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Food Classification Systems Based on Food Processing: Significance and Implications for Policies and Actions: A Systematic Literature Review and Assessment

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Abstract This paper is the first to make a systematic review and assessment of the literature that attempts methodically to incorporate food processing into classification of diets. The review identified 1276 papers, of which 110 were screened and 21 studied, derived from five classification systems. This paper analyses and assesses the five systems, one of which has been devised and developed by a research team that includes co-authors of this paper. The quality of the five systems is assessed and scored according to how specific, coherent, clear, comprehensive and workable they are. Their relevance to food, nutrition and health, and their use in various settings, is described. The paper shows that the significance of industrial food processing in shaping global food systems and supplies and thus dietary patterns worldwide, and its role in the pandemic of overweight and obesity, remains overlooked and underestimated. Once food processing is systematically incorporated into food classifications, they will be more useful in assessing and monitoring dietary patterns. Food classification systems that emphasize industrial food processing, and that define and distinguish relevant different types of processing, will improve understanding of how to prevent and control overweight, obesity and related chronic non-communicable diseases, and also malnutrition. They will also be a firmer basis for rational policies and effective actions designed to protect and improve public health at all levels from global to local.

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Introduction

The general purpose of this paper is to contribute to a new approach to industrial food processing, in which its importance, its relevance to the nature of food supplies and systems and dietary patterns, and its impact on human health, becomes properly understood. The paper does not discuss the social, economic, environmental, and other wider aspects of food processing.

Food processing is ubiquitous. Almost all food consumed in almost all settings is now processed in some way. Various types of food processing have beneficial or else adverse effects on foods, diet quality, and human health. Food systems and supplies worldwide are changing, and supplies of ready-to-consume food and drink products are displacing traditional dietary patterns based on freshly prepared dishes and meals. Yet current food classifications, epidemiological studies, and reports containing dietary guidelines, do not pay much attention to food processing. Terms like 'processed foods' or 'highly processed' are often not defined, and intrinsically vague names like 'fast food', 'convenience food' and even 'junk food', are used to identify some types of processed food products. (In this paper, 'food' includes drink).

Verdicts on food processing in general have little or no meaning. Food scientists and technologists and food manufacturers rightly emphasize the benefits of originally ancient and also relatively novel processes such as drying, skimming, non-alcoholic fermenting, freezing, pasteurization, and

vacuum-packing. On the other hand, evidence on the harm done by charring, alcoholic fermenting, salt-pickling, hydrogenation, and sugaring (as with soft drinks or 'soda'), is conclusive or very strong. It is possible to make sense of food processing and its effects on human health only when analysis and assessment is discriminating and precise, with terms defined, and types, uses and effects of processing identified and distinguished.

The impact of industrial food processing on well-being, health and disease is a leading topic in lay and mass communications including the internet and social media as well as broadcasting and print. The shift from dietary patterns based on freshly prepared dishes and meals and artisanal products, to modes of consumption largely of ready-to-consume industrially processed food and drink products, is well known as a cause for concern. Food processing has become much more important as a determinant of dietary patterns, dietary quality, and impact on body weight, diet-related diseases, health and well-being, than was the case 200 or even 30 years ago. Yet reports, papers and other publications concerned with diet, nutrition and health continue to base their findings and recommendations on classifications of the nutritional profile and chemical composition of foods, which give only occasional and sporadic attention to food processing.

This paper reviews and assesses five food classification systems that attempt to categorize foods in terms of food processing. Of these, one has been devised and applied in Europe, one has been devised and applied in the US, two were devised for and applied in Latin American countries, and one originated in Brazil has a global scope and application. Such studies are a potential new basis for epidemiological and experimental research, and thus for official and other authoritative international and national reports that include dietary guidelines. In turn, the purpose of such guidelines is to generate rational public policies and effective actions to promote and protect good health and well-being, and to prevent and control obesity and diet-related conditions and disease.

Background

Food preparation and cooking, and methods of food cultivation and preservation, have enabled the evolution and adaptation of the human species [1], and the creation and increase of settled communities, populations, and civilizations [2].

The Rise of Humanity

The corresponding evolution of food processing can be separated into three overlapping stages. In the first stage, pre-industrial methods of food processing developed slowly and gradually over many tens of thousands of years, with the general shift from gatherer-hunter to pastoral-migrant to peasant-agricultural ways of life, and with the growth of towns and cities most of whose food was supplied from the surrounding countryside. This was almost all fresh or else preserved with the aid of simple hand tools by drying, salting, pickling, smoking and other methods. Wheat bread was an exception, being made from flour processed by mills powered by draught animals or water since the classical Roman period, and later as from the medieval period in the Arab world and Europe also powered by wind [3].

The Industrial Revolution

The second stage of food processing began roughly two centuries ago in the early 1800s as part of the Industrial Revolution, notably in Europe and the US, and later in other regions and countries. Heavy machines initially fuelled and powered with coal and by steam were invented and developed [4]. The specific properties of protein and other macronutrients and some minerals were discovered, and nutrition became identified as a biochemical discipline [5]. Steam ships and trains revolutionized intercontinental transport [4]. Trade barriers were lifted. The price of culinary and industrial ingredients such as fats, oils, sugars, flour, and salt plummeted.

Industrial food processing has transformed the nature, purpose, scope and scale of the food supplies of industrialized countries and settings. In the later 1800s and into the 1900s the mass manufacture and thus consumption of processed food products increased rapidly. These were mostly preserved by sugaring, salting, canning and bottling, and chilling and freezing, or made using powerful mechanical techniques such as roller milling, pressure rendering and extrusion, or with chemical technology such as hydrogenation and hydroxylation, using preservatives and additives such as bleaches, dyes, and flavors. These new industrial products included mass-produced and increasingly cheap breads, buns and cakes, breakfast cereals, cookies (biscuits), candies (confectionery), preserves (jams), syrups, condensed milk, soft drinks, and meat, lard, cheese and dairy products [6–8]. Three successful processed products originally formulated in the middle or late 1800s were meat and yeast extracts, baby formula, and margarine [5, 9]. These transformations are now complete in high-income countries and settings, but elsewhere are still taking place.

Until well into the 1900s the main diet-related public health problems identified in industrialized countries as well as the rest of the world remained nutrient deficiencies [10]. National and other authoritative dietary guidelines issued in the first half and early in the second half of the century, derived from the food classifications of the time, usually emphasized the need for adequate intakes of dietary energy, protein, and micronutrients [6, 11, 12].

However, from the 1950s and 1960s, starting in the US, the UK and other high-income countries, and then later

elsewhere, rates of cardiovascular disease increased rapidly. This was attributed notably to increases in consumption of saturated fat mostly from meat and other animal sources, and to decreases in physical activity [13–15]. In response UN, national, and other official dietary guidelines shifted priorities, and emphasized the need to reduce consumption of saturated fat, and also sugar and salt, and to increase consumption of dietary fiber, relative to the amounts typically consumed in higher-income countries and settings [16]. Dietary recommendations remained nutrient-based. They corresponded to officially accepted food classifications which themselves remained based on the relative nutrient profile and chemical composition of different types of food.

