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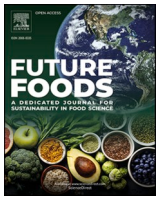

Food processing levels and processed food intake classification

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ABSTRACT

A causal relationship between food processing and adverse health outcomes is often incorrectly reported. This is evidenced by several processed food classifications which mistakenly claim to categorize foods based on their processing level. Here we used chemical engineering principles to divide food processing to unit operations (physical processing) and unit processes (chemical processing) and established 5 food processing levels (FPL). Unit operations represent the lowest processing levels, FPL 0 and 1. Unit processes may include minor or major (bio)chemical changes resulting in FPL 2 and 3, respectively. FPL 4 is assigned to processing of food formulations with one or more ingredients from FPL 3 and 4. Foods from the different FPL are categorized with guidelines to corresponding processed food intake (PFI) classes, which provides improvements in comparison to the NOVA and other processed food classifications. The PFI classification combines processing and formulation as factors with possible but separate impact on nutritional, health and other outcomes of food intake. The concept of the FPL and PFI classification may be further expanded to indicate the impact of food processing in other applications, such as affordability and sustainability of food products.

Introduction

The impact of food processing on human nutrition and public health has become of a wide concern, including adverse health outcomes incorrectly related to food processing as published in dietary guidelines of a few countries (e.g., Monteiro, 2015; Koios et al., 2022; Forde, 2023; Hess et al., 2023). Furthermore, assumptions among the general public that food processing is harmful to health have arisen from the demonization of food processing as purported by the media (e.g., Koios et al., 2022; Berg, 2024; Anon., 2025).

The NOVA concept of Monteiro (2009) and Monteiro et al. (2010, 2017) divides foods to four arbitrary and nominal categories. Foods from the ultra-processed foods (UPF) category of the NOVA "classification" are often reported as the most detrimental to human and public health (Monteiro, 2009; Monteiro et al., 2010; 2019). Although, classification typically divides the objects of classification to groups which may or may not be known prior to classification (Gordon, 1999), the NOVA categories have no common processing variable for the grouping of processed foods. Classification must involve a decision on the number of classes to which the objects should be allocated while the number of NOVA categories have varied over time without clear differences of processing between foods allocated to various groups (e.g., Gibney et al., 2017; Petrus et al., 2021). Conversely, identification of the differences in the levels of processing which should be used to allocate processed foods to the different NOVA categories is necessary, but such differences for classification in the NOVA system are not available.

Food processing may be classified, for example, to nominal categories according to the type of processing involved, such as physical operations and microbial, biochemical and chemical processes (Saravacos and Kostaropoulos, 2016). Food products, and processed food in particular, may be classified to ordinal categories, for example, on the basis of changes occurring in foods during processing. Monteiro (2009) and Monteiro et al. (2010) reported processed food classes, that is, unprocessed or minimally processed foods; processed culinary or industry ingredients; and ultra-processed food (UPF) products. This NOVA classification is also known as the origin of the popular UPF misconception. The authors later updated the NOVA grouping by dividing the processed culinary or industry ingredients group to separate culinary ingredients and processed foods groups (Monteiro et al., 2017). The NOVA classification uses nominal categorization, and it has been widely criticized as it fails to provide clear principles for classification and for the grouping of processed foods (e.g., Gibney et al., 2017; Petrus et al., 2021; Anon., 2025). Conversely, Monteiro et al. (2010) claimed that the NOVA classification introduced groups of foodstuffs according to the extent and purpose of the industrial processing applied to them, but no factual processing variable for grouping based on the differences

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Table 1
Food classifications systems providing processed foods categories and used in studies reporting food processing -related adverse health outcomes.

