Ristic *et al.*
Food Production, Processing and Nutrition (2024) 6:79
https://doi.org/10.1186/s43014-024-00256-2

Food Production, Processing and Nutrition

REVIEW

Open Access

Towards a definition of food processing: conceptualization and relevant parameters

Dusan Ristic[1,2*], Denisse Bender[3], Henry Jaeger[2], Volker Heinz[1] and Sergiy Smetana[1,4]

Abstract

There are several classifications of foods that also include the level of their processing, with NOVA classification appearing to be the most adopted. However scientific consensus is still missing on how to define, characterize and classify food processing. The classifications are typically based on the health impacts of foods and do not fully include the engineering perspective of processing, i.e., the application of physical, chemical, or biotechnological unit operations during food manufacturing, and the composition of a food product.

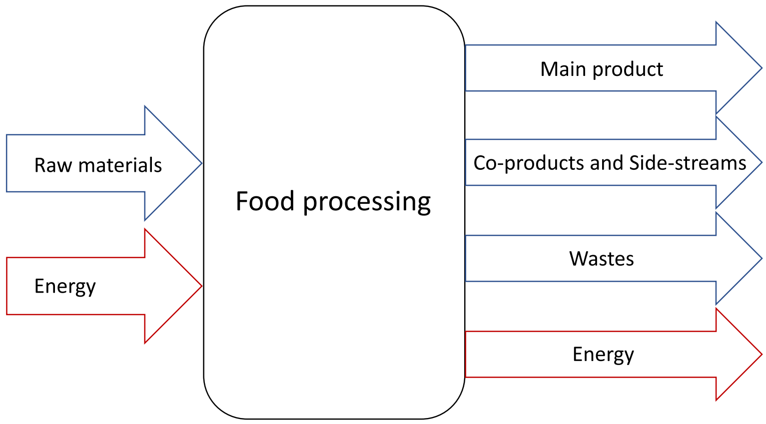
This review offers an engineering perspective and definition of food processing, based on the change of mass and energy, allowing distinguishment of the impacts caused by food processing during the biomass transformation to food products. The improved understanding of the causes of undesired changes in food properties could be used for nutritional public policy recommendations and would contribute to combating some of the chronic diseases related to food consumption patterns.

Proposed is the definition of "Food processing" as a sum of all intentional additions or removals of either edible matter or energy (except for any transport or for removal of inedible parts of food) between the harvest of ingredients and consumption of the product.

Keywords Food processing definition, Processed food, Food biotechnology, Food classification, Food properties

*Correspondence:
Dusan Ristic
d.ristic@dil-ev.de
Full list of author information is available at the end of the article

Graphical Abstract



Introduction

Processed foods are an integral part of our daily lives, as almost all foods are processed to some extent. For millennia, humans have processed food, and there is evidence that this has influenced human evolution (Pellegrini & Fogliano 2017). Ancient processing techniques such as roasting, baking, fermenting, drying, and smoking, are still widely used today. Still, the definition of food processing, the term "processed food" and the level of food processing continue to be among the controversial topics in public discourse.

Food is often altered physically and (bio-)chemically during processing, which determines the final state and form of the food before consumption. These changes influence the sensorial and nutritional properties of food, and hence its perception, consumption, and potential impact on pleasure and health. To investigate potential correlations between food processing and food properties it is necessary to develop an appropriate food processing definition, and then a scientific basis to quantify the intensity of food processing.

According to Lane et al. (2021) and Monteiro, Cannon, Lawrence, et al. (2019), increased consumption of highly processed ("ultra-processed") foods may be linked to a higher risk of developing several noncommunicable diseases as well as all-cause mortality. An increased risk of non-communicable diseases has been linked to being overweight, obesity, abdominal obesity, metabolic syndrome, adult depression, wheezing, cardiometabolic diseases, frailty, irritable bowel syndrome, functional dyspepsia, cancer and dyslipidemia in children (Lane et al. 2021). This is alarming and calls for a comprehensive and in-depth understanding of food processing and the impacts it has on foods.

Definitions of food processing

There is a variety of definitions of food processing, with differences depending on the intended use of the definition, but also on the author's understanding of food processing. None of the definitions appear to be widely accepted as definitive or complete (Sadler et al. 2022). One of the most intuitive definitions of food processing is that it is "any deliberate change in a food that occurs before it is available" for consumption (Augustin et al. 2016). In contrast, in Nova classification, it is defined as "all methods and techniques used by the food, drink and associated industries to turn whole fresh foods into food products" (Monteiro et al. 2010), which was accepted and slightly modified by The European Food Information Council (EUFIC) ("any method used to turn fresh foods into food products" (Eufic 2022) and Food Standards Australia New Zealand (FSANZ) ("activity conducted to prepare food") (Standard 3.2.2 - Food Safety Practices & General Requirements 2023). Similarly, (Poti et al. 2015) accepted the definition that food processing is "any procedure that alters food from its natural state and includes all processes and technologies that transform raw food materials and ingredients into consumer food products", considering only industrial processes. Further, they noted that "with the exception of raw agricultural commodities, all foods and beverages can be considered "processed foods". Some definitions include a range of operations when defining processing (Eufic 2022; Floros et al. 2010; Standard 3.2.2 - Food Safety Practices & General Requirements 2023). European Food Safety Authority (EFSA) made a table of different processing methods applied to food, classifying them both by the technique used and by the end goal (European Food Safety Authority (EFSA) 2017).

It might be worth noticing that some definitions focused on industry and industrial processing, while others omitted it. Indeed, most classification systems that use food processing as a relevant measure do not consider homemade or artisanal foods, or define them as less processed (Sadler et al. 2021, 2022). This leads to favoring homemade or artisanal foods and considering them as healthier (Silva Meneguelli et al. 2020), which appeared to be supported by the machine learning predictions (Menichetti et al. 2023), although home cooking can dramatically vary in quality and lead to significant nutrient changes (de Castro et al. 2021). Even Nova proponents agree that "some types of food processing contribute to healthful diets", criticizing not the food industry as a whole, but pointing towards "a small number of transnational corporations" as the source of the problem (Monteiro et al. 2018, 2021). This is also mostly in line with the perception of consumers, as food items produced at a lower scale are perceived as more natural (Etale & Siegrist 2021). It might, however, be argued that the scale of food processing may not necessarily correspond to the intensity of food processing. This can particularly apply to some novel food processing techniques. Fardet (2016) distinguishes "industrial ultra-processing" by its purpose "to create products that are ready to eat, to drink or to heat, liable to replace both unprocessed or minimally processed foods that are naturally ready to consume". Yet, some operations can be conducted both in an average home kitchen and on a large, industrial scale. There are indications that, when comparing the same meals, the difference in nutrient composition is not caused by industrial processing (Calais & Thituson 2021; Eicher-Miller et al. 2012). The culinary term "food processor", used for "an electric kitchen appliance with a set of interchangeable blades revolving inside a container", implies the understanding of food processing as something that may also be done at the kitchen scale (and that can be limited to physical changes only) (Merriam-Webster 2023b). Ultimately, operations such as washing and drying are often listed among food processing stages, which implies that effectively all foods are processed, as everything that is to be used in human nutrition should at least be washed. It is also noted that the difference in perspectives may be dependent on professional background and area of expertise as well as on professional motivations, with conflict of interest being one of the main challenges (Sadler et al. 2022). Finally, the Food and Agriculture Organization of the United Nations' (FAO) report emphasizes that the terms "processing" and "industrial" are quite generic and are therefore not helpful in making determinations about which foods may be regarded as processed (Monteiro, Cannon, Lawrence, et al. 2019). Interestingly, online focus group discussion between representatives of different stakeholder groups and professions indicates that some (but not all) find the pursuit of a universal definition unnecessary, as a rigid focus may prove to be restrictive and unhelpful. It is commonly recognized that consensus is difficult to achieve (Sadler et al. 2022).

