the NOVA and Siga classification systems, is a critique of nutrient-based approaches and the relevance of conventional food groupings to industrial food products (Fardet, 2018; Monteiro, Levy, Claro, De Castro, & Cannon, 2010).

In response to the indiscriminate use and application of the term "processed food" and its potential utility as a variable in epidemiological analyses, researchers have increasingly sought to develop appropriate means of operationally defining the term.

In general, these classification systems were designed by researchers to study the relationships between industrial products and nutritional intake and/or health or risk of disease (Chajès et al., 2011; da Costa Louzada et al., 2017, 2015; Monteiro, 2009; Monteiro et al., 2010, 2011, 2018a, 2018b, 2019; Moubarac et al., 2014; Moubarac, Batal, Louzada, Martinez Steele, & Monteiro, 2017; Schnabel et al., 2018; Slimani et al., 2009). NOVA has since also been recommended for use as the basis of dietary guidelines (Moubarac et al., 2014). The Siga classification system seeks to improve upon NOVA, and to be a tool to help industry revise their product offering and guide consumers (similar to labelling schemes) (Fardet, 2018; Siga, 2019).

While the classification system of the International Food Information Council (IFIC) has been used in research, it was created to provide a communication tool to communicate facts, clear up misinformation and guide consumers (Eicher-Miller, Fulgoni, & Keast, 2012, 2015; International Food Information Council, 2010). As such, it emphasizes the benefits of food processing.

3.3. Basis

The basis of the classification systems is often not explained further than "degree of processing" (Asfaw, 2011; Chajès et al., 2011; Slimani et al., 2009). Where more details are given, these refer to the *extent of change* (from the natural state) (Eicher-Miller et al, 2012, 2015; Poti, Mendez, Ng, & Popkin, 2015). However, it is not clear how this is determined. The category definitions imply classification based on the *nature of change*, including changes to a food's inherent properties, or by the addition of ingredients including fat, sugar or salt, or food additives. Siga is based upon the holistic approach, which views whole food as more than the sum of its parts (Fardet, 2018).

NOVA and Poti classification systems cite definitions of food processing that are restricted to the methods used by *industry* (Monteiro et al., 2010; Poti et al., 2015). Only a few classification systems appear to also classify foods processed *at home* (IARC-EPIC, Louzada, IFIC), whereby home-made foods can be "minimally" or "moderately" processed (Chajès et al., 2011; da Costa Louzada et al., 2015; Slimani et al., 2009). Some classification systems include socio-cultural elements, for example by segregating culinary ingredients because they are used in home cooking (Monteiro et al., 2018a; Monteiro, Moubarac, Cannon, Ng, & Popkin, 2013; Moodie et al., 2013; Moubarac et al., 2014).

The categorisations implicitly reflect the extent of transformation from ingredient to product (and value-added). Classification systems refer to the value brought by processing: preservation, safety, making foods edible or enjoyable to eat, and increasing convenience. Hence there are blurred lines between the concepts of processing and convenience, which are classified separately by Poti (Poti et al., 2015). The NOVA and Poti classification systems also reportedly assess the "*purpose*" of processing (Monteiro et al., 2018a; Poti et al., 2015), which appears to relate to consumption of natural foods or consumer cooking and eating habits, however these qualities are not systematically assessed.

Most classification systems based on processing do not include a quantitative nutritional assessment. Only Siga evaluates nutritional content (added fat, sugar, salt) in relation to dietary recommendations (Fardet, 2018).

These elements are illustrated in Fig. 1, and further explored below.

3.3.1. Extent of change

This dimension reflects the extent of change from nature, ranging from unaltered foods in their original form to industrial products. Several classification systems use this definition either explicitly or implicitly: IFIC, the National Institute of Public Health in Mexico (NIPH), IARC-EPIC, NOVA, Poti, and Siga. Some classification systems draw on the concepts of "natural", "wholesome" and "raw" to define the "unprocessed" category. However, these terms are themselves unclear and contested concepts. The IFIC classification system does not include "unprocessed", the lowest level is "minimally processed" (Eicher-Miller et al., 2012).

The classification systems from NIPH and IARC-EPIC both describe un- or non-processed foods as raw, with a few exceptions of [minimal] processing (e.g. cleaning) (as cited in Moubarac et al., 2014; Slimani et al., 2009). The IARC-EPIC classification system assesses each process per food group, for example drying potatoes is deemed highly processed, whereas dried raisins, legumes, green tea, walnuts or parsley are moderately processed, because for these foods drying is "close to the natural process" (Slimani et al., 2009). However, what is considered a "natural" process is a moot point. For instance, food spoilage is a natural process.

According to NOVA, unprocessed/minimally processed foods are natural foods, including plants, animals, fungi, algae and water (Monteiro et al., 2018a). The classification of processed food, as derived by NOVA, is based on the degree of modification of so-called "whole foods", however this term is not clearly defined.

Reflecting the *extent of change*: minimally processed foods are single whole foods; processed foods are whole foods combined with ingredients; ultra-processed foods are defined as formulations of ingredients (Monteiro et al, 2018a, 2019) which typically contain little or no whole foods (Moodie et al., 2013; Moubarac et al., 2014). Hence ultra-processed foods are also described as "not 'real food'" (Monteiro et al., 2019). NOVA refers to several steps/stages in processing ultra-processed foods, involving the fractioning of whole foods into substances and further processing through chemical modification, re-combination, and use of additives (Monteiro et al., 2019). Ultra-processed foods are described as "typically energy dense; have a high glycaemic load; are low in dietary fibre, micronutrients, and phytochemicals; and are high in unhealthy types of dietary fat, free sugars, and sodium" (Moodie et al., 2013).

NOVA makes no distinction between refined and whole grains, all types of rice are included in group 1 (unprocessed and minimally processed foods), and all flours and "raw" pasta in group 2 (processed culinary ingredients) (Moubarac et al., 2014). The Poti classification system separates whole grain foods, but while there is a distinction, basic products such as white rice or whole grain rice are all considered less processed (Poti et al., 2015). Meanwhile IARC-EPIC classifies "white boiled rice" as highly processed, and "wholemeal boiled rice" as moderately processed (Slimani et al., 2009).

Several classification systems assign specific types of processing methods to different categories of processed foods, with little justification or consistency. IARC-EPIC categorises several processes such as pasteurisation, fermentation, smoking, curing (particularly meat) and salting as highly processed (Slimani et al., 2009), whilst these would be deemed by NOVA to be minimally processed or processed (Monteiro et al., 2019).

The classification systems do not encompass processing steps across the entire food chain, for example modern storage and transportation conditions (refrigeration, modified atmospheres etc.), or how foods are processed at home are not considered.