Classification	Classification basis	Food categories	Processing categories	Reference
IARC-EPIC	• Industrially prepared • Industrially prepared/home prepared • Raw foods (fruit, vegetables, etc.) • Unknown preservation/making	• Highly processed foods • Moderately processed foods • Non-processed foods • Foods with unknown process	Not provided	Slimani et al. (2009)
IFIC	• Packaged foods • Home prepared foods • Packaged/store prepared foods • Packaged/jarred sauces • Canned vegetables • Homemade soups	• Prepared foods/meals • Ready-to-eat processed foods • Mixtures of combined ingredients • Foods processed for preservation • Minimally processed foods	Not provided	Eicher-Miller et al. (2012)
IFPRI	Degree of processing (undefined)	• Highly processed foods • Partially (primary) processed foods • Unprocessed foods	Not provided	Asfaw (2011)
IUFoST	Formulation and processing impact on nutritional value	• NOVA categories	Not provided	Ahrné et al. (2025)
NOVA	Processing level (undefined)	• Ultra-processed foods • Processed foods • Processed culinary ingredients • Unprocessed and minimally processed foods	Not provided	Monteiro (2009); Monteiro et al. (2010); Monteiro et al. (2017)
Poti	Degree of industrial processing (undefined)	• Highly processed • Moderately processed • Basic processed • Less processed	Not provided	Poti et al. (2015)
Siga	Degree of food processing (undefined) with ingredients and matrix effects.	NOVA classes with sub-classes.	Not provided	Fardet (2018b); Davidou et al. (2020)
Wc-UPF™	Ingredients degree of processing (undefined), potential health impacts, and added sugar content.	Processed food categories: minimal, light, moderate, ultra, and super-ultra.	Not provided	Benitez et al. (2025)

in processing levels was introduced. Indeed, the definition of processing level, although classification of processed foods according to their processing level is claimed, is missing from the NOVA and many other food processing-related classification systems (Sadler et al., 2021; Koios et al., 2022).

Numerous studies and articles have been published in the nutritional sciences, public health and medical areas reporting casual relationships between food processing or the degree of food processing and obesity and NCDs (Monteiro, 2009; Moubarac et al., 2014; Fardet, 2018a; Lane et al., 2021; Forde and Decker, 2022), and even mortality (e.g., González-Gil et al., 2025). Most studies are observational using the nominal NOVA grouping of foods, and thereby the relationships between foods and adverse health outcomes. Many articles mistakenly report processing as the contributing adverse health outcomes-related factor although only relationships between food formulation ingredients and NCDs or other adverse health outcomes can be justified (Forde and Decker, 2022; Forde, 2023; Koios et al., 2022).

Here we take into account significant differences of food processing and processed foods as concepts and objects of classification. Classification of food processing based on *food processing level* (FPL) as an ordinal variable is introduced and used for ordinal categorization of *processed food intake* (PFI) according to the established food processing levels. The classification system presented may be used to analyze whether food processing *per se* or processed food, including food formulation, is responsible for the development of nutrition and diet-related diseases of public health concern. The FPL will be useful also in a wider context, such as in affordability or environmental and sustainability studies.

Food processing *vs.* processed food

Food processing and processed foods as expressions or terms are not descriptive and they do not refer to any variable which could be used in ordinal food processing or processed food classification. Conversely, food processing and processed food have very different meanings. Foods which have entered one or more treatments at any stage from production to digestion could be considered as "processed food". A clear definition for processed foods does not exist and the term processed food has little meaning as it does not provide information of the nature of the processing or whether the food was processed before or after ingestion or otherwise. Furthermore, food processing varies across different manufacturers, and different food processing methods may be used to obtain similar foods under equal labeling. It should be noted that food processing as a pre-consumption treatment of food occurs before food intake. That is, food processing as such and prior to ingestion, and when the food is not yet consumed, cannot determine the nutritional quality or health outcomes of food intake, whether positive or negative (Forde, 2023).