Economic Globalization

The third stage of food processing began in the 1980s. It amounts to a revolution that has transformed food systems and supplies and dietary patterns in most countries and settings in just over one generation. This transformation is partly one of nature, mostly one of scale and penetration. An aspect of economic globalization is the very rapid growth of food distribution, manufacturing, retailing, and catering corporations with worldwide operations [17–19]. As a result, the food supplies of high-income countries, and then of higher-income and urban settings in lower-income countries, and more recently even of rural areas of many middle- and low-income countries, increasingly consist of mass-produced branded processed food products.

The impact of this shift is least dramatic in those high-income countries like the US, Canada, Australia, the Nordic region and the UK, whose food supplies were already industrialized before the 1980s. The shift has been and is away from dietary patterns based on home and artisanal preparation of foodstuffs, dishes and meals, toward consumption of ready-to-consume food and drink products [20–23]. There is a profound difference between the two types of consumption. Meals and dishes prepared and cooked at home and by artisanal methods are mostly made from unprocessed and minimally processed foods together with processed culinary ingredients. By contrast, most ready-to-consume products are ultra-processed, meaning that they are not modified foods, but formulations of industrial ingredients that contain little or no whole food [24–26, 27••].

Beginning around the 1960s, adult obesity became recognized as an increasingly serious public health problem in the US and some other industrialized countries, and also in territories and settings such as some Pacific island and Native American reservations where diets were largely made up from imported ‘store’ food. Since the 1980s, rates of childhood and early life as well as adult overweight and obesity and directly related diseases, notably diabetes, have risen explosively throughout the world, and now amount to an uncontrolled pandemic [14, 22, 28].

There are a number of interconnected basic reasons for the parallel increases in consumption of processed products and in weight gain, overweight, obesity and also diabetes. These include the ‘free trade’ economic system that has enabled the growth of colossal transnational food and drink corporations, the corresponding deregulation of food standards, and the privatization of public goods [29••, 30–32, 33••, 34]. Such reasons are beyond the scope of this paper.

Since the 1990s there has been a move toward food-based dietary guidelines [20]. Influential reports with a global scope concerned with prevention of cancer and also of obesity have issued food-based population goals and personal guidelines. However, World Health Organization and other reports that include dietary goals and guidelines have usually continued to focus on dietary energy and macro- and micro-nutrients, with secondary attention to foods and only sporadic reference to food processing [15, 35]. Again, a plausible reason is that the conceptual framework of the food classifications that are a basis for dietary guidelines still remains focused mostly on the nutrient profile and chemical composition of foods. One joint WHO-UN Food and Agriculture Organization report identifies the need to evaluate traditional and industrial food processing methods [35].

References to Processing

This section summarizes references to food processing in recent epidemiological and other papers and reports concerned with dietary patterns, nutritional status, and disease, health and well-being.

Trans-Fatty Acids

There is now a large amount of literature identifying *trans*-fatty acids as at least as pathogenic as saturated fats, and *trans*-fats are now commonly identified as toxic [36].

However, a search has identified only one research group that focuses not so much on *trans*-fats as on the partial hydrogenation process that generates *trans*-fats [37].

Specific Processes or Products

Reports prepared for the World Cancer Research Fund in 1997 and 2007 [38, 39] contain recommendations on prevention of cancer, and on prevention and control of obesity, itself a cause of some common cancers notably in industrialized parts of the world. These emphasize the general lack of epidemiological evidence on food processing. They do however identify various forms of originally artisanal methods of food preservation such as salting, salt-pickling, smoking and curing, and some

methods of preparation that involve cooking in direct flame and charring, as risk factors for some cancers. One of these reports also refers to refrigeration as a protective process [38].

In the case of overweight and obesity, and some cancers, epidemiological evidence has however accumulated. These reports and other analyses summarize evidence judged to amount to probable or convincing causal association between consumption of specific types of processed food products and obesity or directly of cancers. Energy-dense foods, sugary soft drinks, and 'fast foods', are identified as probable causes of weight-gain, overweight and obesity and thus of obesity-related cancers [38, 39]. 'Processed meats' [39] or 'preserved meats' [35] are identified as convincing [39] or probable [35] causes of colorectal cancer. These and other reports and studies provide evidence on specific food processing methods and specific conditions and diseases, but do not consider the significance of industrial food processing as a whole.

Convenience

Some studies focus on convenience and specifically on the effort and length of time between the acquisition of food or food products and the preparation and then consumption of dishes and meals [40, 41]. These do not take processing into account and therefore may group food of different processing types. For instance, both portable fruits and potato chips are seen as convenient because they both are "ready-to-eat".

Addiction

A growing literature, much originating in the US, identifies some foods as quasi-addictive, or by the usual methods of judgment, actually addictive, based on animal and also human studies [42, 43]. While this literature frequently refers to such foods as processed or highly processed or as fatty or sugary, a search has not identified any author explicitly suggesting that types of food processing are themselves implicated, with one exception [44].

Home-Made and Industrial Products

Other studies distinguish 'processed foods' as being unlikely to be prepared at home. The CESSIAM group in Guatemala defines processed foods as 'those food products that were manipulated, mixed, cooked, and/or packaged in industrial settings and for which there were no equivalents in home-made preparations' [45–47]. This distinguishes industrial processing from domestic or artisanal preservation and preparation, but does not take into account industrial products such as breads and pizzas that mimic home-made food.

Indigenous Dietary Patterns and 'Market' Foods

Research done from the Centre for Indigenous Peoples' Nutrition and Environment (CINE) at McGill University in association with the UN Food and Agriculture Organization [48], distinguishes between the original and traditional food systems of Indigenous populations in North America, Latin America, Africa, Asia and the Pacific region, and what are commonly known as 'market' or 'store' food supplies. These are mostly industrially processed, and form an increasing percentage of the diets of most indigenous populations [48]. Displacement of traditional foods by 'market' foods reduces the quality and diversity of their diets [49–51], and they also have important social, cultural and environmental implications [48]. However, studies that examine indigenous dietary patterns do not identify the different types of processing in 'market' foods, and so do not assess processing as such.

Traditional and Cultural Dietary Patterns

There is a colossal lay and a very extensive scientific literature on traditional dietary patterns of regional and national populations, and other dietary patterns practiced by groups or people for cultural, culinary or other reasons, which are identified or claimed as healthy. These include the Mediterranean diet [52–54], the traditional Chinese, Japanese, Thai and Indian diets [55, 56], the Paleolithic diet (strictly speaking an indigenous dietary pattern) [57], the 'Diet for a Small Planet' [58], the '100 mile diet' [59], the Seventh-day Adventist diet, the Macrobiotic diet, and many others, not to mention diet regimes designed to reduce body fat. A review of all these patterns and regimes would be a comparably vast task. However, most by their nature refer to or recommend dietary patterns that are pre-industrial; an exception is the Mediterranean diet, specified by authors as including cold-pressed oils, traditional wholegrain bread, and other artisanal foodstuffs [53, 54]. However, none of this literature examines industrial food processing.