3.3.2. Nature of change

Some classification systems (e.g., Poti, IFIC, Siga, NOVA) refer to the nature of change; categorising foods according to how processing affects the properties of the original food. This includes the addition of ingredients.

3.3.2.1. Changing inherent properties. The Poti and IFIC classification systems reportedly take into account the physical and chemical changes in foods that result from processing (Eicher-Miller et al., 2012; Poti et al., 2015). Using the IFIC classification system, Eicher-Miller et al. suggest that minimally processed foods retain most of their inherent properties (Eicher-Miller et al., 2012, 2015). Similarly, two NOVA papers refer to the maintenance of nutritional properties in minimally processed foods (Fardet, 2016; Monteiro, 2009). NOVA lists processes such as pasteurisation and sterilisation as examples of minimal processes (Moubarac et al., 2014), which have inconsequential effects on nutritional content.

The concept of whole foods is developed further by Siga, which assesses the integrity of the food matrix (Fardet, 2018). Conversely, NOVA appears not to consider the food matrix in its definition of whole food, since it indicates that minimal processes are mostly physical, which would presumably disrupt the food matrix (Monteiro et al., 2010, 2011).

Classification systems are not systematically based on *changing inherent properties*. Processes that have different effects on foods are often assigned to the same processed food category (e.g., drying, crushing, grinding, fractioning, roasting, boiling, pasteurisation, refrigeration, freezing, placing in containers, vacuum packaging, non-alcoholic fermentation are all minimal processing according to NOVA). The nutritional value of starchy foods may be more affected by boiling than non-starchy foods because the gelatinisation of starch makes it much more digestible than when it is in the native state. Grinding and crushing affect the integrity of the food matrix and increase nutrient bioaccessibility, whereas drying, refrigeration and vacuum packaging would be expected to have negligible effects. Conversely, some processes may also be assigned to numerous categories, depending on the publication, even when the same classification system is being applied. For example, sometimes NOVA assigns the processes of hydrogenation and hydrolysis under ultra-processed food (Moubarac et al., 2014), but elsewhere those processes are associated with the production of culinary ingredients (Monteiro et al., 2011; Steele et al., 2016). This may relate to the *purpose* of the process or the function of the product (discussed below, in 3.3.4.*Purpose of processing*).

3.3.2.2. Adding ingredients. Merely adding ingredients is deemed a form of processing. Both NOVA and Poti describe minimally processed foods as single foods compared to multi-ingredient highly/ultra-processed products (Monteiro et al., 2010; Moubarac et al., 2017; Poti et al., 2015). Most classification systems factor-in the ingredients added, either referring to the number, quantity, or type of ingredients. Fat/sugar/salt are considered separately to food additives.

Derivations of NOVA assess whether *fat, sugar or salt are added*, specifying that these ingredients are not added to minimally processed foods (Cooper, Pelly, & Lowe, 2017; da Costa Louzada et al., 2017, 2015; Kimenju, 2018; Monteiro et al., 2019; Moubarac et al., 2014, 2017; O'Halloran et al., 2017). Within the IARC-EPIC classification system, the addition of syrup, oil or sauce, via canning, denotes highly processed foods, compared to canning in juice, water or brine, which would be labelled moderately processed (although brine is high in salt) (Slimani et al., 2009). It is not clear whether other classification systems make this distinction.

Several classification systems assess the use of *additives*. There are nuanced arguments as to how these ingredients should be considered when classifying the "degree of processing". The main concerns are why the additives are used (their purpose) and the number of additives.

Additives are said to be the major ingredients of ultra-processed foods (Moubarac et al., 2014). NOVA also appears to evaluate the function of additives (discussed below, in 3.3.4.*Purpose of processing*). According to Monteiro et al. the mere presence of "flavours, flavour enhancers, colours, emulsifiers, emulsifying salts, sweeteners, thickeners, and anti-foaming, bulking, carbonating, foaming, gelling and glazing agents" can be used to identify ultra-processed products (Monteiro et al., 2019).

Poti et al. (2015) distinguish foods containing additives used for flavour (flavouring single foods) as *moderately* processed. The Siga classification system further categorises the quantity, number and function of additives (Fardet, 2018), as well as the risk. According to the associated website (Siga, 2019), this categorisation is based on the evaluations of the World Health Organization (WHO), the European Food Safety Authority (EFSA) and the French Agency for Food, Environmental and Occupational Health & Safety (ANSES), but further explanation was not provided.

There are discrepancies between how papers using NOVA classify the addition of synthetic nutrients, a process which is sometimes mentioned within the categories of minimally processed foods, culinary ingredients or ultra-processed foods, again perhaps relating to *purpose* (Monteiro et al., 2009, 2019; Moubarac et al., 2014, 2017; O'Halloran et al., 2017). By comparison, IARC-EPIC denotes fortification and enrichment as indicative of highly processed foods (Slimani et al., 2009).

3.3.3. Place of processing

Classification systems (e.g. IARC-EPIC, NOVA, Louzada, NIPH) distinguish between home/artisanal processing and industrial processing, encompassing where the processing occurs, by whom, and the associated methods and ingredients.

One similarity between the systems is the focus on industrial processing. Most classification systems do not classify home-made or artisanal foods, or unquestionably define them as less processed. Indeed, several NOVA authors highlight that some processes used in ultra-processing have "no domestic equivalents" (Monteiro et al., 2018a; Moubarac et al., 2017). Ultra-processed foods also contain ingredients that are generally exclusively used by industry, and not traditionally used, or not available in consumer stores (Cediel et al., 2018; da Costa Louzada et al., 2017; Drewnowski, 2018; Fardet, 2016; Monteiro et al., 2018a, 2019; Moubarac et al., 2014, 2017; O'Halloran et al., 2017). The IARC-EPIC classification system also mentions the use of "industrial ingredients" in highly processed foods (Slimani et al., 2009).

"*Place of processing*" is also evident in elements of the classification system developed by NIPH, which explicitly relate to cultural and social practices, by drawing on the concepts of "traditional" and "modern" preparations, as well as "locally made", to denote "non-industrialized" processed food categories (Gonzalez-Castell, 2007; as cited in Moubarac et al., 2014).

Some classification systems group basic or culinary ingredients together (e.g., oils, sugars, flours, salt), seemingly regardless of the processing. While the original food's natural properties are changed, and turned into products that are typically of higher energy and lower nutrient density, they are intended to be used in preparing/cooking minimally processed ("whole foods"), at home (or in restaurants, i.e. by hand) (Monteiro et al., 2010, 2011).

A further example that implies *place of processing* defines classification includes the labelling of "*mass-produced*" packaged breads as ultra-processed (Monteiro et al, 2018a, 2019), which suggests *scale of production* as a defining feature. Upon further analysis, however, this appears to reflect the ingredients (additives) in mass-produced breads (Monteiro et al., 2019).