Food processing according to IUFoST is defined as "treatment of a food material to achieve a desired effect" (Ahrné et al., 2025). Food processing -related classifications often report arbitrary and nominal processed food groups, such as those of the NOVA classification. Such groups have no common variable and there is no parameter which could be used to justify allocation of foods to the different processed food classes on the basis of their processing level. The ultra-processed foods concept introduced by Monteiro (2009) has very little relationships with food processing (Carretero et al., 2020; Daniel and Henle, 2025). The prefix **ultra** in food processing literature is typically a descriptor of a measurable processing parameter, such as temperature, i.e., ultra-high temperature (UHT), or particle size in ultra-filtration (Carretero et al., 2020; Fellows, 2022). The term ultra normally refers to something being much beyond normal (Anon., 2025). Foods are seldom processed to beyond normal, which would typically mean uneconomical over-processing and a treatment being detrimental to food quality. For such reasons, foods should not be referred to as ultra-processed food, an expression introduced by Monteiro (2009), or by using even more exaggerated expressions such as super-ultra-processed food (Benitez et al., 2025). This terminology should be avoided and not used in scientific literature or elsewhere, as was also proposed by Daniel and Henle (2025).

Table 2
Regulations of the EU and USA which provide definitions of food processing and processed food.

Regulation	Area	Definition	Examples
EC 852/2004	EU	"Processing" means any action that substantially alters the initial product.	Including heating, smoking, curing, maturing, drying, marinating, extraction, extrusion or a combination of those processes.
		"Unprocessed products" means foodstuffs that have not undergone processing.	Includes products that have been divided, parted, severed, sliced, boned, minced, skinned, ground, cut, cleaned, trimmed, husked, milled, chilled, frozen, deep frozen or thawed.
		"Processed products" means foodstuffs resulting from the processing of unprocessed products.	These products may contain ingredients that are necessary for their manufacture or to give them specific characteristics.
FDA (21 CFR 117.3)	USA	Manufacturing/processing means making food from one or more ingredients, or synthesizing, preparing, treating, modifying or manipulating food, including food crops or ingredients.	Baking, boiling, bottling, canning, cooking, cooling, cutting, distilling, drying/dehydrating raw agricultural commodities to create a distinct commodity (such as drying/dehydrating grapes to produce raisins), evaporating, eviscerating, extracting juice, formulating, freezing, grinding, homogenizing, irradiating, labeling, milling, mixing, packaging (including modified atmosphere packaging), pasteurizing, peeling, rendering, treating to manipulate ripening, trimming, washing, or waxing.
Federal Food, Drug, and Cosmetic Act (FFDCA), Section 201(gg)		The term ‘‘processed food’’ means any food other than a raw agricultural commodity.	Includes any raw agricultural commodity that has been subject to processing, such as canning, cooking, freezing, dehydration, or milling.

Most food processing -related classification attempts have reported qualitative processed food classifications, where undefined expressions, such as processed food, highly processed foods, ultra-processed foods or other descriptive terms have formed processed food categories, as summarized in Table 1. These expressions are often mistakenly claimed to indicate classification based on the level of processing. However, as noted in Table 1, none of the well-known classifications provide processing levels and, therefore, the processing levels are undefined, as was also reported by Medin et al. (2025).

Legislation

Carretero et al. (2020) and Anon. (2025) noted that there is no legal standard that defines ultra-processed food. Conversely, definitions for ‘*food processing*’ are provided by European Commission in the EU and FDA in the USA, as listed in Table 2. Furthermore, the Regulation EC 852/2004 also provides definitions for the terms ‘*unprocessed products*’ and ‘*processed products’*, which, thereby, form the only legally binding processed food groups across all member states of the EU.

Definitions for food processing and types of processed foods are not provided in many other countries or jurisdictions, but food processing and various types of processed foods are often discussed in dietary guidelines. The Nordic Dietary Guidelines discuss food processing in line with the EC definitions (Table 2) and note that the concept of ultra-processed foods as a category does not add to already existing food classifications and recommendations (Blomhoff et al., 2023). Indeed, appropriate dietary guidelines and nutritional recommendations are expected to follow existing legal definitions of concepts.

Interestingly, the NOVA classification could be reduced to two main categories of foods: unprocessed foods and processed foods. Obviously, these two categories would agree with the regulatory definitions of both the EU and the USA, but such two food classes are not sufficient to satisfy intentions to relate processed food consumption and adverse health outcomes. However, since the grouping of foods to the processed food and UPF categories is often subjective, the UPF concept is inaccurate and of a poor legal basis, the two categories, processed food and ultra-processed food, should form a single factual processed food category. For that reason, the inclusion of an additional UPF category to dietary guidelines is not justified. It has not been used, for example, in the Dietary Guidelines for Americans 2020-2025 (U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2020), although the UPF concept is well-recognised and addressed by the 2025 Dietary Guidelines Advisory Committee (2024).