Classifications of food processing

There is a variety of food classifications, each developed for its specific purpose, and each has its strengths and weaknesses. Making a single comprehensive classification that fits all purposes is a very challenging task (Hess & Slavin 2016; J. Ireland et al. 2002). Trying to differentiate food systematizations, J. D. Ireland & Møller (2000) proposed their division into food classifications and food descriptions. Then, the food classifications should focus on the end-user of data, grouping or aggregating "foods with similar characteristics", while description systems would be a tool for data originator, focusing on the preciseness of the food description, without the need for aggregation (J. D. Ireland & Møller 2000).

As foods almost always include multiple nutrient groups, it is difficult to group the foods according to their nutritional contribution, including grouping by predominant macronutrients (Hess & Slavin 2016; J. Ireland et al. 2002). Interestingly, EFSA has developed a classification (FoodEx2) focusing on the assessment of exposure to chemical and biological hazards (European Food Safety Authority (EFSA) 2017). Yet, the need for a simple, aggregated food classification that is easily understandable to the end consumer is one of the reasons behind the relatively recent emergence of food classifications according to the level of their processing.

There are several classifications of food that take their processing into account. In this regard, one of the older classifications is the one of food processing itself, into primary, secondary, and tertiary processing of foods (Grumezescu & Holban 2018; Ionescu 2016). But when it comes to the classification of processed foods, typically the aim is to link processed foods with nutrition and health outcomes (Sadler et al. 2021).

Even though there are differences between the systems listed in Figs. 1 and 2, and in Table 1 (number of categories, naming, and definitions of some of them), there are also apparent similarities. Indeed, originally, five of these classifications (FSANZ, which divides foods into processed and not processed, Asfaw 2011; Slimani 2009, IFIC, and University of North Carolina (UNC)) showed a relatively high level of accordance, with 6th classification, Nova, introducing slightly more variations (Crino et al. 2017). However, more recently, another research also comparing the same 5 classifications (Asfaw 2011; Slimani 2009, IFIC, Nova and UNC, but not FSANZ) found

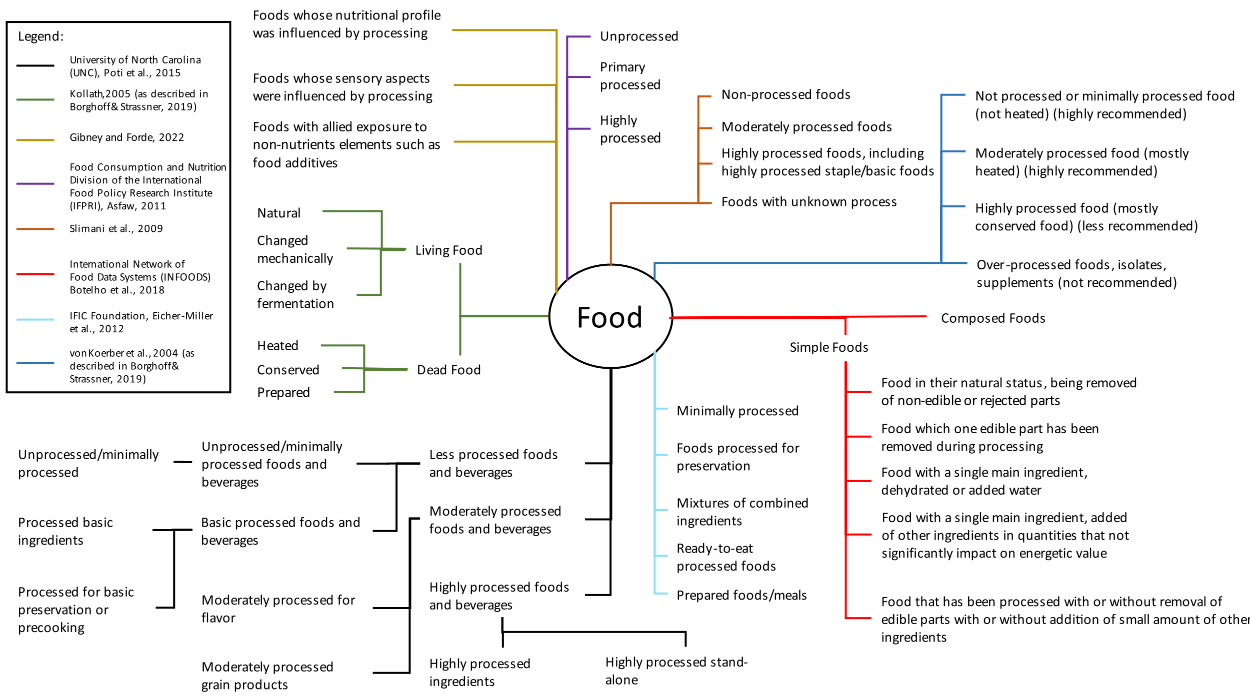


Fig. 1 Different food classifications based on the level of food processing (Asfaw 2011; Borghoff & Strassner, 2019; Botelho et al. 2018; Eicher-Miller et al. 2012; Gibney & Forde 2022; Kollath 2005; Poti et al. 2015; Slimani et al. 2009; von Koerber K et al. 2004)

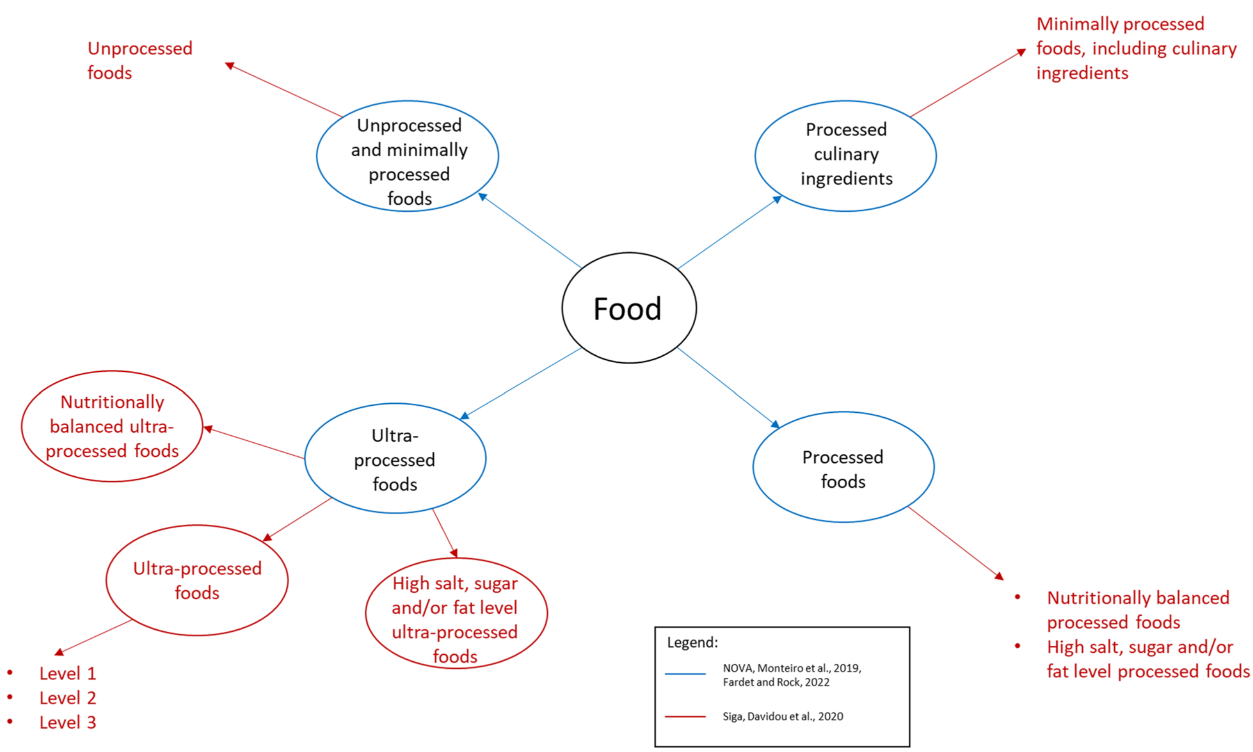


Fig. 2 NOVA and Siga food classifications (Davidou et al. 2020; Fardet & Rock 2022a; Monteiro, Cannon, Lawrence, Laura Da Costa Louzada, et al. 2019)