Modern Dietary Patterns

The epidemiological literature on modern dietary patterns occasionally refers to food processing. A report on prevention of cancer and obesity refers to 'Western' dietary patterns 'which are energy-dense, and increasingly made up from processed foods' including 'fatty or sugary foods such as processed meats, pastries, baked goods, confectionery, sugared and often also alcoholic drinks' [39]. Seen in studies conducted in many parts of the world as causally linked with obesity [60–66] and related chronic diseases [61, 67–72], these contain a high proportion of processed meats, refined grains, and candies, but also include unprocessed and minimally processed sources of animal food such as meat, milk,

and eggs. A 'processed' dietary pattern has been linked with increased risk of obesity and cardiovascular disease [73, 74], whereas dietary patterns largely composed of 'unprocessed foods' including whole grains, vegetables, fruits, legumes and fresh meats, have been identified as protective [75–78]. But in the absence of definitions of 'processing' and of types of processing, these findings on 'Western', 'processed' and other dietary patterns are vague and not really informative.

Dietary Guidelines in Official Reports

Recent UN and other reports that include dietary guidelines and recommendations now pay some attention to foods as distinct from nutrients [15, 35], and refer to food processing in general, but make little reference to specific methods of food preservation and preparation, or to industrial food processing. When reference is made, terms like 'processed', 'highly processed', 'industrialized', 'convenience', and 'fast' food, are commonly used but typically are not defined and used vaguely without reference to specific types of processing.

Nutritional Epidemiology

The evidence summarized in this section indicates that the epidemiological and other literature includes only fragmentary information and insight on relationships between processed foods and eating patterns, energy and nutrient intake, and health.

Nutritional epidemiology is itself based on food classifications that group foods according to their nutrient profile and chemical composition, with little reference to what is done to them before they are acquired and consumed.

The rest of this paper focuses on studies whose purpose is to integrate food processing into food classifications.

Method

Search Strategy

The method used was systematic review. The following electronic databases were searched for entries in the ten years between 1 September 2003 and 1 September 2013: PubMed; and Virtual Health Library, which includes LILACS, MEDLINE, MEDCARIB, OPAS/OMS, PAHO, WHOLIS, and SCIELO. The search was conducted in English, Portuguese, French, and Spanish. Along with the term 'food processing', other key words used were: 'convenience foods', 'industrialized food', 'processed food', 'unprocessed', 'minimally-processed', 'highly-processed', and 'ultra-processed'.

Selection of Papers

Two of the authors screened titles and abstracts of papers to decide whether they should be reviewed. Studies selected for abstraction, were original research studies in the fields of nutrition, public health or epidemiology, that included some measure and classification of food processing, and that included a diet or health outcome. The reference lists of the selected papers were also screened; this yielded additional papers for abstraction.

Abstraction

Abstraction tables for selected papers included the study's title, its authors, the publication year, the country where it was conducted, and study design, sample size (if any), details of food processing definition and classification system, and measurement of health outcomes.

Evaluation of Quality

The following criteria were used to identify and evaluate the quality of selected studies (see Table 1).

- Specific. Concerns industrial food processing, and distinguishes between industrial processing, and artisanal and domestic processing and preparation.
- Coherent. Makes internal sense, such that the food and product categories and characterizations relate to one another logically.
- Clear. Defines the categories and sub-categories without gaps or overlaps, and gives examples of the food products included in each of them.

Table 1 Criteria and definitions to evaluate food classification systems

Criteria	Definition
Specific	Whether the system is based on criteria related to industrial food processing, and differentiates between industrial and artisanal-domestic (home-made) methods of processing
Coherent	Whether the system makes internal sense, such that the food and product categories and their characterizations relate to one another logically
Clear	Whether the system defines each of the categories and sub categories, without gaps or overlaps, and gives examples of the food products included in each of them
Comprehensive	Whether the system covers all types of foods and products, and so can be used to study whole diets
Workable	Whether the system can be readily applied to dietary data from household and population based nutrition surveys

- Comprehensive. Covers all types of foods and food products, and so can be used to study whole diets.
- Workable. Applies readily to dietary data from household and population based nutrition surveys

Two raters conducted the quality assessment scoring and a third rater reconciled discrepancies. A Likert scale was used to rate the extent to which each criterion was met as follows: (3) completely, (2) mostly, (1) partially, (0) hardly, or not at all.

Evaluation of Relevance

Assessment of the relevance in use of the classifications did not use a scoring method, because so far most of them have been used only once or twice, and only among one or two population groups. Instead, a descriptive evaluation was used. This gauges the classifications in terms of the extent to which they can be used among different types of populations, and their potential for identifying the quality of diets and also associations with obesity and related chronic non-communicable diseases.

Results

The dataset search yielded a total of 1276 papers from the selected databases (PubMed, n=401; Virtual Health Library, n=875). After title screening, 110 abstracts were reviewed, and studies that did not use a classification system were excluded. A total of 21 studies were fully abstracted. This led to identification of five food processing classification systems, described and evaluated below.

Europe

In Europe, a classification system has been devised by researchers at the International Agency for Research on Cancer (IARC) using methodology devised for the European Prospective Investigation into Cancer and Nutrition (EPIC) study. It was first used in a study published in 2009 [79], and later updated and used in a second paper in 2011 [80].

The classification relies on the degree of processing. It identifies three main groups and sub-groups. The first group is of "non-processed foods" consumed raw without any further processing, preparation, except washing, cutting, and squeezing. The second group is of "modestly/moderately processed foods', sub-divided into industrial and commercial foods that are consumed with no further cooking, and foods processed at home and prepared/cooked from raw foods or moderately processed foods. The third group is of 'processed foods', sub-divided into 'staple/basic foods' and 'highly-processed foods'. Recoding and classification work is done at the food/ingredient level, after recipes are broken down into ingredients and processed foods (see Table 2).

Quality

This European system is partially specific. It does not include a definition of industrial food processing. It establishes a rather incomplete distinction between domestic and industrial processing. For instance, its moderately processed foods include industrial and commercial preparations that require no further processing at home (such as canned vegetables), foods processed at home and prepared/cooked from raw ingredients (such as from fresh vegetables), and dishes prepared at home from moderately processed foods (such as from canned vegetables).

The classification is partially coherent. The degree of food processing is ranged from 'unprocessed' through 'moderately' to 'highly processed', but the criteria to define degree of processing are unclear. For example, drying, industrial deep-frying, and hydrogenation, are grouped together. Also, drying is defined as a high processing method, whereas dried fruits are classified as moderately processed, and products like butter, vegetable oils and margarine are all classed together as highly processed.

The classification is mostly clear, but some information on categories is not included. For instance, there are no formal definitions of the sub-categories 'processed staple-basic foods' and 'highly processed foods'; these were introduced in the second paper [80]. The system can be scored as completely comprehensive, as it includes a wide range of food and food products.

The classification is mostly workable. It was applied twice to 24-hour dietary recalls data from the EPIC study itself, but it has not been applied to household food expenditure surveys.