Typical food safety legislation requires that food placed to the market must be safe. For example, according to the Regulation EC 178/2002 ‘food shall not be placed on the market if it is unsafe’ and ‘food shall be deemed to be unsafe if it is considered to be (a) injurious to health; (b) unfit for human consumption’. ‘In determining whether any food is unsafe, regard shall be had (a) to the normal conditions of use of the food by the consumer and at each stage of production, processing and distribution, and (b) to the information provided to the consumer, including information on the label, or other information generally available to the consumer concerning the avoidance of specific adverse health effects from a particular food or category of foods’. A food is injurious to health when causing ‘not only to the probable immediate and/or short-term and/or long-term effects of that food on the health of a person consuming it, but also on subsequent generations’. These statements of the Regulation EC 178/2002 imply, at least theoretically, that if the consumption of foods assigned to the UPF category are shown to cause adverse health outcomes, such foods need to be withdrawn from the EU market. The Regulation EU 2015/2283 on novel foods furthermore requires that food production processes not used prior to 15 May 1997 need to be assessed for their safety, i.e., the safety of novel food processing is ensured by regulations.

Food materials are typically processed for their safety, desired properties and delivery of sensory properties as well as energy and nutrients (Fig. 1) besides possible other functionalities. The nature and properties of the food with chosen processing treatments and formulation within the legal framework provide the operating foundation for manufacturing of food products. Formulation according to IUFoST definition refers to ‘systematic selection of relative quantities of ingredients for a food product’ (Ahrné et al., 2025). Processing and formulation of the food materials can be used to modulate food properties, including structure, performance and overall benefits. Depending

Fig. 1. Food processing and formulation as foundation of food manufacturing within the applicable legal and regulatory framework to achieve optimal food characteristics for the delivery of desired characteristics of the processed food.

Table 3
Classification of food processing to Unit Operations I and II (UO I and II) and Unit Processes I and II (UP I and II) with respective Food Processing Level (FPL), object, result, typical processes, purpose and conditions as well as examples.

Processing class	FPL	Object	Result	Typical Processes	Purpose and conditions	Examples
Unit operations I	**0**	Minor physical change.	Retention of natural food characteristics.	Washing, hulling, peeling, mixing, blending, forming, shaping, molding, shredding, cutting, sieving, screening, filtration, centrifugation, refrigeration, freezing.	Cleaning, removal of impurities and undesired material, low-temperature preservation, operations maintain natural cellular structures, ambient and subambient conditions.	Slicing of fruit and vegetables. Chilling and freezing of food. Mechanical mixing or separation processes.
Unit operations II	**1**	Major physical change.	Intense physical operation and disintegration of natural cellular structures.	Grinding, milling, mincing, pressing, brining, salting, coagulation, gelling, emulsifying, homogenization, whipping, high pressure processing, blanching, pasteurization, water extraction, concentration, membrane separations, crystallization, evaporation, distillation, steaming, drying.	Pulverization, stabilization, clarification, equilibrium processes, thermal fractionation, blanching, killing bacteria, inactivation of enzymes, food temperature <100 °C to minimize unintended changes..	Processing of plant materials and animal products to extend shelf life and manufacturing of traditional food ingredients, e.g., flour and sugar. Cold pressing of fresh juices and virgin oils.
Unit processes I	**2**	General food processing but minor chemical changes.	Physical, chemical and enzymatic changes as part of food preparation, processing and traditional fermentation.	Baking, boiling, brewing, canning, cooking, grilling, frying, fermentations, simple extrusion, smoking, UHT processing, electrodialysis, ion exchange.	Preservation, conversion of food and ingredients to food products. Food temperature from ambient to >100 °C to obtain desired shelf life and chemical, physical, nutritional and sensory properties.	Home cooking, bread making, most preserved foods and fermented products, pasta and noodles manufacturing, protein concentrates and isolates manufacturing.
Unit processes II	**3**	Chemical processing.	Major chemical and compositional changes	Toasting, puffing, solvent extraction, chemical and enzymatic refining, chemical processing, extrusion cooking, irradiation, starch and carbohydrates processing, biotechnological processes.	Most recovery processes, food structuring, chemical modifications, intense mechanical processing, chemical purification, ionizing radiation, food temperature from ambient to >>100 °C for the desired treatment..	Starch and starch products, alternative sugars, sweeteners, hydrolyzed materials, enzymatically and chemically modified materials, synthetic chemicals.