3.3.4. Purpose of processing

Some classification systems provide assessments, often limited in depth and scale, as to why food processing was performed, and the value added, i.e. for food safety, preservation, palatability, convenience, profitability, and whether essential or cosmetic. These attributes, however, are complex, and the assessments are largely based on the implicit belief of the assessors that cosmetic food processing is problematic and should be assigned to an "ultra" category.

Explicitly, the NOVA and Poti classification systems do not only assess the "*extent*" of processing, they also judge the "*purpose*" of processing. This includes whether the processing aims to 1) preserve and make (single/natural) foods edible or safe (Monteiro et al., 2018a; Poti et al., 2015), 2) produce culinary ingredients for home/restaurant cooking, or 3) make branded, convenient, attractive (hyper-palatable) and highly profitable (low-cost ingredients) products designed to displace other foods (Monteiro et al., 2018a). NOVA definitions of ultra-processed foods express concern about how these products may influence consumer behaviour and encourage over-consumption, through marketing, convenience and hyper-palatability (Monteiro et al., 2013, 2018a; Moodie et al., 2013). The categories of the IFIC classification system also refer to the function of the food processing (e.g., "Foods processed for preservation") (Eicher-Miller et al., 2012).

The function of additives is (subjectively) judged, reflecting the *purpose of processing*. The NOVA definitions indicate that (minimally processed/processed) foods may contain additives if the *purpose* is to preserve the properties of the original food or prevent microbial proliferation (Monteiro et al., 2019; Moubarac et al., 2017). Hence, additives for preservation and safety of foods are accepted, but those judged as "cosmetic", i.e. used for the *purpose* of disguise, imitation, attraction or palatability, denote the product as ultra-processed (Monteiro et al., 2019; Moubarac et al., 2017). In contrast, Poti distinguishes foods (moderately) processed for flavour, providing these foods are still "directly recognisable as original plant/animal source" (Poti et al., 2015). Whereas definitions of ultra-processed foods allude to fortification (adding nutrients, regardless of whether these are normally contained in the food) (Monteiro et al., 2010; Moubarac et al., 2014). Enrichment (replacing nutrients lost in processing) is given as an example of minimal processing, by NOVA (Monteiro et al., 2019; Moubarac et al., 2017). Fortified ingredients, however, such as iodised salt, are classified as culinary ingredients (Monteiro et al., 2019; Moubarac et al., 2017), again highlighting the unsystematic nature of many of the classification systems.

3.4. Scientific basis

While there are some links between the evidence and the design of the classification systems, they often lack a solid underpinning. Epidemiological studies collect little information on how foods are processed, and existing food composition databases do not contain complete information on processing, or on the compounds found in processed foods (van Boekel et al., 2010).

Slimani et al. refer to direct and indirect evidence which suggests adverse effects of industrially processed foods. For example, a high intake of energy-dense micronutrient-poor foods or sugar-sweetened beverages is linked with obesity; trans fats with cardiovascular disease (CVD); processed meat and salt-preserved foods with cancer; low fruit and vegetable intake with CVD and cancer; fibre-containing foods with reducing risk of colorectal cancer; and our relationship with the food environment, including marketing of energy-dense foods and large portion sizes, is associated with obesity (Slimani et al., 2009). However, in this publication they acknowledged that the World Cancer Research Fund made recommendations for only specific food processing methods (e.g., processed meat preserved by smoking, curing, salting or addition of chemicals), and not on food processing more generally, due to the limited evidence (Slimani et al., 2009). While the IARC-EPIC classification system does account for these known associations, Slimani et al. state that the definitions used "were conservative and independent of any *a priori* knowledge of diet–disease associations" (Slimani et al., 2009). For example, the IARC-EPIC definition of "highly processed" includes staple foods such as cereals, milk and vegetable oils "although their consumption tends to be inversely associated with several chronic diseases" (Slimani et al., 2009).

In early publications of the NOVA classification system, Monteiro et al. also refer to evidence related to specific processed foods such as processed meats, sugar-sweetened beverages and "fast foods" and snacks, and the built environment (Monteiro et al., 2010). Later publications also refer to the process of partial hydrogenation (Monteiro et al., 2018a).

Fardet (2018) supports the role of the food structure or matrix in health effects of food in relation to satiety, glycaemic index, bioavailability and possible synergistic effects of the compounds. Yet he acknowledges that there is a lack of research on the role of food structure, especially related to satiety (Fardet, 2018).

In general, the existing classification systems do not make quantitative, systematic assessments of the properties of the food. Furthermore, they do not directly measure known risks of processing, such as acrylamide formation.

Monteiro et al. (2018a) criticise dietary guidelines for paying limited attention to food additives, but provide no evidence regarding their risks. Fiolet et al. (2018) warn that ultra-processed foods contain "authorised, but controversial" additives, referring to sodium nitrite and titanium dioxide "for which carcinogenicity has been suggested in animal or cellular models" as well as (controversial) effects of intense artificial sweeteners such as aspartame on the gut microbiota and long-term human health. In addition, whilst they acknowledge that the safety of exposure to individual additives is assessed, the maximum permitted levels in a food product are based on the known effects of each individual substance; the authors express concern that the potential "cocktail effects", meaning the interactions of additives in the human body, "remain largely unknown" (Fiolet et al., 2018).

4. Discussion

This review set out to examine the features underlying the classification of processed foods, and to identify the major points of debate. While these classification systems are being used and are deemed relevant to public health, we argue that adoption by others, including influential organisations/bodies, does not therefore mean no further discussion/critique is warranted. There is no clear agreement on what features make a food less or more processed. Clarifying the underlying methods, meanings and rationales of classification is a first step towards standardisation of frameworks for more robust evidence development to inform public health and sustainability policy.

4.1. Degree of processing

There are clear disagreements as to what features determine the degree of processing, reflecting the differences in how processed foods are defined.

Critically, the classification systems may account for any added ingredients, including additives, naturalness, convenience-level, as well as the predicted influence on home cooking and eating habits, in addition to technical processes. These features are not systematically appraised. Likewise, the classifications do not strictly correspond to toxicological risk, although this is partially accounted for. For instance, the Siga classification system assesses the health risk of additives (Fardet, 2018). Highly processed foods as defined by IARC-EPIC, were found to correlate with higher levels of plasma elaidic acid, a trans fatty acid (Chajès et al., 2011). In contrast, Morales, Mesías, and Delgado-Andrade (2020) found that acrylamide and hydroxymethylfurfural (HMF), both heat-induced chemicals, were not significantly higher in NOVA-4 (ultra-processed) than NOVA-3 (processed) foods. There was a trend towards a high acrylamide content in ultra-processed breakfast cereals, but the difference in the classification was not significant to be able to predict higher contaminant levels. Slimani et al. (2009) recommend using biomarkers alongside, or in place of, dietary assessment, i.e. in addition to use of classification systems.