Overall, the European classification system as devised by IARC-EPIC is judged to be partially specific (1), partially coherent (1), mostly clear (2), completely comprehensive (3), and mostly workable (2). It scores 9 out of 15.

Relevance in Use

The first study using this European classification from 23 centers in ten countries (N=36,034 adults) [79], reported that highly processed foods dominate diets especially in Nordic and Central European countries, whereas non-processed and highly processed staple foods contribute more to dietary and nutrient intakes in Southern Europe. This finding has important implications for obesity, since many highly processed foods are energy-dense and high in fats, sugar, and low in dietary fiber.

The second study from 16 centers (N=3003 adults) [80], reported strong and consistent correlations between mean intakes of highly processed foods and mean levels of plasma

Table 2 Europe (IARC-EPIC)

Food groups and definition	Examples
1 Non-processed	
Foods consumed raw without any further processing, preparation, except washing, cutting, squeezing	Raw fruits; non-processed nuts; fresh raw vegetables; fresh grated vegetables; raw crustaceans/ mollusks; fresh juices; fresh and not enriched farmer's milk; whole fresh cream; raw meat; raw egg white; honey.
2 Modestly or moderately processed	
2.1 Industrial and commercial foods involving relatively modest processing and consumed with no further cooking	2.1 Dried or semi-dried fruits; nuts and seeds; raw, vacuum packed or controlled atmosphere foods (e.g. salads); frozen or vacuum-packed raw meat; extra virgin olive oil; fruits, vegetables canned in water, brine, own juice; green and chamomile tea.
2.2 Foods processed at home and prepared/cooked from raw foods or moderately processed foods	2.2 Fresh vacuum-packed or frozen cooked potato (including homemade French fries); fresh fruit, compote, boiled; cooked fruit; fresh or frozen cooked vegetables; dried boiled legumes, boiled grain; whole-meal boiled rice; fresh or vacuum-packed cooked meat, fish, offal; whole cooked egg.
3 Processed	
Foods industrially prepared involving high degree of processing such as drying, flaking, hydrogenation, heat treatment, use of industrial ingredients and industrial deep frying. It also includes foods from bakeries and catering outlets requiring no or minimal domestic preparation apart from heating and cooking. This category is subdivided into processed staple/basic foods and highly processed foods, with examples given.	3.1 Processed staple/basic Bread; pasta; rice; milk; butter; vegetable oils. 3.2 Highly processed Cakes; biscuits; breakfast cereals; crisp bread; confectionery; processed meat; fish; yoghurt; cheese; cream.

(Adapted from: Slimani N, Deharveng G, Southgate DA, Biessy C, Chajes V, van Bakel MM, et al. Contribution of highly industrially processed foods to the nutrient intakes and patterns of middle-aged populations in the European Prospective Investigation into Cancer and Nutrition study. Eur J Clin Nutr. 2009; 63 Suppl 4:S206-225; and Chajes V, Biessy C, Byrnes G, Deharveng G, Saadatian-Elahi M, Jenab M, et al. Ecological-level associations between highly processed food intakes and plasma phospholipid elaidic acid concentrations: results from a cross-sectional study within the European prospective investigation into cancer and nutrition (EPIC). Nutr Cancer. 2011;63(8):1235-1250) [79, 80]

elaidic acid (the *trans*-fatty acid produced by partial hydrogenation of vegetable oils used as ingredients in processed food products) [80]. This also suggests that the classification could be useful in predicting diet quality and relationship with obesity and other disease outcomes.

US

In the US, a food classification system has been devised by the International Food Information Council Foundation (IFIC) in an *Understanding our Food Communications Tool Kit* [81] responding to the official *2010 Dietary Guidelines for Americans*. The Tool Kit was elaborated in a paper [82•] prepared by a 'joint task force' of the US Academy of Nutrition and Dietetics, the American Society for Nutrition, the Institute of Food Technologists, and the International Food Information Council.

Food processing is defined as 'any deliberate change made in a food from the time of origin to the time of consumption' [82•]. The classification relies on relative complexity in 'a continuum' of processing, and the physical, chemical, and sensory changes in food products caused by processing. In the Joint Task Force paper, derived and developed from the IFIC Tool Kit, foods and products are classified as 'minimally processed'; 'foods processed for preservation'; 'mixtures of combined ingredients'; 'ready-to-eat processed foods'; and 'prepared foods/meals' (see Table 3). A further follow-up paper derived from a 'Is "processed" a four-letter word?' symposium [83] emphasizes that there should be closer collaboration between the nutritional and the food science and technology professions.

Quality

The US IFIC-Joint Task Force system concerns industrial processing, but makes no distinction between industrial processing and artisanal-domestic methods of processing and preparation. So it is partially specific. It is partially coherent, for it does not follow a logical order. For example, it is hard to see why 'mixtures of combined ingredients', with the examples given, are less processed than 'prepared foods/meals'. The conceptual difference between 'foods processed to help preserve and enhance nutrients and freshness of foods at their peak' (identified as 'foods processed for preservation') and 'foods packaged for freshness and ease of preparation' (identified as 'prepared food/meals') is also hard to understand.

Table 3 US (IFIC-Joint Task Force)

Food groups and definition	Examples
1 Minimally processed	
Foods that require little processing or production, which retain most of their inherent properties.	Washed and packaged fruits and vegetables; bagged salads; roasted and ground nuts, coffee beans; homemade soups.
2 Foods processed for preservation	
Foods processed to help preserve and enhance nutrients and freshness of foods at their peak.	Canned tuna, beans and tomatoes; frozen fruits and vegetables; pureed and jarred baby foods; soups made from other canned vegetables or broth.
3 Mixtures of combined ingredients	
Foods containing sweeteners, spices, oils, colors, flavors, and preservatives used for promotion of safety, taste, visual appeal. Group further divided into 'packaged mixes and jarred sauces' and 'mixtures probably home prepared' (no details or examples given of foods in these sub-categories).	Some packaged foods, such as instant potato mix, rice, cake mix, jarred tomato sauce, spice mixes, dressings and sauces, and gelatin.
4 Ready-to-eat processed	
Foods needing minimal or no preparation. Group subdivided into 'packaged ready-to-eat foods' and 'mixtures possibly store prepared' (no details or examples given of foods fitting in these sub-categories).	Breakfast cereal; flavored oatmeal; crackers; jams and jellies; nut butters; ice cream; yogurt; garlic bread; granola bars; cookies; fruit chews; rotisserie chicken; luncheon meats; honey-baked ham; cheese spreads; fruit drinks; carbonated beverages.
5 Prepared foods/meals	
Foods packaged for freshness and ease of preparation	Prepared deli foods and frozen meals; entrées; pot pies and pizzas.