on chosen processing methods and formulation, various weaknesses and opportunities may be taken into account. A systematic consideration in choosing food formulation ingredients and optimal processing technologies is important for identifying an appropriate level of food processing. Thereby, food classification based on their processing levels provides a tool to product development, particularly for the manufacturing of novel and future foods. In this context, we note that food additives, processing aids and other substances used in food products should not be confused with food processing. Conversely, the use and safety of such substances are regulated by relevant legislation and based on robust scientific studies and comprehensive risk assessments. Indeed, such substances do not form any part of food processing, and they should not be included in food classifications based on processing levels. As processing aids, ingredients and additives, these substances may be included separately in an overall assessment of the health impact of commercial and other foods.

Unit operations, unit processes and food processing classification

Food processing typically consists of several separate processes which according to chemical engineering principles can be divided into unit operations and unit processes (Groggins, 1938; Maroulis and Saravacos, 2003). Unit operations cover treatments resulting in physical changes of materials during processing. Unit processes refer to

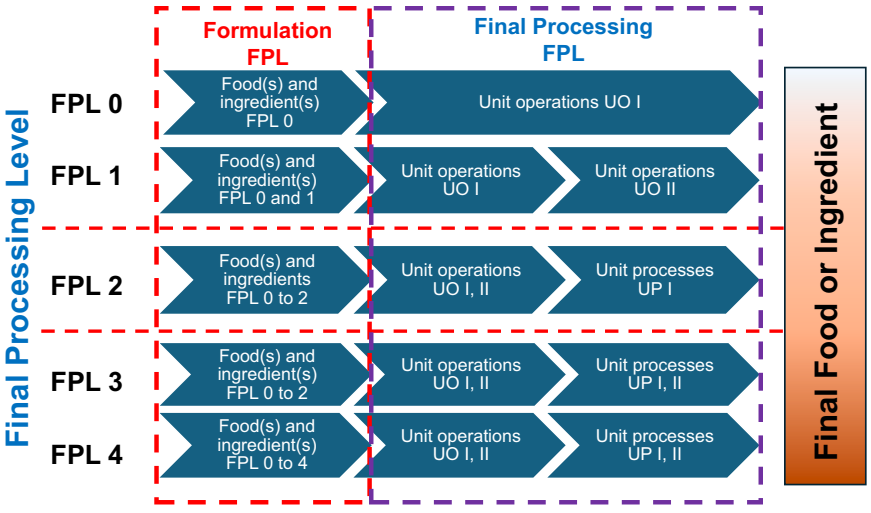

Fig. 2. Food processing level (FPL) of the final food or food ingredient as determined by food formulation ingredients (Formulation FPL) and unit operations and unit processes (Processing FPL) used during food processing to obtain the final products.