While the classification systems are reportedly based on processing, there is an implicit assertion that the greater degree of processing, the "poorer" the nutritional/health value. The legal definition (USDA) indicates minimally processed foods are processed, but retain their inherent properties (physical, chemical, sensory, and nutritional) (as cited in Jones, 2019), which is similar to the definition cited by the IFIC classification system. Some food scientists/technologists dictate that "minimally processed" fruits and vegetables must also retain an active metabolism of plant tissue (Botelho et al., 2018). Correspondingly, freezing and drying would not be considered minimal processes (Botelho et al., 2018), despite NOVA and Poti defining them as such.

Davidou, Christodoulou, Fardet, and Frank (2020) found that products classified as ultra-processed have on average 13 ingredients, vs. less than 4 ingredients in other processed products. As discussed by Botelho, from a food science and technology perspective, adding ingredients does not define the level of food processing (Botelho et al., 2018), while the classification systems conflate ingredients and processes. However, the USDA definition of food processing includes the addition of ingredients such as fat, sugar, salt, nutrients and additives (Fox, 2012; Jones & Clemens, 2017). Interestingly, the EC Directive No 95/2/EC would appear to support this stance by dictating that unprocessed foods should be free of additives (European Parliament and Council Directive No 95/2/EC, 1995). Meanwhile, since manufacturers are not obliged to indicate processes or their purposes on food labels, Monteiro et al. recommend that ultra-processed products are identified through their list of ingredients, by the presence of at least one substance rarely used in kitchens or 'cosmetic additive' (Monteiro et al., 2019). This raises questions about the relative importance and validity of using ingredients in determining the food classification.

The disagreements over the "degree of processing" possibly stem from different perspectives and intentions since many of the classification systems were developed for epidemiology. The complexity of food processing, including multifactorial processes, with diverse and varying effects on different foods, also makes quantifying or classifying the degree of processing challenging and difficult for scientists to agree on even for those who are very familiar with the processing methods.

4.2. Industry vs. home/artisanal

Positioning home/artisanal processing as "less processed", suggests that the methods and ingredients used by industry are nutritionally or otherwise inferior. To some extent, this is well justified: for instance, the industrial process of *partial* hydrogenation, which has no domestic equivalent, used to turn liquid oils into solid fats, leads to the formation of trans fat, which has been discovered to be harmful to human health. Hence, industrially-produced trans fats are being removed from the food supply (World Health Organization, 2019).

However, some processing methods such as cooking, fermentation, drying, salting, and smoking are ancient techniques, used both at home and industrially (Floros et al., 2010; Weaver et al., 2014). Such methods, whether used at home or industrially, can have similar effects on food, including acrylamide formation, which may negate this apparently subjective distinction (van Boekel et al., 2010; Weaver et al., 2014). Acrylamide is unavoidably formed during heat treatment (above 120 °C) of starch-rich foods, between asparagine and reducing sugars via a Maillard reaction. Increased cooking temperatures and times can increase acrylamide formation. This can be countered by adding processing steps, changing processing methods and/or starting materials. Acrylamide content is regulated and checked within the food industry, whereas chefs and home cooks/consumers may need guidance on how to reduce acrylamide formation and exposure (Mesias, Delgado-Andrade, Holgado, & Morales, 2020; Sanny, Jinap, Bakker, Van Boekel, & Luning, 2012). Therefore, the focus on industrial processing in dietary guidelines, may imply that home-made foods are unequivocally healthier (nutritionally superior and pose less health risk), when this is not necessarily the case (Jones, 2019; van Boekel et al., 2010).

From a food science and technology perspective, processes can be optimised to enhance the positive and minimise the negative effects, which may be better controlled on an industrial scale than at a household level (van Boekel et al., 2010). The definitions of minimally processed foods describe treating the food "as little as possible, but as much as necessary", to preserve nutritional and sensory quality and guarantee food safety (Alzamora, López-Malo, Tapia, & Welti-Chanes, 2016). Minimal processing is often achieved with "the combination of several mild antimicrobial agents" (hurdles) (Alzamora, López-Malo, Tapia, & Welti-Chanes, 2016). This includes emergent technologies (such as high pressure, ultra-sound, and pulsed electric fields) (Alzamora, López-Malo, Tapia, & Welti-Chanes, 2016), which are not traditional methods used at home.

NOVA raises concern over several processes that have no domestic equivalents, such as extrusion and moulding, and pre-processing for frying (Moubarac et al., 2017). However, pre-treatments before frying can be beneficial, for example blanching potatoes before frying can reduce oil absorption and adding an enzyme (asparaginase) can prevent the formation of acrylamide (van Boekel et al., 2010). Hence, here an additional processing step has nutritional benefits and reduces health risks, again highlighting the limitations of assuming "linear" correlations between the extent of processing and the value of the final product.

Comparatively, Fardet and Rock indicate the concern regarding industrial processing is the use of processes that greatly breakdown the food matrix, such as puffing, extrusion cooking, extreme fractioning and refining (Fardet & Rock, 2019). These "dramatic processes" are suggested to make starch and sugars more easily accessible to digestive enzymes and lead to rapid increases in blood glucose levels, potentially leading to increased risk of weight gain and type 2 diabetes (Fardet & Rock, 2019).

In summary, whilst industrial processing can have unintended consequences, there is nevertheless a need to understand and monitor the health-related outcomes of food processing both industrially and at home to provide an evidence base for this distinction.

4.3. Conflicts with dietary guidelines

Classification systems based on processing are not always aligned with nutritional guidelines. Crino et al. (2018) found "Sugars, honey and related products" were all (100%) classified as *discretionary* (energy-dense and nutrient-poor foods, considered not necessary for providing the nutrients the body needs), whereas only half (52%) of these foods were *highly processed* (Poti classification system). This is because sugar is considered a processed basic ingredient, while honey is considered un/minimally processed (Crino et al., 2018; Poti et al., 2015). However more foods were classed as highly processed than discretionary, and this includes products which are not nutrient-poor, such as hummus (Crino et al., 2018). Likewise, Derbyshire showed that many ultra-processed foods are not deemed "less healthy" according to the UK nutrient profiling model (Derbyshire, 2019). Furthermore, Crino et al. (2018) found that levels of saturated fat were actually higher in foods defined by Poti as *moderately* compared to *highly* processed. Unprocessed foods such as cream (as categorised by the IARC-EPIC classification system; Slimani et al., 2009), are also high in saturates, and no distinctions are made between plant and animal fats. Gibney also highlighted the incongruity of the NOVA categories with regards to sodium content (Gibney, 2019).