Table 1 Food classifications based on the level of food processing (Asfaw 2011; Borghoff & Strassner 2019; Botelho et al. 2018; Eicher-Miller et al. 2012; Gibney & Forde 2022; Kollath 2005; Poti et al. 2015; Slimani et al. 2009; von Koerber K et al. 2004)

Classification (authors)	**Food categories**		
University of North Carolina (UNC), Poti et al.,2015	Less processed foods and beverages	Unprocessed/minimally processed foods and beverages	Unprocessed/minimally processed
		Basic processed foods and beverages	Processed basic ingredients
			Processed for basic preservation or precooking
	Moderately processed foods and beverages	Moderately processed for flavor	
		Moderately processed grain products	
	Highly processed foods and beverages	Highly processed ingredients	
		Highly processed stand-alone	
Kollath, 2005 (as described in Borghoff & Strassner 2019)	Living Food	Natural	
		Changed mechanically	
		Changed by fermentation	
	Dead Food	Heated	
		Conserved	
		Prepared	
Gibney and Forde 2022	Foods whose nutritional profile was influenced by processing		
	Foods whose sensory aspects were influenced by processing		
	Foods with allied exposure to non-nutrients elements such as food additives		
Food Consumption and Nutrition Division of the International Food Policy Research Institute (IFPRI), Asfaw 2011	Unprocessed		
	Primary processed		
	Highly processed		
Slimani et al. 2009	Non-processed foods		
	Moderately processed foods		
	Highly processed foods, including highly processed staple/basic foods		
	Foods with unknown process		
von Koerber et al. 2004 (as described in Borghoff & Strassner 2019)	Not processed or minimally processed food (not heated) (highly recommended)		
	Moderately processed food (mostly heated) (highly recommended)		
	Highly processed food (mostly conserved food) (less recommended)		
	Over-processed foods, isolates, supplements (not recommended)		
International Network of Food Data Systems (INFOODS) Botelho et al. 2018	Simple Foods	Food in their natural status, being removed of non-edible or rejected parts	
		Food which one edible part has been removed during processing	
		Food with a single main ingredient, dehydrated or added water	
		Food with a single main ingredient, added of other ingredients in quantities that not significantly impact on energetic value	
		Food that has been processed with or without removal of edible parts with or without addition of small amount of other ingredients	
	Composed Foods		
IFIC Foundation, Eicher-Miller et al. 2012	Minimally processed		
	Foods processed for preservation		
	Mixtures of combined ingredients		
	Ready-to-eat processed foods		
	Prepared foods/meals		
NOVA, Monteiro et al. 2019a,2019b, Fardet and Rock 2022a,2022b	Unprocessed and minimally processed foods		
	Processed culinary ingredients		
	Processed foods		
	Ultra-processed foods		

Table 1 (continued)

Classification (authors)	Food categories		
Siga, Davidou et al. 2020 (expanding NOVA)	Unprocessed and minimally processed foods	Unprocessed foods	
	Processed culinary ingredients	Minimally processed foods, including culinary ingredients	
	Processed foods	Nutritionally balanced processed foods	
		High salt, sugar and/or fat level processed foods	
	Ultra-processed foods	Nutritionally balanced ultra-processed foods	
		Ultra-processed foods	Level 1
			Level 2
			Level 3
		High salt, sugar and/or fat level ultra-processed foods	

that "inconsistencies among classifications were huge and the contribution from highly/UPF presented high discrepancies". These inconsistencies were especially prominent in classifications of cereals and cereal products, milk and milk products, added lipids, sugar and sugar products, and alcoholic beverages, while the level of agreement was the highest for meat, potatoes, fruits, non-alcoholic beverages, and eggs. Interestingly, Nova presented the lowest ultra-processed foods contribution (10.2%), followed by UNC (15.2%), IFPRI (16.7%), IFIC (17.7%), and Slimani 2009 (47.4%) (de Araújo et al. 2022) which is mostly in accordance with results of Martinez-Perez et al. (2021) (Slimani 2009 60.7% of ultra-processed foods in the considered foods, IFIC and UNC 31.1% for both, Nova 27.4%) but exactly the opposite of the results of Bleiweiss-Sande et al. (2019) where Nova classified the highest part of considered 5532 unique foods as highly processed (70%), when compared to UNC (62%) and IFIC (53%) classifications. The obtained results led de Araújo et al. (2022) to conclude that Nova underestimates the contribution of ultra-processed foods – yet they do not give a recommendation on how to appropriately select a classification system. Trying to consolidate the classifications of food by the level of processing, Sadler et al. point out underlying themes that define the food classification systems: 1. Extent of change (from the natural state); 2. Nature of change (properties, adding ingredients); 3. Place of processing (where/by whom); and 4. Purpose of processing (why, essential/cosmetic) (Sadler et al. 2021).

Sadler et al. (2021) conclude that "processing is a chaotic conception, not only concerned with technical processes". Specifically, the term "processed food" is often used in a way that does not reflect processing (Sadler et al. 2022) and for both product formulations, and actions and operations conducted on the food (Forde et al. 2020). Further, "processed foods" is often used in a context associated with health implications without directly referring to processing (Sadler et al. 2022). This reflects the use of the term in a part of the scientific community, too: "The degree and purpose of the processing is recognized to be an important determinant of the food's nutrient profile, and, therefore, diet quality and population's health" (Mertens et al. 2022). This likely explains why the term "processing" was, counterintuitively, not found useful by FAO for the definition of "processed foods" (Monteiro, Cannon, Lawrence, et al. 2019). On the other hand, there are calls for a "robust, objective, evidence-based definition" of food processing and processed foods (Gibney 2022). This all highlights the ambiguity around the extent to which the food matrix and composition can be changed by food processing without altering human health (Fardet & Rock 2022a).

These ambiguities underline the semantical question of distinguishing "processed foods", as foods that have gone through some kind of treatment, and "processed foods" as foods whose nutritional profile was significantly deteriorated or changed by processing, but also potentially in other ways, such as by addition of certain ingredients. Even if the two may overlap, they do not seem to be used with the same meaning. It appears as if the term "ultra-processed foods" was partially introduced because of this unclarity. It may allow referring to foods that have gone through some kind of treatment but are deemed to be less detrimental to health as "processed foods", thus distinguishing them from "ultra-processed foods" which refer to foods that have also gone through some kind of treatment but are deemed to be more detrimental to health. Trying to explain the difference between the "ultra-processed" and other foods, the proponents of NOVA classification even make distinction between "ultra-processed" and "real" foods, implying that the former should not be considered as food at all (Monteiro, Cannon, Levy, et al. 2019).

Going one step further, Siga introduces markers of ultra-processing, defining them as "deliberately added substances obtained by synthesis or by a succession of physical, chemical, biological processes leading to their purification and/or high deterioration compared to the original material". According to this classification, ultra-processed foods contain at least one marker of ultra-processing (Davidou et al. 2020, 2021). However, this does not solve the semantical problem, as the strict understanding of the prefix "ultra" (Merriam-Webster 2023c) may imply that "ultra-processed foods" have simply gone through more extensive processing than "processed foods", which may not necessarily be the case (Levine & Ubbink 2023). On the other hand, if the distinction between "processed-" and "ultra-processed foods" is indeed predominantly based on their impacts on human health, then the naming of the two groups might be misleading, as their names come from processing, not health effects.