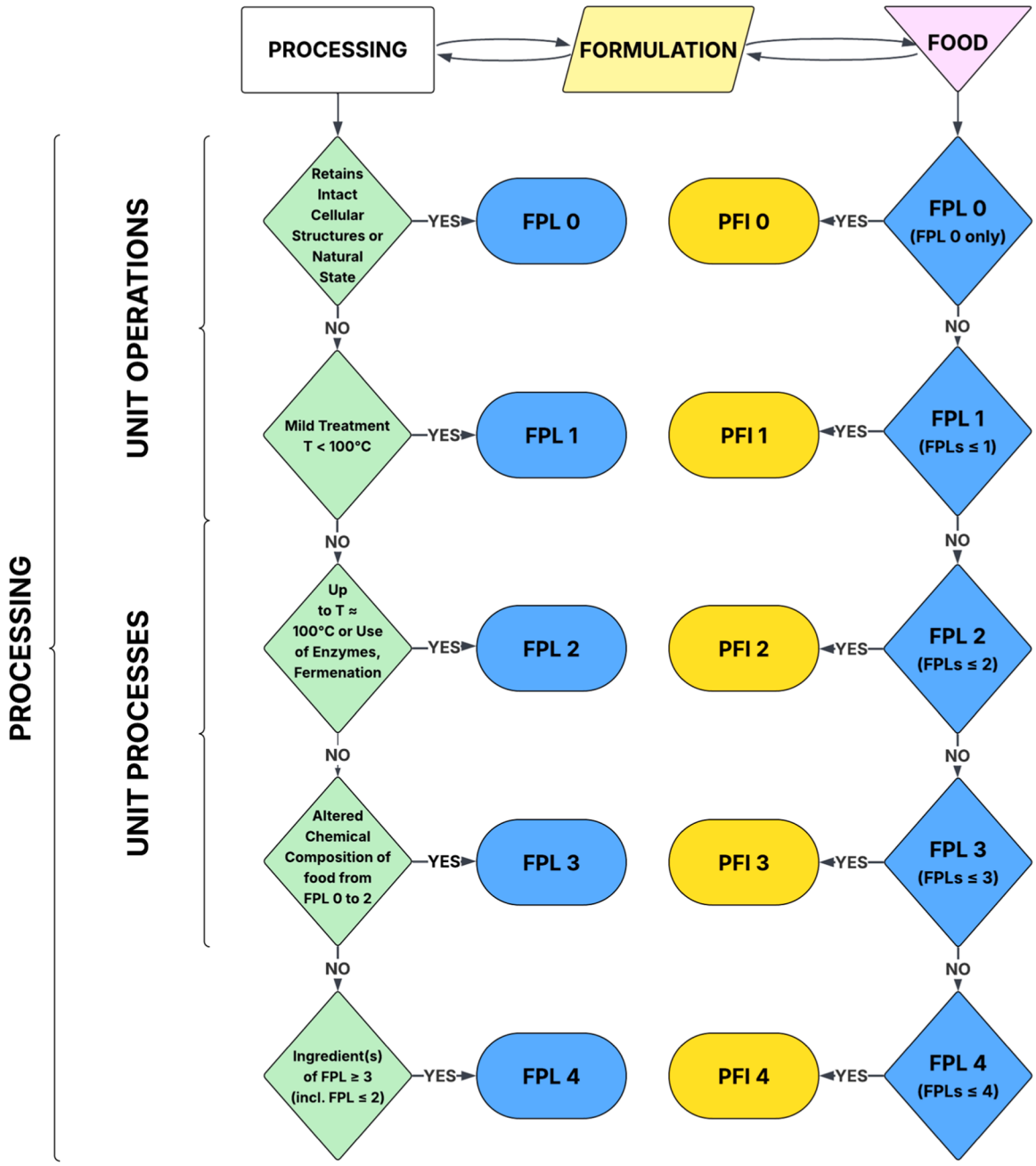

Fig. 3. Decision diagram for identification of the Food Processing Levels (FPL) of food ingredients and final foods for their Processed Food Intake (PFI) classification. Formulation ingredients and the final food may originate from several processing and formulation cycles as indicated by the top arrows connecting processing, formulation and food. The highest FPL of the formulation ingredients and the FPL of the final processing of a food product determine its PFI category. A final food product may also consist of a mechanical mix of two or more ingredients of different PFI categories. FPL 4 results from the use of any ingredient from FPL 3 or FPL 4 corresponding to the PFI 4 of the final formulated food. Temperature values shown indicate those of the food material during a particular process.

treatments aiming at chemical changes, i.e., input and output materials are chemically different. The exact number of existing food processes may be difficult to establish, as unit operations and unit processes commonly used in food processing include numerous individual processes and sets of their combinations (Saravacos and Kostaropoulos, 2016; Carretero et al., 2020). Hence, setting a single variable for ordinal classification of food processing to establish a small number of processing levels requires a variable that can be identified for any treatment of a food material.