The conventional nutrient-based approach ranks foods for their contribution to dietary intakes, for example, Bailey et al. identified sweetened beverages and sweet bakery products are among the highest contributors of added sugars (Bailey, Fulgoni, Cowan, & Gaine, 2018). Such an approach allows targeted public health strategies, tailored for different population groups. This study also found that for diets with the highest intakes of added sugar, tea and coffee (which are classified as unprocessed/minimally processed by NOVA) are also one of the top sources of added sugars, which illustrates a shortcoming of the classification system (Bailey et al., 2018).

The socio-cultural concerns are apparent in wider discussions about ultra-processed foods, which describe negative social, cultural and environmental impacts, including "weakening of traditional food cultures, the loss of culinary diversity and the decline of family life" (Monteiro et al., 2011). The will to go back to traditional diets ignores that some cultural dishes, such as churros (in Spanish and Portuguese speaking countries), are traditionally made with refined flour, and high in fat and sugar (Popkin & Reardon, 2018). Likewise, in Europe traditional foods include white baguette (France), white pasta or pizza (Italy), pastry pies (UK) and other calorific foods, further questioning the perceived association between "traditional" and "healthy".

Attention on food processing may exclude consideration of a balanced diet and portion sizes. Furthermore, the focus on home cooking could lead to the presumption that cooking from scratch equals a healthy meal (a biased heuristic). Although evidence is limited, a few studies have found that recipes for home cooking do not meet nutritional guidelines and may even be worse than (ultra-processed) ready meals (Poti, Braga, & Qin, 2017). Cooking at home may bring some benefits in terms of diet, health, as well as developing personal relationships, confidence, and strengthening gender or cultural identities. However, the strength of the evidence to support such a claim is low, and further well-designed longitudinal studies are needed to properly evaluate home cooking (Mills et al., 2017; Reicks, Kocher, & Reeder, 2018).

4.4. Whole foods vs. fractionated substances

The IFIC classification system has been used to demonstrate that nutrients in our diets come from the whole spectrum of processed foods (Eicher-Miller et al, 2012, 2015; Weaver et al., 2014). However, the concerns underlying the development of other classification systems are broader than nutrients.

Some classification systems allude to whole foods, without defining them, or evidencing their benefits. Most discussion around processed food definitions and classification systems is heavily biased towards discussion of ultra-processed foods, rather than the full spectrum.

Fardet perceives "whole, natural and minimally processed foods as more beneficial to a person's health than recombined and refined ultra-processed foods" (Fardet & Rock, 2015). He comments that "whole grain" products are milled and "recombined", and in his opinion do not have the same nutritional value as "natural whole grain foods" (which are not fractionated-recombined), since bioactive compounds act synergistically (as a "whole" package) (Fardet, 2018). This "holistic" approach is opposed to the conventional, reductionist approach which "reduces" the focus on foods/diets to single compounds/nutrients; this divergence appears to trigger disagreement in the literature. It has been noted that the nutrients tracked and catalogued by food databases represent a small fraction of the >26,000 distinct, definable biochemicals in food (Barabási, Menichetti, & Loscalzo, 2019). Fardet (2018) also notes that nutritional indices like the NutriScore only evaluate nutrients and not the food matrix or additives. He goes on to criticise fortification and reformulation for their failure to recognise the "matrix effect" (Fardet, 2018).

Monteiro (and Scrinis) also express scepticism about fortification and reformulation, for focusing on single nutrients, which may bring a "health halo" and lead consumers to believe those foods are healthy (Monteiro, 2009; Scrinis & Monteiro, 2017). However, fortification and enrichment are recognised by some nutritionists as providing important contributions to nutritional intakes (Eicher-Miller et al., 2012; Weaver et al., 2014). Fortification has been shown to improve intake and status of key micronutrients (Hennessy, Walton, & Flynn, 2013). For example, in Finland the prevalence of vitamin D deficiency, in a group of 196 young males, decreased from 19 to 5% within one year of fortification of liquid milk products, butter and margarines (Laaksi et al., 2006). It has also been demonstrated that the prevalence of spina bifida is lower in regions with mandatory vs. voluntary or no folic acid fortification (35.22 vs. 52.29 per 100,000 live births) (Atta et al., 2016).

Scrinis and Monteiro (2017) recommend "wholefoods reformulation" - instead of exchanging ingredients such as fat, sugar or salt with other processed-refined-reconstituted ingredients, replace them with intact or minimally processed ingredients. Davidou et al. state that while minimally processed foods may be altered by processes, such as grinding, the ingredients "have not been highly modified from the initial food matrix" and are "not devoid of protective bioactive compounds" (Davidou et al., 2020).

On further review of the wider literature, whole foods are described as containing a host of bioactives, which can be affected by processing. Studies have shown that the phytochemicals in wheat, barley and beans are primarily located in the outermost layers and/or skin and thus their removal through processing would lower potential health benefits, beyond nutritional analysis (Shahidi, 2009). However, it is not clear cut: different types of processes affect different compounds in different ways. For example, vitamin C is sensitive to thermal treatment, whereas processing tomatoes increases the bioavailability of the phytochemical lycopene (Shahidi, 2009; van Boekel et al., 2010). While the classification systems mention whole foods, they do not account for these effects of processing.

The whole foods concept is associated with a plant-based diet ("Whole-Food, Plant-Based Diet"), rich in vegetables, legumes, fruits, whole grains, nuts and seeds, and which restricts meat, fish, dairy and processed foods (Storz, 2018). The American Institute for Cancer Research definition of minimally processed foods, cited by Jones and Clemens, refers to plant foods (vegetables, grains, beans) (Jones & Clemens, 2017). Accordingly, Monteiro et al. state that whole or minimally processed foods are mostly from plant sources (Monteiro et al., 2018b), although this is not clear from the definitions contained within the classification system.

There is a need to conceptualise whole foods better, and how this relates to plant-based diets, fruit and vegetable intakes and food processing.

4.5. Ultra-processed = unhealthy?

Is ultra-processed just another term to identify "junk food" or "empty calories"? Some scholars equate ultra-processed foods with such value-laden terms (Fardet, 2018; Popkin, Adair, & Ng, 2012). For instance, Monteiro describes ultra-processed foods as "intrinsically unhealthy" (Monteiro et al., 2019). Fardet also asserts that ultra-processing produces "unhealthy foods, rich in energy and poor in protective micronutrients and fiber, i.e., "empty" calories" (Fardet, 2018).

However, "junk food" is an abstraction, where *junk* refers to low-quality and is implicitly unhealthy (Finardi & Tognon, 2014). Finardi and Tognon (2014) recommended to underpin the meaning of "junk food" with nutrient profiling combined with a calculation of preservatives and additives that improve taste and are suggested to trigger over-consumption ("emulsifiers, texture ingredients, sweeteners and flavour enhancers"). They also suggested a holistic assessment of a product, including advertising, availability and price (Finardi & Tognon, 2014). This parallels the intentions of the ultra-processed category which refers to additives and other features associated with over-eating, except the NOVA classification system does not include nutrient profiling and other aspects are not formally assessed.