Proposed definition of food processing

The exact role and degree of importance of each of the 3 factors, namely health implications, nutritional values, and application of processing, in definitions of "food processing" and "processed foods", remain somewhat unclear. While all three factors appear or are implied in at least some of the above-mentioned definitions, their direct dependencies, discussed below, remain questionable (Ludwig et al. 2019; Srour & Touvier 2021). Until these dependencies are clearly defined, it is challenging to differentiate the impacts caused by food processing from properties of originating biomass translated to final food products (Bröder et al. 2023). The lack of clear differentiation between the nutritional properties defined by a formulation and nutritional properties altered by food processing is discussed by Levine & Ubbink (2023).

In an attempt to re-correlate applied food processing steps and the term "processed food", which should refer to the food that the processing steps were applied to, it is worth taking a step back and looking at food processing, with its inputs and its outputs, as generally as possible. Inputs of food processing include some kind of raw materials or ingredients, and some kind of energy that is spent for the processing. The outputs always include the (main) product but can include some energy, side-streams or side-products, as well as wastes. In short, if considered this way, food processing can be purely theoretically regarded as a sequence of energy and mass transfers, eventually resulting in food as at least one of its products.

Therefore, in this article, "food processing" refers to all intentional additions or removals of either edible matter (mass transfer) or energy (except for any transport or for removal of inedible parts of food) between the harvest of ingredients and consumption of the product. Hence, "processed foods" are those that have gone through some kind of food processing.

To begin with, "edible" refers to the possibility of being used as food, as defined in Article 2 of Regulation (EC)—178/2002 (EUR-Lex 2002). It might be worth tackling here some theoretical, border examples that may contribute to the clarification of the definition. Perhaps counterintuitively, per the above-mentioned definition, not all processing taking place in the food industry is necessarily food processing. For example, the action of packaging food in passive packaging, which is not food, and which does not exchange matter or energy with the food, would not be considered food processing. The use of active packaging, which directly exchanges the matter or energy with the food, would contribute to processing. In that case, consideration of the action of packaging might be somewhat more complicated: if the exchange of mass of packaging with the food takes place, the mass that has entered the food would be considered an ingredient, and then the action of packaging would be considered processing. If an exchange of energy between the packaging and the food takes place, that would be considered a food processing step that occurs in the packaging, and then the action of packaging is not considered food processing. Also, if it doesn't involve an intentional exchange of edible matter or energy with the foodstuff, washing would not be considered processing either. Chilling, however, along with other thermal techniques, would be considered processing, due to the exchange of energy. Many processing steps include processing during which additions/removals of both edible matter and energy take place, however, some novel technologies, such as pulsed electric fields or high-pressure pasteurization can process foods without the (intentional) change in mass – yet the fact that they consume energy in order to process foods qualifies them to be considered as food processing. Further, the definition above can be applied to different scales of food processing, from a home kitchen to large-scale industrial processing. Interesting, highly relevant, and increasingly important border cases are biotechnology applications in food, to which it can be a little more difficult to apply the definition.

Food processing and biotechnology applications in the food sector

Examination of biotechnology applications in the food industry in terms of food processing definitions and quantifications appears to be lacking. Bearing in mind that a variety of fermented foods are used for millennia, it is interesting that they were typically not considered in detail in classifications of food processing. What is more, with the latest developments in biotechnology, the line between (primary) food production and food processing is becoming increasingly blurred and sometimes it appears as if the two are competing. The understanding of processing, in this case, may draw the line between food production and food processing – which, due to different public and legal perceptions of primary food production, or food farming (such as agriculture) and the food industry, may have practical implications.

Rather generally, Britannica defines biotechnology as "the use of biology to solve problems and make useful products" (Britannica 2023). European Federation of Biotechnology proposes a more specific definition: "Biotechnology is the integration of natural sciences and engineering sciences in order to achieve the application of organisms, cells, parts of thereof and molecular analogs for products and services" (Nagel et al. 1992). Food biotechnology was defined as "the application of modern biotechnological techniques to the manufacture and processing of food products as well as food ingredients and food additives" (Kermasha & Eskin 2021). It is worth noting that already the definition of food biotechnology states that it can be used both for food manufacturing and food processing. While biotechnology applications in the food sector are often related to genetically modified foods, other applications are very numerous and various. The rest of this article considers only the non-genetical biotechnology applications in the food sector (food biotech).

The oldest and most widely used food biotech application is fermentation. The resulting fermented foods are defined by The International Scientific Association for Probiotics and Prebiotics (ISAPP) as "foods made through desired microbial growth and enzymatic conversions of food components" (Marco et al. 2021). Fermentation has been considered in some of the definitions of food processing, as some authors list it among the operations through which food processing is accomplished (Floros et al. 2010).

However, food biotech goes beyond fermented foods, as today, biotechnology is being used to make foods both without microbial growth and through conversions of materials that are not all food components. The so-called "Cultured meat", (also "Clean meat", "In-vitro meat", "Cell-based meat", and "Artificial meat") or legally "Human Food Made Using Animal Cell Culture Technology" (U.S. Food & Drug Administration 2023) is one of the examples of food biotech going far beyond traditional foods, but in some countries reaching legal approval. Having in mind how different applications of biotechnology in food are, it is clear that they can hardly be treated as equal when it comes to the level and definition of food processing.

Growing food without soil, and consequently without agriculture (strictly understood) (Merriam-Webster 2023a) is already practiced, in aquaculture, hydroponics, aquaponics, aeroponics, and similar. Thus similarly, the use of biotechnology for the production of new biomass which can be used as food or food ingredients should also be regarded as food production, or farming, and not as food processing. In this article, it will further be referred to as "biotechnological-" or "biotech farming", even though that term has been used before, with a different meaning (Ammann 2003; Bozhinov & Bozhinov 2011). Some of the known examples of foods that can be produced through biotech farming are nutritional yeast and other kinds of single-cell protein, but also the "clean meat".

On the other hand, if the main product is predominantly changed starting food(s), then biotechnology is used as a food processing step. When defining the relationship between food biotech and food processing, the product providing the highest revenue (the main product) of a given process should be the defining factor, similar to the logic applied in economic allocation in life cycle assessment (Ardente & Cellura 2012). In the case of food biotech applied for food processing, the main product refers to foods whose majority of biomass originates directly from the starting foods and whose majority of ingredients, though changed by biological activity, originate from the starting foods. If the main product is newly produced food biomass, then biotechnology is used as biotech farming and should not be considered as food processing. Food produced in biotech farming can also be processed after the farming step.

As food biotech is currently experiencing substantial expansion, the language in the sector is still developing and the vocabulary is not standardized. Many of the terms used are not necessarily making or intended to make a distinction between biotech farming and biotech food processing. For example, "cellular agriculture", as defined by Cellular Agriculture Society (2023), is the process of farming animal products from cells instead of animals. Even though it often refers to production that would fall under biotech farming, it might in some cases also refer to novel types of biotech food processing. Similarly, "precision fermentation", defined as the production of high-value functional food ingredients at high yields and purity with a lower environmental footprint through the utilization of microbial cell factories (Chai et al. 2022), may again refer to both biotech farming and biotech food processing. It can be also expected that some of the definitions in the field of food biotech will be adjusted to accommodate future innovations, as the field keeps growing.