(Adapted from: Eicher-Miller HA, Fulgoni VL III, Keast DR. 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. J Nutr. 2012;142(11):2065S-2072S) [82•]

Overall the classification is partially clear, because of incomplete information, and because food categories are described with uneven attention. The group 'mixtures of combined ingredients' is sub-divided into 'packaged mixes and jarred sauces' and 'mixtures probably home prepared', but there are no details or examples of products fitting in these sub-categories. Jarred tomato juice and cake mix are 'mixtures of combined ingredients', together with rice. Bread is classified as a 'mixture of combined ingredients', whereas garlic bread goes into the 'ready-to-eat foods needing minimal or no preparation' category together with candies and alcoholic drinks. Differences between 'packaged ready-to-eat foods' and 'mixtures possibly store prepared' are not evident. There are also overlaps in the criteria used to define food categories. Thus, enhanced palatability is a common feature of most industrialized food products, including jarred (bottled) baby food, carbonated drinks, and pizzas.

The classification is partially comprehensive. Its lists of foods and products are incomplete. Foods such as grains, legumes, milk, eggs, fresh meat, and fish are not categorized. Unprocessed foods are not included.

The classification is judged to be partially workable at least in the US, since it has been applied once [82•]. To be used with food expenditure surveys it would need development, since processed culinary ingredients such as table sugar and salt are not included.

Overall, the US IFIC-Joint Task Force classification system is judged to be partially specific (1), partially coherent (1), partially clear (1), partially comprehensive (1), and partially workable (1). It scores 5 out of 15.

Relevance in Use

The US classification has been applied once to 24-hour recall data from the US National Health and Nutrition Examination Survey (NHANES) 2003-2008 to determine first, the contribution of processed food products according to type identified in the classification to total energy intakes, and second, the percent contribution of specified nutrients to total reported daily nutrient intake [82•]. The conclusion is that minimally processed food provides considerable amounts of vitamins and minerals, but little dietary energy, whereas 'ready-to-eat' processed food products supply a lot of dietary energy and added sugars but little dietary fiber. Minimally processed foods of animal origin such as meat and eggs supplied a lot of dietary cholesterol, whereas 'ready-to-eat' processed foods, whose ingredients are mostly of plant origin, were usually low in dietary cholesterol. The study concludes that 'processing is not a major determinant of food's nutrient contributions to the diet and does not have a clear association with the health of a food'.

An overall conclusion of the paper using the US IFIC-Joint Task Force system is that it is not appropriate to make dietary recommendations with specific reference to food processing. This conclusion is reached by emphasizing the importance of saturated fat and of dietary cholesterol, of which fresh and

minimally processed foods of animal origin are important sources. If dietary cholesterol was not given a prime prominence as a dietary indicator it would be difficult to come to this conclusion. It would be impossible to come to such a conclusion if energy density and *trans*-fats were included as prime dietary indicators, but they are not included, and the papers also omit to discuss their own findings as shown in a table that ready-to-eat processed food products are the main sources of sodium and of saturated fats in the US diet.

Mexico

This classification system, devised in 2007 by researchers from the National Institute of Public Health in Mexico [84], uses criteria of elaboration and of temporality: it distinguishes between industrialized and local food and products, and between modern and traditional foods and products. It divides foods and products into three categories. The first group is 'industrialized modern foods' now incorporated into the Mexican diet. The second group is 'industrialized traditional foods' that have been part of the traditional Mexican diet since before the 20th century, but that are now mass-produced. The third group is of 'non-industrialized foods', sub-divided into 'modern and traditional preparations made out of the home', 'traditional preparations made at home or artisanally', and 'unprocessed foods' (see Table 4).

Quality

This classification is partially specific. It lacks a definition of industrial food processing, and the distinction between industrialized and local foods is the form and scale with which they are marketed rather than their properties and nature. The distinction between methods of industrial and artisanal-domestic processing is not complete. For instance, food classified as 'modern preparations outside the home' includes dishes like hamburgers and pizzas that even if not produced on an industrial scale, may be made from industrialized ingredients such as bread, ketchup, and cheese.

The classification is completely coherent: the categories relate to each other in terms of temporality and processes of elaboration. It is mostly clear; the categories are well-defined, with no overlaps, but examples are rather uneven or sparse: thus 'industrialized traditional foods' have a few examples only. It includes many types of food and products, but is rated as mostly comprehensive because some types common in other countries are not included. It is judged as mostly workable, since it has been applied just twice, once to 24-hour dietary recalls [84] and once to food frequency questionnaires [85].

Overall, the Mexican classification system is judged to be partially specific (1), completely coherent (3), mostly clear (2), mostly comprehensive (2), and mostly workable (2). It scores 10 out of 15.

Relevance in Use

The Mexican classification system has been applied to surveys using 24-hour dietary recalls (N=1070 children, 1–4 years old) [84], and using food frequency questionnaires in two Mayan communities (N=51 families) [85].

In the first study, industrialized foods (modern and traditional combined) contributed more than 39 % of total energy, total protein, animal protein, carbohydrates, total fats, and saturated fats [84]. This only partly identified the impact of industrial processing on body weight, because the distinction between industrialized and non-industrialized foods was broad, and did not account for the extent of processing.

However, the paper did identify specific products. Soft drinks, defined within industrialized modern food, were among the highest contributors to total energy, while non-industrialized foods including fruits, vegetables, grains, legumes, and tubers provided the highest amount of dietary fiber.

Higher income and urban residence were associated with high consumption of industrialized modern food products [84]. Increased income, monetary support from government, and emigration of family members into cities, were also associated with relatively high consumption of industrialized modern food products in two Mayan communities of Yucatan [85].

Guatemala

A food classification system devised by a researcher then at the International Food Policy Research Institute (IFPRI), has been used in a study carried out in Guatemala [86•] building on previous work examining the contribution of processed food products to food supplies in lower-income countries [87]. Three food categories are identified. The first is of 'unprocessed foods', including staple foods such as corn, roots and tubers, vegetables, fruits, meat, fish, beans. The second includes 'primary or partially processed foods', such as corn products, dairy products, and animal fats. Neither group is formally defined. The third group is of 'highly-processed foods', defined as having undergone 'secondary processing into a readily edible form' and 'likely to contain added sugars, hydrogenated fats (trans-fatty acids), and-or salt' [86•] (see Table 5).

Quality

This Guatemalan classification is partially specific. It lacks a definition of industrial processing, and does not make a clear distinction between industrial and domestic methods of

Table 4 Mexico (NIPH)

Food groups and definition	Examples
1 Modern industrialized	
Foods that have been incorporated into the Mexican diet. They can be found as a single product or mixed with other ingredients, impossible to separate.	Powdered milk, non-fat milk, 1 % milk; breakfast cereals; whole wheat bread; salty wheat bread; sausages; packaged sweet breads; oil and modified oils; granulated and liquid sugar; sweetened drinks; instant coffee; baby formulas; compotes; supplements.
2 Industrialized traditional	
Foods that have been part of the traditional Mexican food culture according to customs and traditions since before the 20th century and that nowadays are being produced at a large scale in an industrial way.	Corn flour for tortillas or *atoles*; whole cow milk.
3 Non-industrialized	
3.1 Modern preparations outside the home	3.1 Modern preparations outside the home
Preparations, ingredients not typical of Mexican food.	Burgers; sandwiches; pizza; milkshakes.
3.2 Traditional preparations outside the home	3.2 Traditional preparations outside the home
Preparations with ingredients often impossible to separate. Prepared locally or at home, and that have been part of the traditional food culture of Mexico.	Beans or stews with beans; *tacos; atoles; tamales*; fresh water; artisanal sweetened drinks; *gordassolas o rellenas*; broths; salsas; fish; meat stews; fried fish; vegetable or legume pies; *pozole; chilaquiles*; soups; salads; *carnitas*.
3.3 Locally made traditional foods	3.3 Locally made traditional foods
Typical Mexican cuisine. Home-made or artisanal on a small and very small scale.	Corn tortillas; salty and sweet bread (*bolillo*); animal fats such as pig skin or lard; home-made sugar and drinks.
3.4 Not processed	3.4 Not processed
Raw foods not processed except by collection, selection, cleaning.	Fruits; vegetables; legumes; cereals; tubers; red and white meats; fish; eggs.