Fardet and Rock clarify that ultra-processed foods are not only "junk foods", they include products marketed as healthy. The authors indicate a key distinction between the concepts, ultra-processed foods are made-up of fractionated ingredients "detached from their 'natural' food matrix" (Fardet & Rock, 2019). As discussed previously, this concept needs further development and consensus.

As previously alluded to, in 4.3. 'Conflicts with dietary guidelines', there are alternative concepts of less healthy foods, including "discretionary foods" (Australian Government Department of Health Ageing, 2013) and "high in fat, salt and sugar (HFSS)" foods (UK Department of Health and Social Care, 2011), and other nutrient profiling models. There are lots of other terms sometimes used interchangeably, many of which are not scientifically defined.

The foods categorised as ultra-processed generally have poor nutrient profiles, and dominate the market (Luiten, Steenhuis, Eyles, Mhurchu, & Waterlander, 2015; Monteiro et al., 2013). Notwithstanding the debate around the classification of processed foods, healthier choices could be made easier through reformulation and new product development. Healthier options must be more accessible (and prevalent) and fulfil the needs of consumers e.g. convenience.

4.6. Weight of evidence

Implicit in processed food classification systems is their public health implications, especially when used to define dietary guidelines. However, evidence for association between processed foods and health outcomes is not clear. It appears that the classification systems were developed to generate evidence regarding broader categories of processed foods, in order to make generalised conclusions about industrial processing. Hence, studies using NOVA are cited to support claims made by the definitions, which may be a circular argument. Poti et al. (2017) concluded that while there is "fairly consistent" evidence that intake of ultra-processed foods is associated with obesity and cardiometabolic health, it is not yet clear whether this is independent of nutritional content (or related to processing). Further longitudinal studies that control for such confounding are needed (Poti et al., 2017). Hence, there is an ongoing search for a causal relationship between properties of ultra-processed foods and health outcomes.

Gibney argues that we still need to understand fully how food structure and texture influences eating behaviour and satiation/satiety, and there is insufficient evidence to support the existence of "hyper-palatability" (Gibney et al., 2017) a negative consequence often equated with ultra-processing.

A good starting point is a randomised controlled trial which found that people consumed more energy and gained weight when provided an ultra-processed diet, versus an "unprocessed" diet (matched for energy, macronutrients, sugar, fibre, sugar and sodium) (Hall et al., 2019). Further research is needed to uncover the underlying mechanism, which is speculated to relate to a greater eating rate (observed), oro-sensory properties (texture), appetite regulating hormones, or differences in energy density, protein content or the gut microbiome response (Hall et al., 2019). Forde, Mars, and de Graaf (2020) showed that the link between "ultra-processed foods" and obesity may be confounded by differences in energy density and eating rate, highlighting the relevance of "energy intake rate" (kcal/min). Another study identified that "cost per calorie" may be another mechanism linking ultra-processed foods with negative health outcomes (Gupta, Hawk, Aggarwal, & Drewnowski, 2019). We also speculate that the "intactness" of the food matrix may influence digestibility and metabolisable energy, as shown with almonds (Grundy, Lapsley, & Ellis, 2016).

Regarding food additives, the debates may result from a lack of understanding of the process of risk assessment/management *or* disagreement over how the uncertainties or limitations of the available knowledge, are handled. Food additives are evaluated at a global level by CODEX and by EFSA in the EU and by the Food and Drug Administration in the US. Recently, EFSA has been re-evaluating all food additives that were authorised for use prior to 2009 and has adopted several measures to safeguard independence and scientific integrity (Commission Regulation (EU) No 257/2010; EFSA, 2017). In 2019, EFSA introduced "a harmonised framework to use across its scientific panels when evaluating the potential "combined effects" of chemical mixtures in food and feed" (EFSA, 2019), although the extent to which this framework has been applied is not yet clear. The risk assessment includes review of all available evidence, and communication of uncertainties. Risk managers may apply *the precautionary principle* and "take measures without waiting until all the necessary scientific knowledge is available", when there are uncertainties around safety which warrant a precautionary approach (Commission of the European Communities, 2000). For example, due to the uncertainty regarding the carcinogenicity of titanium dioxide, the French government has decided to temporarily suspend the use of this additive (Boutillier, Fourmentin, & Laperche, 2020).

4.7. Moralisation

Similar to previously published reports (Crino et al., 2017; Gibney, 2019), this literature review identified that classification systems may be laden with ambiguous terms: for instance, the use of terms such as "natural" (e.g., *"minimally processed foods are natural foods";* Monteiro et al., 2018a). These value-laden terms may not be helpful for consumer understanding and choice when they are used to imply the level of healthfulness. Siegrist and Sütterlin (2017) explained that "perceived naturalness is a heuristic attribute that consumers may use as a positive indicator of the quality of foods" and "the use of heuristics can result in biased decisions". Meanwhile, naturalness is not legally defined, and from a natural science perspective, naturalness does not equal healthy and natural components in foods can also be toxic (Barabási et al., 2019; Román, Sánchez-siles, & Siegrist, 2017). Conversely, both risks and benefits of ingredients and technological innovations and their contribution to healthy and sustainable diets, for example, alternative protein sources, must be assessed.

Definitions of processed foods overlap with those of convenience foods. *Convenience food* is also "a highly contested food category", which similar to *processed foods*, are "frequently contrasted with 'fresh' foods using raw ingredients, cooked from scratch" (Jackson & Viehoff, 2016). Jackson and Viehoff (2016) report that "the consumption of convenience food is frequently moralized". The term "convenience" is traditionally associated with "laziness, immorality and unhealthiness" (Jackson & Viehoff, 2016). Home cooking is highly valued, seen as "good", and using convenience products is guilt-ridden and even a source of shame (Jackson & Viehoff, 2016; Wheeler, 2018). Comparably, the mere fact that "processed culinary ingredients" are associated with domestic activity seems sufficient, according to some classifications systems, to "upgrade" such food processing to "low or moderate".

Different social practices are intertwined. Jackson and Viehoff (2016) believe that any attempt to change the use of convenience foods would need to consider the constraints of other social practices (not only shopping, cooking, eating, but also relationships, transport, work etc.). The authors recognise that "convenience" and "care" are not mutually exclusive, and the use of convenience foods can represent an expression of care and fulfil values such as family time. Popkin and Reardon (2018) point out that the market of processed foods, and consumer demand for these foods, developed together, reinforcing each other. This was partly related to the increase in women working outside the home, and the need to save time. To focus only on the promotion of cooking denies the need for convenience.