Impacts of food processing on food properties

As proponents of the above-mentioned processing-based classification systems mostly imply that processing decreases the positive health influence of food, or that ultra-processed foods "often have a suboptimal nutritional profile" (Mertens et al. 2022), it is indicative that none of the classifications includes a quantitative nutritional assessment. As the disclosure of nutritional profiles of foods is often a legal requirement, and as nutritional values of processed foods have been evaluated before (Calixto Andrade et al. 2021; Cuadrado-Soto et al. 2018), attempts are recently being made to use these nutritional profiles for the prediction of the NOVA classification of foods (Marcos et al. 2022; Menichetti et al. 2023). However, it was also reported that discrepancies between food classifications and nutrient profiles are common (de Araújo et al. 2022). Additionally, Kapsokefalou et al. (2019) noted that the nutritional properties of processed foods are constantly changing, in order to protect or increase market share and profits and respond to policy changes. It is still unclear if the reformulations also lead to improved nutritional properties of the foods (Monteiro & Cannon 2012).

It was attempted to use the Health Star Rating (HSR) system to connect the number of ingredients in food products and their nutritional value. This system was developed by the Australian government assigning each food between half a star (low nutritional value) and five stars (high nutritional value) using a nutrient profiling algorithm. The study showed that the number of ingredients per product was lower in products with higher HSR. However, the association was not linear, as the number of ingredients in products with HSR between 0.5 and 3.5 was approximately similar, dropping significantly in products with HSR 4 to 5. A progressive decline in the number of ingredients per product took place across HSR values from 3.5 to 5.0. (Gaines et al. 2021).

When a range of foods was nutritionally assessed and classified per Nutri-Score, the share of ultra-processed foods did rise going from categories A to E. However, they accounted for 26.08% of foods already in recommendable category A. There are proposals on how Nova and Nutri-Score can be combined (Gómez-Donoso et al. 2021; Romero Ferreiro et al. 2021), but the differences often appear to be substantial. Australian Guide to Healthy Eating was compared to Nova classification and it was found that nearly one-quarter of the foods would be recommended to the public by one classification but not by the other (Mackerras 2019). Similar results were reported for U.S. Department of Agriculture & U.S. Department of Health and Human Services (2010), as no clear association was found between the level of processing and the presence of "nutrients to encourage" or "food components to reduce", as defined in the Dietary Guidelines (Eicher-Miller et al. 2012). The differences persisted in the comparison between the Nutri-score, the Traffic Light Labelling System, and the Siga index, leading to a proposal of a hierarchy of indexes/scores. The priority was given to the degree of processing as "the first indicator of the health food potential" over the food composition (Ebner et al. 2022). From all the mentioned comparisons it can be inferred that, per currently used classifications, the level of food processing cannot be reliably used as a predictor of the nutritional value of food.

Even though the presence of certain ingredients (or their combination) is used as an indication of (ultra-) processing, some proponents of Nova and Siga questioned the value of a "reductionistic approach", referring to the calculation of nutritional values of a food item, citing that "considering foods as only sums of nutrients" fails to note "all unhealthy foods that can be well rated nutritionally, although they are highly processed and contain many additives or hidden sugars and have lost their "matrix" effect through fractionation or extrusion-cooking" (Davidou et al. 2020; Fardet & Rock 2018, 2019, 2022b). The argument is that the "health potential" of a food is not "primarily and only associated with its nutritional composition", and that the key is in preserving the original food "matrix" (Fardet & Rock 2022a). The relationship between food processing and the structure of the final product has been considered, concluding that processing generally leads to the loss of food structure, but also noting that the two are not directly dependent (Fardet 2016). While the structure of foods often changes during processing, and this may include "the loss of food structure" (e.g. milling of grains), it can also be reconstituted or formed differently, in the subsequent stages of processing (e.g. in bread baking). The importance of the food structures – matrices—is emphasized by the fact that foods may have different metabolic, physiological, and health effects even if they have identical compositions. Yet, the fully preserved "matrix" may not always be the best option as it may lead to less digestible, bioaccessible, and/or bioavailable nutrients (Fardet & Rock 2022a).

Change in nutritional properties as the basis for food processing classifications

Various types of food processing can have a wide range of effects on different nutrients in different foods, some of which may be beneficial while others may be detrimental. To sum up the undesired effects of food processing, they have been classified into four groups: losses of (essential) nutrients due to chemical reactions, formation of undesired compounds (with a potential negative impact on health), formation of compounds that have a negative effect on flavor perception, and undesired changes of food properties, such as loss of texture, discoloration, etc. (van Boekel et al. 2010).

On the other hand, food processing is employed for millennia for the benefits it provides, and five groups of beneficial effects of food processing were listed: the destruction of unwanted compounds and micro-organisms, the prolongation of shelf-life, enhanced digestibility of food and bioavailability of nutrients, the formation of desired compounds, and the effects of processing on health-promoting compounds. Further, beneficial aspects of food processing have been summarized into 9 points: Food safety (pathogens), Food safety (other aspects), Nutritional value, Sensory quality, Functional health benefits, Convenience, Cost, Diversity, and Quality of life (van Boekel et al. 2010). Per example, there is evidence that processing can positively affect food functionality, be it e.g. by improving the bioavailability of nutrients, reducing the anti-nutrient effects (Fardet & Rock 2022a), improving protein digestibility, improving the phenolic profile of the food, or facilitating the absorption of iron and calcium (Alongi & Anese 2021; Drulyte & Orlien 2019; Hurrell 2002a 2002b; van Boekel et al. 2010), just to name a few.

For each of the positive and negative effects, multiple examples can be found, and many cases can simultaneously be examples of both positive and negative effects. This implies that food processing, which brings benefits, typically comes with some tradeoffs as well, and that evaluation of the overall impact of processing on food is, ultimately, a judgment of which of the two prevails, and perhaps by how much. For example, thermal processes, which are among the most commonly used processes in both the food industry and home cooking, are generally expected to bring the benefits of safety, quality, largely maintained nutritional value, inactivation of anti-nutritional factors and some allergens, inactivation of enzymes, sensory attractiveness, ease of use, and cost-effectiveness. On the other hand, they cause the formation of undesired compounds, and loss of freshness and related sensory attributes (van Boekel et al. 2010). The assessment of food processing is further complicated by the fact that neither the desirable nor undesirable effects occur in all cases, and to the same degree. It may also be argued that even what is desirable and what is not may change from case to case.

Thus, at least from a nutritional perspective, evaluating all food processing at once, comprehensively, universally, and objectively, remains not only challenging but nearly impossible. This probably explains the lack of food processing classifications based on a quantitative nutritional assessment. On the other hand, this does not mean that food processing classifications need to be abandoned—after all, their number and use indicate the need for such classifications. However, when evaluating and classifying food processing, it would be good to note which compromises were made and make sure they are aligned with the intended use of the classification/evaluation.

It can be assumed that the first step towards a widely accepted view of the processing impacts on food could be the definition of food processing and the definition of limitations of each of the classifications of foods based on their processing. Once the agreement on those is reached, clear dependencies and grounded conclusions might also prove easier to reach. This research proposes a definition of food processing and a view on present classifications of foods per level of their processing.

Conclusions

Food processing is defined differently in literature, emphasizing the kind or extent of processing, place, scale, or other. However, it has been indicated that processed foods may have an influence on public health. This drew the attention of both researchers and the wider public to processed foods. None of the several classifications of processed foods (e.g., Nova) achieved a consensus: definitions of processed foods, groups of processed foods, and differentiation of the groups remain highly discussed topics.

It was defined that food processing changes food properties and may lead to both improvement and reduction of health or nutritional benefits of foods. This makes classification based on a combination of food processing and the health and nutritional impacts of foods very difficult. Additionally, it is becoming increasingly important to define food processing in a way that tackles novel technologies as well as traditional ones. It was indicated that food processing is done through energy application and that it sometimes results in a change of mass. Such changes are associated with changes in the properties of food, such as food structure, and thus could be used to define food processing. If needed, this definition may eventually lead to the development of an unbiased method for the assessment of the level of food processing.

In this work, food processing was defined as all intentional additions or removals of either edible matter or energy (except for any transport or removal of inedible parts of food) between the harvest of ingredients and consumption of the product. This definition does not attempt to indicate the foods' health implications but focuses purely on food processing instead. The proposed approach requires experimental confirmation and further development, aiming to eventually allow the definition of the benefits and drawbacks of different processing methods.