(Adapted from: González-Castell D, González-Cossío T, Barquera S, Rivera JA. Contribution of processed foods to the energy, macronutrient and fiber intakes of Mexican children aged 1 to 4 years. Salud Publica Mex. 2007;49(5):345-356) [84]

processing. For example, hand-made tortilla from corn is grouped with tortilla from a mixture of industrially produced corn flour and corn. Also, it is not clear how products like pastries and cookies that could be home-made or else industrially processed are classified.

The system is mostly coherent. Its food groups are related by scale of processing, but the criteria for classification are unclear. While 'highly-processed foods' are well defined, there are no specific criteria for 'primary or partially processing' or for unprocessed foods.

The classification is partially clear. It lacks definitions for two main food groups, and has incomplete information on each food group. Several foods like vegetables and fruits are not distinguished according to degree of processing. Terms

Table 5 Guatemala (IFPRI)

Food groups and definition	Examples
1 Unprocessed	
Not defined	Staple foods like corn and other grains; roots and tubers; beans; vegetables; fruits; meat; fish; eggs; dairy including fresh, dried milk, cream.
2 Primary or partially processed	
Not defined	Corn products, including tortillas; dairy products like evaporated milk, cheese; yogurt; animal fats including lard and butter.
3 Highly processed	
Foods that have undergone secondary processing into readily edible form, likely to contain high levels of added sugars, fats or salt.	Pastries; cookies; crackers; sausage and prepared meats; ice cream; frozen desserts; breakfast cereals; confectionery (sweets, chocolate); fat spreads and shortening; pasta products; soft drinks; prepared meals like dried soup; formula and complementary foods.

(Adapted from: Asfaw A: Does consumption of processed foods explain disparities in the body weight of individuals? The case of Guatemala. Health Econ. 2011;20(2):184-195) [86•]

like 'processed grains' and 'pasta products' are not clear. The classification is mostly comprehensive because it does include a wide range of food and food products.

The classification is judged as partially workable, since it has been applied only once to food expenditure data from Guatemala [86•]. It would require development to be applicable to dietary data using 24 hour recall methodology. It is not clear how mixed dishes could be treated.

Overall, the Guatemalan classification system as devised from IFPRI is judged to be partially specific (1), mostly coherent (2), partially clear (1), mostly comprehensive (2), and partially workable (1). It scores 7 out of 15.

Relevance in Use

The Guatemalan study identifies degrees of food processing as relevant to body weight. The classification has been applied to food expenditure data from the 2000 Living Standard Measurement Survey of Guatemala (N=7276 households) to examine the contribution of processed food products to prevalence of overweight/obesity [86•]. A 10 % increase in partially processed foods from total household food expenditure increased BMI of family members aged 10 years and above by 3.95 %, and a 10 % point increase in highly processed food items increased the BMI by 4.25 %.

Global

In Brazil, researchers based at the Centre for Epidemiological Studies in Health and Nutrition at the School of Public Health, University of São Paulo, three of whom are co-authors of this paper, have developed a thesis about the role of industrial processing in nutrition and human health [24–26, 27••]. This followed analysis and assessment of studies on national trends in household food acquisitions and their health implications carried out in the last quarter of the twentieth century [88, 89]. The thesis proposes that industrial food processing is now the main shaping force of the global food system, and the main determinant of nature of diets and related states of health and well-being. It is thus global in scope.

In order to investigate this thesis, a classification system (now known as NOVA) was initially published as a work in progress in 2009 [24] and 2010 [25, 26], and later revised [27••]. It has been used in a series of studies in Brazil [26, 90•, 91] and internationally [33••, 92•, 93–95].

It defines industrial food processing as 'the methods and techniques used by food manufacturers and associated industries to make unprocessed or "raw" foods less perishable, easier to prepare, consume or digest, or more palatable and enjoyable, or else to transform them into food products'. Home-made and artisanal dishes and preparations of all types are by definition not industrially processed, and are disaggregated into their components which are classified appropriately.

With NOVA, foods and products are classified according to the nature, extent and purpose of industrial food processing, in three main groups, together with subgroups and items. Group 1 is of unprocessed or minimally processed foods. Group 2 is of processed culinary ingredients. Group 3 is of ready-to-consume products, with two sub-groups of processed food products, and what NOVA terms ultra-processed products (see Table 6).

Quality

The NOVA classification system defines industrial processing, as distinct from artisanal-domestic processing and preparation, and thus is completely specific. Artisanal or home-made items (breads, for example) and freshly prepared dishes are distinguished from industrial products and pre-prepared dishes.

NOVA is completely coherent: there is a continuum in the nature, extent, and purpose of processing from 'unprocessed' to 'ultra-processed'. Each group is also conceptually different in various ways that are specified. Thus minimal processing of group 1 foods is used to preserve the foods, and to make them suitable for storage, facilitate their culinary preparation, enhance their nutritional quality, and often to make them more enjoyable to eat and easier to digest. Group 2 processed culinary ingredients are highly durable but usually not consumed by themselves. They are combined with foods in the preparation and cooking of dishes and meals. By contrast, group 3 products are ready-to-consume, by themselves or in combinations, and ultra-processed products are typically formulated to be convenient, and intensely palatable. Ultra-processed products are conceptually and actually different from processed foods. They are not modified foods, recognizable as such. They are formulations of industrial ingredients and substances derived from foods or else created in laboratories, and typically contain little or even no whole foods.

In its initial version [24–26, 90•, 92•], the system was not fully developed. Thus it initially did not distinguish between processed food products and ultra-processed products. The later versions [27••, 91, 93] have made revisions and adjustments, but the judgment overall here is that the system is mostly clear. 'Unprocessed and minimally processed foods', 'processed culinary ingredients', 'processed food products' and 'ultra-processed products' are all defined with specific food processes identified and a full list of examples for each categories. It is completely comprehensive, covering the whole range of food and food products.