5. Conclusion and future trends

There are a great number of food processing classification systems and a growing debate about the value/meaning of such categorisation. This paper set out to provide a critical overview of these classification systems and develop a map of criteria underpinning different systems. Food processing and the degree of processing are interpreted in different ways. The classification systems address multiple characteristics of industrial foods as well as eating culture and hence the debates are multifaceted. 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.

In addition to the conflicts with nutritional advice, guidelines based on food processing could be misinterpreted as meaning that processing in itself is bad. Potentially this could encourage consumers to seek out unprocessed foods (e.g. raw milk) or process foods at home, without sufficient food safety controls, and such consumer rejection could also hamper sustainable innovations. This raises the question of whether focusing on "processing" is the optimal approach for food communication.

The bases of the classification systems are not well articulated or evidenced, and highly debated, therefore not yet appropriate for use in policy. Using highly subjective and value-laden terms risks perpetuating misconceptions and other unintended consequences. Greater attention towards how consumers understand food processing is necessary. Caution is needed to balance simple messaging and heuristics with scientific accuracy and to avoid unintended consequences. It would be interesting to analyse in further detail how processed foods are positioned in dietary guidelines.

Some concerns about ultra-processing appear to be communication/regulatory issues, such as the marketing of reformulated or fortified products. For example, when processed ingredients are marketed as "real foods" such as a product containing strawberry flavouring labelled with an image of a strawberry. The scientific risk assessment and risk management of additives, particularly in relation to new and/or frequent combinations, needs further scientific debate.

All stakeholders need to work together, to improve the scientific basis of such classification systems and to support consumer understanding. How processing techniques can be better monitored by food databases, for epidemiological research, needs attention. The concept of "whole food" and the role of the food matrix in relation to the classification of processed foods and healthy diets needs further clarification, and consideration in product development alongside nutrient profiling. The environmental, economic and social impacts of food products could be more comprehensively examined through a Life Cycle Assessment approach (Notarnicola et al., 2017; Silva & Sanjuán, 2019).

Author contributions

Christina R. Sadler: Conceptualization, Methodology, Investigation, Writing – Original Draft, Writing - Review & Editing, Visualization. **Terri Grassby:** Conceptualization, Writing - Review & Editing, Supervision. **Kathryn Hart:** Conceptualization, Writing - Review & Editing, Supervision. **Monique Raats:** Conceptualization, Supervision. **Milka Sokolović:** Conceptualization, Writing - Review & Editing, Supervision. **Lada Timotijevic:** Conceptualization, Writing - Review & Editing, Supervision.

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Appendix

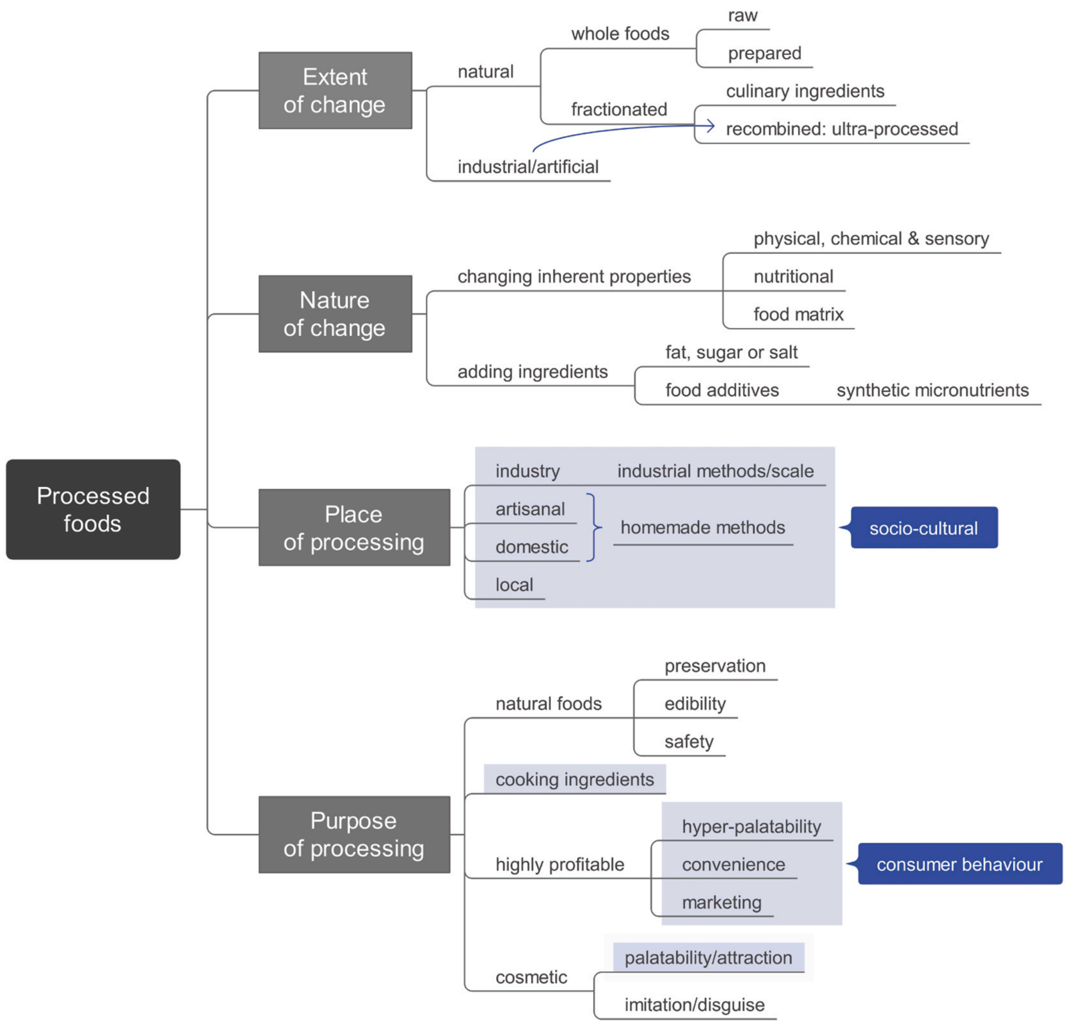

Fig. 1. The various dimensions used in the conceptualisation of processed foods: extent of change from natural state, the nature of the change, place representing by whom, where, with traditional or modern/industrial methods, and the purpose or value of processing. The blue-shaded areas highlight elements which relate to socio-cultural factors and consumer behaviour.