Acknowledgements
Not applicable.

Authors' contributions
Dusan Ristic: Conceptualization, Investigation, Methodology, Formal Analysis, Writing – the original draft. Denisse Bender: Methodology, Writing – review and editing. Henry Jaeger: Conceptualization, Supervision, Writing – review and editing. Volker Heinz: Validation, Writing – review and editing, Funding acquisition. Sergiy Smetana: Conceptualization, Supervision, Writing – review and editing, Funding acquisition.

Funding
Not applicable.

Availability of data and materials
Not applicable.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]German Institute of Food Technologies (DIL e.V.), Prof.-von-Klitzing-Str. 7, 49610 Quakenbrück, Germany. [2]Department of Food Science and Technology, Institute of Food Technology, University of Natural Resources and Life Sciences Vienna, Muthgasse 18, 1190 Vienna, Austria. [3]Department of Food Science and Technology, Institute of Food Science, University of Natural Resources and Life Sciences Vienna, Muthgasse 18, 1190 Vienna, Austria. [4]Institute of Food Quality and Food Safety, University of Veterinary Medicine Hannover, Foundation, Bischofsholer Damm 15, 30173 Hannover, Germany.

Received: 15 February 2024 Accepted: 21 April 2024
Published online: 08 September 2024

References

Alongi, M., & Anese, M. (2021). Re-thinking functional food development through a holistic approach. In *Journal of Functional Foods*. *81*:104466. Elsevier Ltd. https://doi.org/10.1016/j.jff.2021.104466.

Ammann, K. (2003). *Co-existence between organic, traditional and biotech agriculture; Conflict resolution on the basis of discoursive processes and different kinds of knowledge*.

Ardente, F., & Cellura, M. (2012). Economic allocation in life cycle assessment. *Journal of Industrial Ecology,16*(3), 387–398. https://doi.org/10.1111/j.1530-9290.2011.00434.x

Asfaw, A. (2011). Does consumption of processed foods explain disparities in the body weight of individuals? *The case of Guatemala. Health Economics, 20*(2), 184–195. https://doi.org/10.1002/hec.1579

Augustin, M. A., Riley, M., Stockmann, R., Bennett, L., Kahl, A., Lockett, T., Osmond, M., Sanguansri, P., Stonehouse, W., Zajac, I., and Cobiac, L. (2016). Role of food processing in food and nutrition security. In Trends in Food Science and Technology (Vol. 56, pp. 115–125). Elsevier Ltd. doi: https://doi.org/10.1016/j.tifs.2016.08.005.

Bleiweiss-Sande, R., Chui, K., Evans, E. W., Goldberg, J., Amin, S., & Sacheck, J. (2019). Robustness of food processing classification systems. *Nutrients,11*(6), 1344. https://doi.org/10.3390/nu11061344

Borghoff, L., & Strassner, C. (2019). Classification systems of processed food: a comparison. 15th Scientific Conference on Organic Agriculture.

Botelho, R., Araújo, W., & Pineli, L. (2018). Food formulation and not processing level: Conceptual divergences between public health and food science and technology sectors. *Critical Reviews in Food Science and Nutrition, 58*(4), 639–650. https://doi.org/10.1080/10408398.2016.1209159

Bozhinov, M., & Bozhinov, B. (2011). Conventional, organic and biotech farming – possibilities and perspectives. *Agricultural Science (bulgaria),44*(3), 10–15.

Britannica. (2023). Biotechnology Definition & Meaning. https://www.britannica.com/technology/biotechnology.

Bröder, J., Tauer, J., Liaskos, M., & Hieronimus, B. (2023). Verzehr stark verarbeiteter Lebensmittel und ernährungsmitbedingte Erkrankungen: Eine systematische Übersichtsarbeit. In *Deutsche Gesellschaft für Ernährung (Hrsg.): 15. DGE-Ernährungsbericht. Vorveröffentlichung Kapitel 9*.

Calais, A., and Thituson, M. (2021). *Comparison of Nutritional Content in Processed and Homemade Foods* [Master Thesis in Food Engineering]. Lund University.

Calixto Andrade, G., Julia, C., Deschamps, V., Srour, B., Hercberg, S., Kesse-Guyot, E., Allès, B., Chazelas, E., Deschasaux, M., Touvier, M., Augusto Monteiro, C., & Bertazzi Levy, R. (2021). Consumption of ultra-processed food and its association with sociodemographic characteristics and diet quality in a representative sample of French adults. *Nutrients,13*(2), 682. https://doi.org/10.3390/nu13020682

Cellular Agriculture Society. (2023). https://www.cellag.org/?p=m1.

Chai, K. F., Ng, K. R., Samarasiri, M., & Chen, W. N. (2022). *Precision fermentation to advance fungal food fermentations*. In *Current Opinion in Food Science, 47*:100881. Elsevier Ltd. https://doi.org/10.1016/j.cofs.2022.100881

Crino, M., Barakat, T., Trevena, H., and Neal, B. (2017). Systematic Review and Comparison of Classification Frameworks Describing the Degree of Food Processing. *Nutrition and Food Technology: Open Access*, *3*(1). https://doi.org/10.16966/2470-6086.138

Cuadrado-Soto, E., Peral-Suarez, Á., Aparicio, A., Perea, J., Ortega, R., & López-Sobaler, A. (2018). Sources of dietary sodium in food and beverages consumed by Spanish schoolchildren between 7 and 11 years old by the degree of processing and the nutritional profile. *Nutrients,10*(12), 1880. https://doi.org/10.3390/nu10121880

Davidou, S., Christodoulou, A., Fardet, A., & Frank, K. (2020). The holistico-reductionist Siga classification according to the degree of food processing: An evaluation of ultra-processed foods in French supermarkets. *Food and Function,11*(3), 2026–2039. https://doi.org/10.1039/c9fo02271f

Davidou, S., Christodoulou, A., Frank, K., & Fardet, A. (2021). A study of ultra-processing marker profiles in 22,028 packaged ultra-processed foods using the Siga classification. *Journal of Food Composition and Analysis,99*, 103848. https://doi.org/10.1016/j.jfca.2021.103848

de Araújo, T. P., de Moraes, M. M., Afonso, C., Santos, C., & Rodrigues, S. S. P. (2022). Food processing: comparison of different food classification systems. *Nutrients,14*(4), 729. https://doi.org/10.3390/nu14040729

de Castro, N. T., de Alencar, E. R., Zandonadi, R. P., Han, H., Raposo, A., Ariza-Montes, A., Araya-Castillo, L., & Botelho, R. B. A. (2021). Influence of cooking method on the nutritional quality of organic and conventional Brazilian vegetables: a study on sodium, potassium, and carotenoids. *Foods,10*(8), 1782. https://doi.org/10.3390/foods10081782

Drulyte, D., & Orlien, V. (2019). The effect of processing on digestion of legume proteins. *Foods,8*(6), 224. https://doi.org/10.3390/foods8060224

Ebner, P., Frank, K., Christodoulou, A., & Davidou, S. (2022). How are the processing and nutrient dimensions of foods interconnected? an issue of hierarchy based on three different food scores. *International Journal of Food Sciences and Nutrition,73*(6), 770–785. https://doi.org/10.1080/09637486.2022.2060951

Eicher-Miller, H. A., Fulgoni, V. L., & Keast, D. R. (2012). Contributions of processed foods to dietary intake in the US from 2003–2008: A report of the food and nutrition science solutions joint task force of the academy of nutrition and dietetics, American Society for Nutrition, Institute of Food Technologists, and International Food Information Council. *The Journal of Nutrition,142*(11), 2065S-2072S. https://doi.org/10.3945/jn.112.164442