NOVA is mostly workable. It has been successfully applied to food expenditure data in Brazil [26, 90•, 91], Chile [95], Canada [92•, 93], and the UK [94], and to market data from 79 high- and middle-income countries [33••]. Complete workability awaits more publications, including the application to

Table 6 Global (NOVA)

Food groups and definition	Examples
1 Unprocessed and minimally processed foods	
Unprocessed foods are of plant origin (leaves, stems, roots, tubers, fruits, nuts, seeds), or animal origin (meat, other flesh, tissue and organs, eggs, milk), shortly after harvesting, gathering, slaughter or husbanding. Minimally processed foods are unprocessed foods altered in ways that do not add or introduce any substance, but that may involve subtracting parts of the food in ways that do not significantly affect its use. Minimal processes include cleaning, scrubbing, washing; winnowing, hulling, peeling, grinding, grating, squeezing, flaking; skinning, boning, carving, portioning, scaling, filleting; drying, skimming, fat reduction; pasteurization, sterilizing; chilling, refrigerating, freezing; sealing, bottling (as such); simple wrapping, vacuum and gas packing. Malting, which adds water, is a minimal process, as is fermenting, which adds living organisms, when it does not generate alcohol.	Fresh, chilled, frozen, vacuum-packed vegetables and fruits; grains (cereals) including all types of rice; fresh, frozen and dried beans and other legumes (pulses), roots and tubers; fungi; dried fruits and freshly prepared or pasteurized non-reconstituted fruit juices; unsalted nuts and seeds; fresh, dried, chilled, frozen meats, poultry, fish, seafood; dried, fresh, pasteurized full-fat, low-fat, skimmed milk, fermented milk such as plain yoghurt; eggs; teas, coffee, herb infusions; tap, filtered, spring, mineral water.
2 Processed culinary ingredients	
Processed culinary ingredients are food products extracted and purified by industry from constituents of foods, or else obtained from nature, such as salt. Specific processes include pressing, milling, pulverizing. Stabilizing or 'purifying' agents and other additives may also be used.	Plant oils; animal fats; sugars and syrups; starches and flours, uncooked 'raw' pastas made from flour and water, salt.
3 Ready-to-consume products	
3.1 Processed food products	3.1 Processed food products
Manufactured by adding substances like oil, sugar or salt to whole foods, to make them durable and more palatable and attractive. Directly derived from foods and recognizable as versions of the original foods. Generally produced to be consumed as part of meals or dishes, or may be used, together with ultra-processed products, to replace food-based freshly prepared dishes and meals. Processes include canning and bottling using oils, sugars or syrups, or salt, and methods of preservation such as salting, salt-pickling, smoking, and curing.	Canned or bottled vegetables and legumes (pulses) preserved in brine; peeled or sliced fruits preserved in syrup; tinned whole or pieces of fish preserved in oil; salted nuts; un-reconstituted processed meat and fish such as ham, bacon, smoked fish; cheese.
3.2 Ultra-processed products	3.2 Ultra-processed products
Formulated mostly or entirely from substances derived from foods. Typically contain little or no whole foods. Durable, convenient, accessible, highly or ultra-palatable, often habit-forming. Typically not recognizable as versions of foods, although may imitate the appearance, shape and sensory qualities of foods. Many ingredients not available in retail outlets. Some ingredients directly derived from foods, such as oils, fats, flours, starches, and sugar. Others obtained by further processing of food constituents. Numerically the majority of ingredients are preservatives; stabilizers, emulsifiers, solvents, binders, bulkers; sweeteners, sensory enhancers, colors and flavors; processing aids and other additives. Bulk may come from added air or water. Micronutrients may 'fortify' the products. Most are designed to be consumed by themselves or in combination as snacks. They displace food-based freshly prepared dishes, meals. Processes include hydrogenation, hydrolysis; extruding, molding, reshaping; pre-processing by frying, baking.	Chips (crisps), many types of sweet, fatty or salty snack products; ice-cream, chocolates, candies (confectionery); French fries (chips), burgers and hot dogs; poultry and fish 'nuggets' or 'sticks' ('fingers'); breads, buns, cookies (biscuits);breakfast cereals; pastries, cakes, cake mixes; 'energy' bars; preserves (jams), margarines; desserts; canned, bottled, dehydrated, packaged soups, noodles; sauces; meat, yeast extracts; soft, carbonated, cola, 'energy' drinks; sugared, sweetened milk drinks, condensed milk, sweetened including 'fruit' yoghurts; fruit and fruit 'nectar' drinks; instant coffee, cocoa drinks; no-alcohol wine, beer; pre-prepared meat, fish, vegetable, cheese, pizza, pasta dishes; infant formulas, follow-on milks, other baby products; 'health', 'slimming' products such as powdered or 'fortified' meal and dish substitutes.

(Adapted from: Monteiro CA, Cannon G, Levy RB, Claro RM, Moubarac J-C.The Food System. Processing. The big issue for disease, good health, well-being. World Nutrition. 2012; 3(12):527-569) [27••]

dietary surveys using 24 hour recall data which have been completed in studies in US and Brazil but not yet published.

Overall, the NOVA classification system is judged to be completely specific (3), completely coherent (3), mostly clear (2), completely comprehensive (3), and mostly workable (2). It scores 13 out of 15.

Relevance in Use

The NOVA system has been used more often than the other classifications studied here, in papers prepared by its authors and also by other researchers. Studies in Canada and the UK using NOVA have shown that ready-to-consume products and

in particular ultra-processed products have come to dominate dietary patterns in these high-income countries [92•, 94]. Another study shows that the most apparent important factor that has driven changes in Canadian dietary patterns between 1938 and 2011 has been replacement of foods and ingredients used in the preparation of dishes and meals, by ready-to-consume products, mostly ultra-processed [93]. This shift is also evident in the middle-income country of Brazil, where consumption of ultra-processed products as a percentage of dietary energy rose substantially from 2002/03 to 2008/09, and consumption of unprocessed and minimally processed foods and culinary ingredients correspondingly dropped [90•, 91]. One paper indicates that consumption of ready-to-consume products rises as a function of their cheapness relative to unprocessed and minimally processed foods and culinary ingredients [94].

The NOVA classification has also been used to assess the impact of industrial food processing on the overall quality of diets. Taken together, ready-to-consume products are more energy-dense and contain more saturated fats, free sugars and salt, and less dietary fiber, than the combination of unprocessed and minimally processed foods with culinary ingredients made into dishes and meals [90•, 92•]. Higher consumption of ready-to-consume products is associated in Brazil with prevalence of the metabolic syndrome in adolescents [96].

NOVA has also been used to study sites where food is purchased [97], and availability of ultra-processed products in urban settings [98]. A paper published on behalf of the INFORMAS (International Network for Food and Obesity Research, Monitoring and Action Support) project has proposed that the relative dietary share of ultra-processed products can be used to indicate energy-dense, nutrient-poor diets throughout the world, using as data sources household food expenditure and food consumption surveys [99].

Discussion

Industrial food processing has received little systematic attention in public health, nutrition and epidemiology research. This review analyses and assesses the quality and relevance in use of five food classification systems devised to categorize foods in terms of food processing. The quality of the five systems has been evaluated using the following criteria: specific; coherent; clear; comprehensive; workable. These evaluations have been scored. The results are shown in Table 7.