Table 1
Overview of intention and basis of classification systems

Classification	Stated intention	Categories	Basis	Food processing definition
NIPH (National Institute of Public Health in Mexico; González-Castell et al., 2007, as cited in Moubarac et al., 2014)	Epidemiology.	1. Non-industrialized 1.1 Not processed 1.2 Locally made traditional foods 1.3 Traditional preparations outside the home 1.4 Modern preparations outside the home 2. Industrialized traditional 3. Modern industrialized	Based on processing and temporality. Distinguishing features: • traditional vs. modern foods • non-industrialized vs. industrialized foods • locally made • unprocessed	
IARC-EPIC (International Agency for Research on Cancer - European Prospective Investigation into Cancer and Nutrition; Chajès et al., 2011; Slimani et al., 2009)	Epidemiology.	1. Foods with unknown process 2. Non processed foods (consumed raw) 3. Moderately processed foods 3.1 Modest processing, no further cooking 3.2 Cooked foods from raw or moderately processed foods 4. Highly processed foods Chajès et al. (2011) also split category 4 into processed	Processes/foods classified per food group, according to "degree of processing". Distinguishing features: • raw vs. prepared/cooked • no vs. modest vs. high processing[1] • home-made[2] vs. industrially prepared • staple food [1]modest/high not defined, only by examples; text suggests modest processing is "close to the natural process".	Transforming ingredients to products.

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Table 1 (*continued*)

Classification	Stated intention	Categories	Basis	Food processing definition
		staple/basic foods and highly processed foods.	[2]home-made foods are moderately processed.	
NOVA (NUPENS/USP(da Costa Louzada et al., 2015, 2017; Monteiro, 2009; Monteiro et al., 2019, 2018a, 2018b, 2010, 2011; Moubarac et al., 2017, 2014; Schnabel et al., 2018; Steele et al., 2016)	Epidemiology. Later recommended as the basis for dietary guidelines.	The NOVA classification has evolved, from 3 to 4 groups. Original (2009) 1. Minimally processed foods 2. Extracted substances 3. Ultra-processed Latest version (2019) 1. Unprocessed and minimally processed foods 2. Processed culinary ingredients 3. Processed food products 4. Ultra-processed products	Classified by "extent (type/intensity) and purpose" of industrial processing. According to Monteiro et al. (2019) "it considers all physical, biological and chemical methods used during the food manufacturing process, including the use of additives." Descriptions vary. Distinguishing features include: • natural, fresh vs. imitation, industrial • not altered vs. several stages • whole foods vs. fractioned substances (little/no whole food) • derived from food/recognisable vs. not recognisable as foods • single vs. 2–3 vs. 5 or more ingredients • no added fat/sugar/salt vs. added to whole foods vs. formulations • none/additives for preservation/ safety vs. additives for cosmetic purposes • prepared at home vs. no domestic equivalent, displaces home cooking • liable to overconsumption (convenience, marketing, hyperpalatable)	Turning fresh foods to products, by industry. It is clearly stated that the classification does not represent an attack on the industry – however it does insist on the need to regulate large transnational corporations whose profits depend on ultra-processed products (Monteiro et al., 2018a).
IFPRI (International Food Policy Research Institute in Guatemala; Asfaw, 2011, as cited in Moubarac et al., 2014)	Epidemiology.	1. Unprocessed (not defined) 2. Primary or partially processed (not defined) 3. Highly processed	Foods are classified "based on the degree of processing" (not further explained). Classified household purchases (does not consider home processing).	
IFIC (International Food Information Council; as cited in Eicher-Miller et al., 2012, 2015)	Communications; also used in epidemiology.	1. Minimally processed 2. Processed for preservation 3. Mixtures of combined ingredients 3.1 Packaged mixes, jarred sauce 3.2 Mixtures, home prepared 4."Ready-to-eat" foods 4.1 Packaged ready-to-eat foods 4.2 Mixtures, store prepared 5. Prepared foods/meals	Reportedly reflecting the complexity of processing and the physical, chemical, and sensory changes. This classification includes home-made foods, either at level 1 (minimally processed, e.g. home-made soup) or level 3 (mixtures of combined ingredients). Distinguishing features: • preservation of inherent properties • minimal vs. complex preparation • level of convenience/value-added	Any (deliberate) change to a food (since origin).
Louzada (variation of NOVA; NUPENS/USP, da Costa Louzada et al., 2015)	Epidemiology.	1. Unprocessed, minimally, or moderately processed foods 2. Processed foods 3. Ultra-processed foods	Also classifies handmade food. Distinguishing features (based on decision tree): • single ingredient vs. two or more ingredients[1] • handmade vs. industrially prepared • food vs. industrial ingredients[2] • if additives/synthetic substances added [1]sterilised milk is group 1 (single ingredient, nothing added/subtracted) [2]refined grains such as flour are group 1 (parts removed, nothing added)	
Poti (Poti et al., 2015)	Epidemiology.	1. Less processed (Unprocessed/ minimally processed) 2. Basic processed 2.1 Processed basic ingredients 2.2 Processed for basic preservation or precooking 3. Moderately processed 3.1 Moderately processed for flavour 3.2 Moderately processed grain products 4. Highly processed 4.1 Highly processed ingredients 4.2 Highly processed stand-alone Separately categorises convenience: 1. Cooking and/or preparation	Based on the "degree of processing based on the extent to which a food was altered from its natural state by industrial food processing and the purpose …" Distinguishing features: • single ingredient vs. multi-ingredient • preservation of properties • ingredients for cooking • recognisable as food • purpose of additives (flavour)	Alters food from natural state, by industry

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Table 1 (*continued*)

Classification	Stated intention	Categories	Basis	Food processing definition
		2. Ready-to-heat or minimal preparation 3. Ready-to-eat		
Siga (Fardet, 2018; Siga, 2019)	Food product/ portfolio development. Consumer guidance.	A. Un-/minimally processed A0. intact raw initial matrix A1. degraded raw matrix A2. culinary ingredients B. Processed B1. added salt, sugars, fat ≤ official recommendations B2. added salt, sugars, fat > official recommendations C. Ultra-processed – loss of matrix/contain purified and/or denatured ingredient (excludes vitamins, minerals, tolerance of preservatives)[1] C01. balanced nutritional profile & one industrial ingredient/ additive (acceptable) C02. high added fat/sugar/salt C1. unprocessed industrial ingredients and/or limited additives; C2. processed industrial ingredients and/or high additives; C3. ultra-processed industrial ingredients and/or very high additives [1]Descriptions of category C differ between book and website; C01 and C02 added.	This seeks to improve the NOVA classification "taking into account the nature, quantity, function, and degree of transformation of the ingredients and/or additives, and the loss of the "matrix" effect to achieve an even more holistic and realistic classification". Category B appears to also apply to foods processed at home. Not clear if this category also accounts for intact/ degraded matrix. Distinguishing features: • if matrix is intact • if quantity of added fat/sugar/salt is above/below recommendations • processed industrial ingredients (purified or denatured) • quantity, number and function of ingredients and/or additives (cocktail effect) • risk of additive	

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