Etale, A., & Siegrist, M. (2021). Food processing and perceived naturalness: Is it more natural or just more traditional? *Food Quality and Preference,94*, 104323. https://doi.org/10.1016/j.foodqual.2021.104323

Eufic. (2022). *Food Processing Definition & Meaning*. https://www.eufic.org/en/food-production/category/food-processing

EUR-Lex. (2002). *Regulation 178/2002*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32002R0178&qid=1705420808751
European Food Safety Authority (EFSA). (2017). *The food classification and description system FoodEx 2 (revision 2)*. EFSA Supporting Publications, 12(5). https://doi.org/10.2903/sp.efsa.2015.en-804.
Fardet, A. (2016). Minimally processed foods are more satiating and less hyperglycemic than ultra-processed foods: A preliminary study with 98 ready-to-eat foods. *Food & Function,7*(5), 2338–2346. https://doi.org/10.1039/C6FO00107F
Fardet, A., and Rock, E. (2022b). Exclusive reductionism, chronic diseases and nutritional confusion: the degree of processing as a lever for improving public health. In *Critical Reviews in Food Science and Nutrition*. *62*(10):2784–2799. Taylor and Francis Ltd. https://doi.org/10.1080/10408398.2020.1858751.
Fardet, A., & Rock, E. (2018). Perspective: Reductionist nutrition research has meaning only within the framework of holistic and ethical thinking. *Advances in Nutrition,9*(6), 655–670. https://doi.org/10.1093/ADVANCES/NMY044
Fardet, A., & Rock, E. (2019). Ultra-processed foods: A new holistic paradigm? *Trends in Food Science & Technology,93*, 174–184. https://doi.org/10.1016/j.tifs.2019.09.016
Fardet, A., & Rock, E. (2022). Chronic diseases are first associated with the degradation and artificialization of food matrices rather than with food composition: Calorie quality matters more than calorie quantity. *European Journal of Nutrition,61*(5), 2239–2253. https://doi.org/10.1007/s00394-021-02786-8
Floros, J. D., Newsome, R., Fisher, W., Barbosa-Cánovas, G. V., Chen, H., Dunne, C. P., German, J. B., Hall, R. L., Heldman, D. R., Karwe, M. V., Knabel, S. J., Labuza, T. P., Lund, D. B., Newell-McGloughlin, M., Robinson, J. L., Sebranek, J. G., Shewfelt, R. L., Tracy, W. F., Weaver, C. M., & Ziegler, G. R. (2010). Feeding the world today and tomorrow: the importance of food science and technology. *Comprehensive Reviews in Food Science and Food Safety,9*(5), 572–599. https://doi.org/10.1111/j.1541-4337.2010.00127.x
Forde, C. G., Mars, M., and de Graaf, K. (2020). Ultra-Processing or Oral Processing? A Role for Energy Density and Eating Rate in Moderating Energy Intake from Processed Foods. *Current Developments in Nutrition, 4*(3). https://doi.org/10.1093/cdn/nzaa019
Gaines, A., Shahid, M., Huang, L., Davies, T., Taylor, F., Wu, J. H., & Neal, B. (2021). onstructing the Supermarket: Systematic Ingredient Disaggregation and the Association between Ingredient Usage and Product Health Indicators for 24,229 Australian Foods and Beverages. *Nutrients,13*(6), 1882. https://doi.org/10.3390/nu13061882
Gibney, M. J. (2022). Ultra-processed foods in public health nutrition: the unanswered questions. *Public Health Nutrition*, 1–4. https://doi.org/10.1017/s1368980022002105.
Gibney, M. J., & Forde, C. G. (2022). Nutrition research challenges for processed food and health. *Nature Food, 3*(2), 104–109. Springer Nature. https://doi.org/10.1038/s43016-021-00457-9
Gómez-Donoso, C., Martínez-González, M. A., & Bes-Rastrollo, M. (2021). Nutri-Score, ultra-processed foods and health. *Anales Del Sistema Sanitario de Navarra*, *44*(1), 3–8. https://doi.org/10.23938/ASSN.0943
Grumezescu, A. M., & Holban, A. M. (2018). *Food processing for increased quality and consumption* (A. M. Grumezescu & A. M. Holban, Eds.; Vol. 18). Academic Press. https://doi.org/10.1016/C2016-0-00636-8
Hess, J., & Slavin, J. (2016). Defining "Protein" foods. *Nutrition Today,51*(3), 117–120. https://doi.org/10.1097/NT.0000000000000157
Hurrell, R. (2002). Fortification: Overcoming technical and practical barriers. *Journal of Nutrition,132*(4 SUPPL), 806S-812S. https://doi.org/10.1093/jn/132.4.806s
Hurrell, R. (2002b). How to ensure adequate iron absorption from iron-fortified food. *Nutrition Reviews,60*(7 II), S7–S15. https://doi.org/10.1301/002966402320285137
Ionescu, G. (2016). *Sustainable Food and Beverage Industries: Assessments and Methodologies* (G. Ionescu, Ed.). CRC Press.
Ireland, J. D., & Møller, A. (2000). Review of international food classification and description. *Journal of Food Composition and Analysis,13*(4), 529–538. https://doi.org/10.1006/jfca.2000.0921
Ireland, J., van Erp-Baart, A., Charrondière, U., Møller, A., Smithers, G., & Trichopoulou, A. (2002). Selection of a food classification system and a food composition database for future food consumption surveys. *European Journal of Clinical Nutrition,56*(2), S33–S45. https://doi.org/10.1038/sj.ejcn.1601427
Kapsokefalou, M., Roe, M., Turrini, A., Costa, H. S., Martinez-Victoria, E., Marletta, L., Berry, R., & Finglas, P. (2019). Food composition at present: new challenges. *Nutrients,11*(8), 1714. https://doi.org/10.3390/nu11081714
Kermasha, S., & Eskin, M. N. A. (2021). *Enzymes: Novel Biotechnological Approaches for the Food Industry*.
Kollath, W. (2005). *Die Ordnung unserer Nahrung*. Karl F. Haug Verlag.
Lane, M. M., Davis, J. A., Beattie, S., Gómez-Donoso, C., Loughman, A., O'Neil, A., Jacka, F., Berk, M., Page, R., Marx, W., & Rocks, T. (2021). Ultraprocessed food and chronic noncommunicable diseases: A systematic review and meta-analysis of 43 observational studies. *Obesity Reviews,22*(3), e13146. https://doi.org/10.1111/obr.13146
Levine, A. S., & Ubbink, J. (2023). Ultra-processed foods: Processing versus formulation. *Obesity Science & Practice,9*(4), 435–439. https://doi.org/10.1002/osp4.657
Ludwig, D. S., Astrup, A., Bazzano, L. A., Ebbeling, C. B., Heymsfield, S. B., King, J. C., & Willett, W. C. (2019). Ultra-processed food and obesity: the pitfalls of extrapolation from short studies. *Cell Metabolism,30*(1), 3–4. https://doi.org/10.1016/j.cmet.2019.06.004
Mackerras, D. (2019). Mis-match Between the Healthy Food and the Ultra-processed Food Classifications in Australia (OR14–03–19). *Current Developments in Nutrition*, *3*(Supplement_1). https://doi.org/10.1093/cdn/nzz038.or14-03-19.
Marco, M. L., Sanders, M. E., Gänzle, M., Arrieta, M. C., Cotter, P. D., De Vuyst, L., Hill, C., Holzapfel, W., Lebeer, S., Merenstein, D., Reid, G., Wolfe, B. E., & Hutkins, R. (2021). The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on fermented foods. *In Nature Reviews Gastroenterology and Hepatology,18*(3), 196–208. https://doi.org/10.1038/s41575-020-00390-5. Nature Research.
Marcos, I. F. V., Bordel, B., Cira, C. I., & Alcarria, R. (2022). A Methodology Based on Unsupervised Learning Techniques to Identify the Degree of Food Processing. *Iberian Conference on Information Systems and Technologies, CISTI*, *2022-June*. https://doi.org/10.23919/CISTI54924.2022.9820513
Martinez-Perez, C., San-Cristobal, R., Guallar-Castillon, P., Martínez-González, M. Á., Salas-Salvadó, J., Corella, D., Castañer, O., Martinez, J. A., Alonso-Gómez, Á. M., Wärnberg, J., Vioque, J., Romaguera, D., López-Miranda, J., Estruch, R., Tinahones, F. J., Lapetra, J., Serra-Majem, L., Bueno-Cavanillas, A., Tur, J. A., … Daimiel, L. (2021). Use of different food classification systems to assess the association between ultra-processed food consumption and cardiometabolic health in an elderly population with metabolic syndrome (Predimed-plus cohort). *Nutrients*, *13*(7), 2471. https://doi.org/10.3390/nu13072471
Menichetti, G., Ravandi, B., Mozaffarian, D., & Barabási, A.-L. (2023). Machine learning prediction of the degree of food processing. *Nature Communications,14*(1), 2312. https://doi.org/10.1038/s41467-023-37457-1
Merriam-Webster, I. (2023a). *Agriculture Definition & Meaning*. https://www.merriam-webster.com/dictionary/agriculture.
Merriam-Webster, I. (2023b). *Food processor Definition & Meaning*. https://www.merriam-webster.com/dictionary/food%20processor.
Merriam-Webster, I. (2023c). *Ultra Definition & Meaning*. https://www.merriam-webster.com/dictionary/ultra.
Mertens, E., Colizzi, C., & Peñalvo, J. L. (2022). Ultra-processed food consumption in adults across Europe. *European Journal of Nutrition,61*(3), 1521–1539. https://doi.org/10.1007/s00394-021-02733-7
Monteiro, C. A., & Cannon, G. (2012). The food system. Product reformulation will not improve public health. [Commentary]. *World Nutrition,3*(9), 406–434.
Monteiro, C. A., Cannon, G., Lawrence, M., Laura Da Costa Louzada, M., & Machado, P. P. (2019). *Ultraprocessed foods, diet quality, and health using the NOVA classification system*.
Monteiro, C. A., Cannon, G., Levy, R. B., Moubarac, J. C., Louzada, M. L. C., Rauber, F., Khandpur, N., Cediel, G., Neri, D., Martinez-Steele, E., Baraldi, L. G., & Jaime, P. C. (2019). Ultra-processed foods: What they are and how to identify them. *Public Health Nutrition* (Vol. 22(5, pp. 936–941). Cambridge University Press. https://doi.org/10.1017/S1368980018003762
Monteiro, C. A., Cannon, G., Moubarac, J. C., Levy, R. B., Louzada, M. L. C., & Jaime, P. C. (2018). The un Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. *Public Health Nutrition* (Vol. 21(1, pp. 5–17). Cambridge University Press. https://doi.org/10.1017/S1368980017000234