Treatments of foods during processing result in (bio)chemical and physical changes which can be used for the establishment of FPL and subsequent grouping of food processing. The definition of the FPL is fundamental for processed food classification on food processing basis. Since (bio)chemical and physical changes are typical of all food processing, we used the nature of the intended treatments to establish FPL, i.e., unit operations and unit processes (Table 3). It should also be noted that even the simplest food processing often includes several unit operation steps, and the overall process can be regarded as a series or sets of individual unit operations and unit processes.

Food processing includes physical treatments which are necessary to prepare foods for eating, e.g., mixing, washing, slicing, or using low temperatures for food safety, as in chilling and freezing of foods. Such treatments largely preserve cellular structures of food materials or otherwise retain natural properties of foods, e.g., milk. That is,

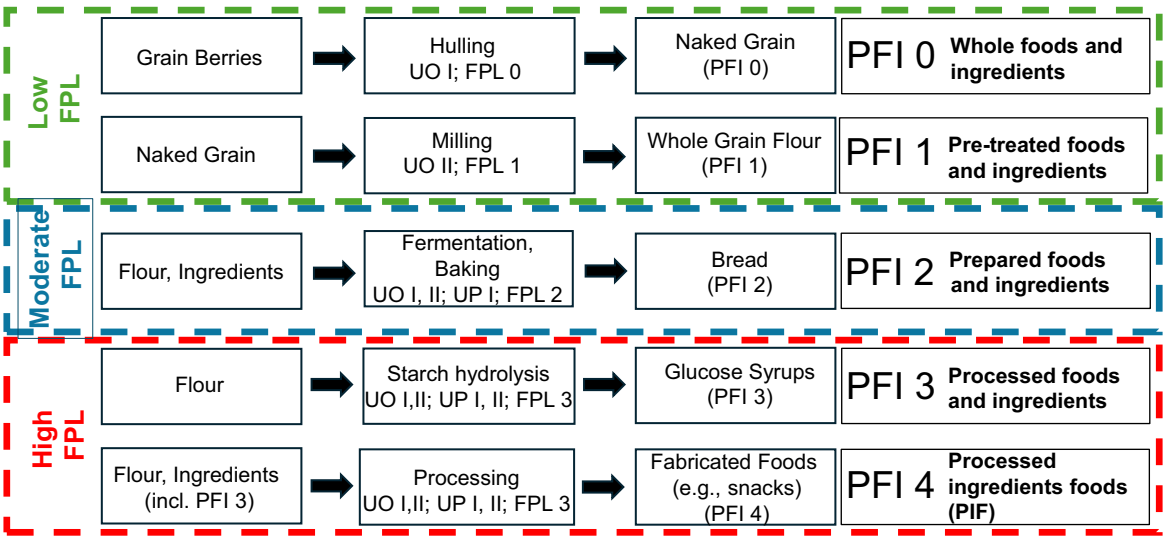

Fig. 4. Food processing levels (FPL) applied to grain berries to obtain various ingredients and foods of different processed food intake (PFI) categories with brief, verbal expressions referring to the different PFI categories.

treatments resulting in mild physical changes and little unavoidable chemical changes (Fennema, 1985) form the food processing category **Unit Operations I** (UO I) corresponding to **FPL 0**. Processed foods originating from UO I processing are defined as 'unprocessed foods' according to the regulation EC 852/2004, and the 'zero' processing level (FPL 0) is assigned accordingly. Unit operations may also result in significant changes in food structures and natural state, as cellular structures may be broken or temperatures up to around 100 °C may affect food properties. These treatments may include minor unavoidable chemical changes, and they are referred to as **Unit Operations II** (UO II) corresponding to **FPL 1**.