Limitations

This review has limitations as follows. First, its search was limited to papers written in English, French, Spanish and Portuguese, and it does not include studies from countries in Asia, Africa, the Arab world, Russia, or some other countries in Europe. Second, the criteria used to evaluate quality and relevance were partially based on established methods for assessing internal and external validity, but have not been previously applied to dietary classification systems.

Table 7 Evaluation of the quality of five food classification systems that incorporate food processing

	Europe IARC-EPIC	US IFIC-JTF	Mexico NIPH	Guatemala IFPRI	Global NOVA
Specific	1	1	1	1	3
Coherent	1	1	3	2	3
Clear	2	1	2	1	2
Comprehensive	3	1	2	2	3
Workable	2	1	2	1	2
Total	9	5	10	7	13

The scale used to rate the extent to which each criterion was met is as follows: (3) completely, (2) mostly, (1) partially, (0) hardly or not at all

Quality

The NOVA system rates highest in terms of quality. It is the only system derived from a formal definition of food processing which clearly differentiates methods of industrial and artisanal/domestic types of processing. It is completely specific, coherent and comprehensive. It is mostly clear because the classification used in early publications had some aspects which now have been updated, adjusted and clarified. It is rated as mostly workable, pending publication of further studies in preparation.

The Mexican system also rates high. It is completely comprehensive, and mostly coherent and clear. It is partially specific, one reason being that the distinction between industrialized and local foods is in terms of the form and scale with which they are marketed rather than their properties and nature. It is rated as mostly workable.

The European system is completely comprehensive and mostly clear. However, it is only partially specific and coherent: it does not fully distinguish between cooking and industrial processing, and lacks a set of classification criteria. It is rated as mostly workable.

The US and Guatemalan classifications rate lower, the main single reason being that they are incomplete and unclear in various ways. Furthermore, these systems would need development to be applied in different contexts or to surveys using different methods of dietary recall.

Relevance in Use

Relevance in use was not scored, because all the classifications are more or less recent, and all but one has been used only in one or two studies [79, 80, 82•, 84, 85, 86•]. The

exception is NOVA, which has been used in a large number of policy-orientated papers and empirical studies [17, 24–26, 27••, 28, 33••, 90•, 91, 92•, 93–99].

Nevertheless, all the classifications but one suggest or propose that industrial food processing is a determinant of nutrient intake, overall diet quality, and also risk of overweight and obesity and related chronic non-communicable diseases. The exception is US IFIC-Joint Task Force, which does not include unprocessed food, and concludes that at least in the US, 'processing level is not a major determinant of foods' nutrient contributions to the diet' [82•].

Completely successful use of food classifications like NOVA which focus on food processing, will require improvements in the information sought for and recorded in dietary surveys. For example, food product brand names and location of food purchase is needed. Also, foods using different types of processing, such as wheat flour and wheat products, or salted and unsalted nuts, or fresh and cured fish, need to be listed separately.

Other Considerations

The classification systems reviewed have other characteristics that might have been assessed and scored. These include:

Scope The European and US systems have been developed in high-income settings and would need a lot more development to be relevant in middle- and low-income countries and settings. Conversely, the Mexican and Guatemalan systems have been developed for lower-income settings and also would need much more development to have application in high-income countries and settings. The NOVA conceptual framework and classification system is global in scope, requiring only new listings of specific foods to apply anywhere, and has already been used for high-income countries (the UK and Canada).

Aim The European and US systems are essentially descriptive. The Mexican and Guatemalan systems indicate that highly processed food products have health disadvantages. NOVA is based on a thesis, that the quality of food systems, and their impact on dietary quality and on health, well-being, obesity and related diseases, is largely determined by the nature, extent, and purpose of industrial food processing.

Range Most systems focus on processing mainly in terms of intensity. By contrast, the NOVA classification takes use and nature into account. Thus, it identifies processed culinary ingredients as being combined with foods to prepare and cook fresh dishes and meals, the quality of which should be judged together and not separately. It also identifies ultra-processed products (a term not used by the other classifications) as formulations of industrial ingredients containing little or no whole food, and proposes that these products, consumed in substantial quantity, are harmful to health.

Validity The US IFIC-Joint Task Force classification omits unprocessed foods. Its conclusions depend on identifying dietary cholesterol as a key dietary indicator and omitting to identify energy density or trans-fatty acids as dietary indicators. It also omits to discuss that processed food products are the main sources of saturated fat and sodium in the US diet. These features do not invalidate the classification but could be seen as invalidating its conclusions.

Conclusion

The importance and significance of industrial food processing, with its beneficial and adverse effects on food systems and supplies, dietary patterns, and personal and population health, well-being and disease, remains overlooked and underestimated, other than in the food science and technology literature. In particular, industrial food processing has received almost no systematic attention in the epidemiological, nutritional and public health literature, other than as summarized in this paper. In the opinion of the authors of this paper, the time for change is overdue.

A new conceptual framework in which food processing, properly articulated and defined, is central, is needed, in order to understand modern industrial food systems and supplies. Food processing should be a central feature of food classification systems, which then will be more useful in assessing and monitoring dietary patterns. Food classification systems that emphasize food processing, and that define and distinguish relevant different types of processing, will improve understanding of how to prevent and control overweight and obesity and diet-related conditions, including malnutrition as well as chronic non-communicable diseases. Used as a basis for dietary guidelines they will also help to identify and promote essential and benign types of food processing and conversely to limit or eliminate unnecessary and malign types. In this and other ways they will be a firmer basis for rational policies and effective actions designed to protect and improve public health at all levels from global to local.

As disclosed, co-authors of this review are also members of the research team responsible for the NOVA food classification system. We have devised the method by which the five classification systems have been analyzed and assessed, and defined terms used, as objectively and carefully as we can. We recognized that other investigators might have other priorities and prefer other criteria, and will welcome further papers and discussion. This said, we believe that NOVA is a sound system and that it is now ready for general use. It can now be used to

inform epidemiological and experimental studies, as the basis for dietary guidelines that recognize the impact of modern food systems. From such guidelines, rational policies and effective actions to prevent and control obesity and chronic non-communicable diseases, and to protect and improve public health and well-being can be constructed.

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Compliance with Ethics Guidelines

Conflict of Interest At the time of writing CAM, GC, and J-CM are members of the UN Food and Agriculture Organization expert consultation on incorporating food processing in food consumption surveys. This has included a meeting held on the occasion of the International Congress of Nutrition in Granada, Spain, to progress an FAO technical report in draft as this paper went to press. CAM, GC and J-CM, together with many other colleagues, are responsible for the development and application of the NOVA food classification system, and are authors or co-authors of many papers using early and current versions of the system published between 2009 to date, and in preparation, some referenced in this paper. CAM is a member of the World Health Organization Nutrition Guideline Expert Advisory Group (NUGAG). GC was director of the project leading to the 1997 World Cancer Research Fund – American Institute for Cancer Research report [38] and was chief editor of the 2007 WCRF-AICR report [39]. None of the authors has conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- • Of importance
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