Monteiro, C. A., Lawrence, M., Millett, C., Nestle, M., Popkin, B. M., Scrinis, G., & Swinburn, B. (2021). The need to reshape global food processing: A call to the United Nations Food Systems Summit. In *BMJ Global Health, 6*(7):e006885. BMJ Publishing Group. https://doi.org/10.1136/bmjgh-2021-006885
Monteiro, C. A., Levy, R. B., Claro, R. M., de Castro, I. R. R., & Cannon, G. (2010). A new classification of foods based on the extent and purpose of their processing. *Cadernos De Saúde Pública,26*(11), 2039–2049. https://doi.org/10.1590/S0102-311X2010001100005
Nagel, B., Dellweg, H., & Gierasch, L. M. (1992). Glossary for chemists of terms used in biotechnology (IUPAC Recommendations 1992). *Pure and Applied Chemistry,64*(1), 143–168.
Pellegrini, N., & Fogliano, V. (2017). Cooking, industrial processing and caloric density of foods. *Current Opinion in Food Science* (Vol. 14, pp. 98–102). Elsevier Ltd. https://doi.org/10.1016/j.cofs.2017.02.006
Poti, J. M., Mendez, M. A., Ng, S. W., & Popkin, B. M. (2015). Is the degree of food processing and convenience linked with the nutritional quality of foods purchased by US households? *The American Journal of Clinical Nutrition,101*(6), 1251–1262. https://doi.org/10.3945/ajcn.114.100925
Romero Ferreiro, C., Lora Pablos, D., & Gómez de la Cámara, A. (2021). Two dimensions of nutritional value: nutri-score and NOVA. *Nutrients,13*(8), 2783. https://doi.org/10.3390/nu13082783
Sadler, C. R., Grassby, T., Hart, K., Raats, M., Sokolović, M., & Timotijevic, L. (2021). Processed food classification: Conceptualisation and challenges. *Trends in Food Science & Technology*. https://doi.org/10.1016/j.tifs.2021.02.059
Sadler, C. R., Grassby, T., Hart, K., Raats, M. M., Sokolović, M., & Timotijevic, L. (2022). "Even We Are Confused": A Thematic analysis of professionals' perceptions of processed foods and challenges for communication. *Frontiers in Nutrition,9*, 74. https://doi.org/10.3389/fnut.2022.826162
Silva Meneguelli, T., Viana Hinkelmann, J., Hermsdorff, H. H. M., Zulet, M. Á., Martínez, J. A., & Bressan, J. (2020). Food consumption by degree of processing and cardiometabolic risk: A systematic review. *International Journal of Food Sciences and Nutrition,71*(6), 678–692. https://doi.org/10.1080/09637486.2020.1725961
Slimani, N., Deharveng, G., Southgate, D. A. T., Biessy, C., Chajès, V., van Bakel, M. M. E., Boutron-Ruault, M. C., McTaggart, A., Grioni, S., Verkaik-Kloosterman, J., Huybrechts, I., Amiano, P., Jenab, M., Vignat, J., Bouckaert, K., Casagrande, C., Ferrari, P., Zourna, P., Trichopoulou, A., & Bingham, S. (2009). Contribution of highly industrially processed foods to the nutrient intakes and patterns of middle-aged populations in the europeanprospective investigation into cancer and nutrition study. *European Journal of Clinical Nutrition, 63*(4), S206–S225. https://doi.org/10.1038/ejcn.2009.82
Srour, B., & Touvier, M. (2021). Ultra-processed foods and human health: What do we already know and what will further research tell us? In *EClinicalMedicine, 32*:100747. Lancet Publishing Group. https://doi.org/10.1016/j.eclinm.2021.100747
Standard 3.2.2 - Food Safety Practices and General Requirements. (2023). *Australia New Zealand Food Standards Code (Australia Only)*. https://www.legislation.gov.au/F2008B00576/latest/text.
U.S. Department of Agriculture, & U.S. Department of Health and Human Services. (2010). *Dietary Guidelines for Americans* 2010.
U.S. Food & Drug Administration. (2023). *FDA Completes Second Pre-Market Consultation for Human Food Made Using Animal Cell Culture Technology*. https://www.fda.gov/food/cfsan-constituent-updates/fda-completes-second-pre-market-consultation-human-food-made-using-animal-cell-culture-technology
van Boekel, M., Fogliano, V., Pellegrini, N., Stanton, C., Scholz, G., Lalljie, S., Somoza, V., Knorr, D., Jasti, P. R., & Eisenbrand, G. (2010). A review on the beneficial aspects of food processing. *Molecular Nutrition & Food Research,54*(9), 1215–1247. https://doi.org/10.1002/mnfr.200900608
von Koerber, K., Männle, T., & Leitzmann, C. (2004). *Vollwert-Ernährung: Konzeption einer zeitgemäßen und nachhaltigen Ernährung*. Karl F. Haug Verlag.

Publisher's Note