Many food processes include heating or other processing where intended physical and (bio)chemical changes occur as processing temperatures from ambient to above 100 °C may be used. This food processing category, **Unit Processes I** (UP I) corresponding to **FPL 2**, includes many common food treatments in industry and cooking at food services and at home to achieve desired, but often complex chemical, structural, physical and sensory properties of the foods (Belitz et al., 2004; Toledo et al., 2018). Food processing may also be intended to change the chemical composition of the input material or otherwise cause significant changes in food composition, as processing temperatures from ambient to >>100 °C of input materials may be used (Shahidi et al., 1997; Coultate, 2023). Such food processes are assigned to the **Unit Processes II** (UP II) category corresponding to **FPL 3**.

Processing, formulation and processed food intake classification

Food processing as treatment of food materials is applied to most foods and is often necessary or unavoidable, and processing may be required by law to ensure food safety. Food materials may consist of formulations including single commodities or one or more ingredients from different FPL (Fig. 2). The FPL used to obtain formulation ingredients, and the final processing of the formulated food provide the required FPL data for PFI classification. It should be noted that food processing or processed foods do not contribute to health outcomes prior to food consumption and, therefore, the PFI classification emphasizes food classification for the understanding of processing impact of foods on diet, i.e., post consumption.

The use of a classification system relies on clear principles or rules allowing an objective labelling of items to assign their correct categories. Such guidelines for grouping of foods to different categories are not provided for classification systems listed in Table 1. A decision diagram for grouping of food processing to different FPL categories is shown in Fig. 3. Individual foods may be agricultural products consumed as such (FPL 0), after processing (FPL 0 to 3) or formulation using ingredients from different FPL with or without further processing steps. The final FPL applied to a food product (FPL 0 to 4) is determined from the highest FPL applied to ingredients used or the final FPL of the final processing if higher than the FPL applied to any of the formulation ingredients.

At the time of consumption, processed foods become part of a diet, and they can be assigned to different PFI categories according to the final FPL of the pre-consumption treatments applied to formulation ingredients and the final processing (Fig. 2). The final FPL applied to a food ingredient or a food, whichever is higher, is used to obtain the PFI category of the ingredient or food (Fig. 3). This classification system is the first of its kind to provide a true processing level -based grouping of foods to different processed food categories with simple methodology for an objective processed food classification. It would also be useful in other applications, such as the WISEcode (Benitez et al., 2025), aiming to use FPL as a criterion in assessing foods.

An example of using the FPL of grain processing in the PFI classification of cereal-based ingredients and foods is shown in Fig. 4. The different PFI categories may also be verbally referred to differently processed foods. It may also be noted that PFI categories 0 and 1 represent food intake from low FPL, PFI 2 ingredients are from moderate FPL and represent most processed foods, including those from home cooking and food service depending on their formulation and final processing. The PFI categories 3 and 4 include food intake from high processing levels, i.e., FPL 3 and 4. Besides providing a processed food classification based on FPL, the PFI system would be useful in choosing ingredients in food product development to obtain desired PFI levels, for example, to improve healthiness of processed foods. Furthermore, the FPL categories may be used to provide a foundation for the classification of food processing impact on, e.g., sustainability, affordability and other food processing -related measures.

Conclusions

The definition of FPL and PFI categories for studies of health outcomes and other impacts of food processing in food systems, diet and public health provides a novel and logical framework for food classifications based on FPL. Food, nutrition and medical professionals are encouraged to ensure correct public understanding of food processing – the UPF terminology should be discouraged and not used. It should be recognized that food processing takes place across the full food chain

while formulation, cooking, oral processing and digestion seem more important to nutritional quality and public health. Food processing classification must be based on clear differences between processing categories, e.g., physical and chemical. It is essential to consider food processing and formulation as separate parameters while their combination is required in the PFI classification. Food consumption from various PFI classes should be followed to observe their role in human health and beyond. Furthermore, the FPL and PFI groupings are useful in reformulation and food product development, particularly in the development of novel and future foods, as processing and formulation can be related to PFI and to other processing outcomes, e.g., affordability and sustainability.

CRediT authorship contribution statement

Yrjo H Roos: Writing – review & editing, Writing – original draft, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data were used for the research described in the article.

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