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The ultra-processed foods hypothesis: a product processed well beyond the basic ingredients in the package

Francesco Visioli[1,2]*, Franca Marangoni[3], Vincenzo Fogliano[4], Daniele Del Rio[5], J. Alfredo Martinez[2], Gunter Kuhnle[6], Judith Buttriss[7], Hugo Da Costa Ribeiro[8], Dennis Bier[9] and Andrea Poli[3]

[1]*Department of Molecular Medicine, University of Padova, Padova, Italy*
[2]*IMDEA-Food, CEI UAM+CSIC, Madrid, Spain*
[3]*Nutrition Foundation of Italy, Milan, Italy*
[4]*Food Quality and Design Group, Wageningen University and Research, Wageningen, The Netherlands*
[5]*Department of Food and Drugs, Human Nutrition Unit, University of Parma, Parma, Italy*
[6]*Department of Food and Nutritional Sciences, University of Reading, UK*
[7]*Academy of Nutrition Sciences, London, UK*
[8]*Department of Pediatrics, Federal University of Bahia School of Medicine, Salvador, Bahia, Brazil*
[9]*Department of Pediatrics, Children's Nutrition Research Center, Baylor College of Medicine, Houston, USA*

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Abstract

The NOVA classification of food items has become increasingly popular and is being used in several observational studies as well as in nutritional guidelines and recommendations. We propose that there is a need for this classification and its use in the formulation of public health policies to be critically discussed and re-appraised. The terms 'processing' and 'ultra-processing', which are crucial to the NOVA classification, are ill-defined, as no scientific, measurable or precise reference parameters exist for them. Likewise, the theoretical grounds of the NOVA classification are unclear and inaccurate. Overall, the NOVA classification conflicts with the classic, evidence-based evaluation of foods based on composition and portion size because NOVA postulates that the food itself (or how much of it is eaten) is unimportant, but rather that dietary effects are due to how the food is produced. We contend that the NOVA system suffers from a lack of biological plausibility so the assertion that ultra-processed foods are intrinsically unhealthful is largely unproven, and needs further examination and elaboration.

Keywords: Ultra-processed foods: Food processing: Diet: Prevention: Public health

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Introduction

Diet contributes to human health, so the scientific community is constantly engaged in defining healthy eating habits that can aid in improving wellbeing and to prevent non-communicable diseases (NCDs) widely spread throughout our society. The public health focus of dietary guidance historically has been on ensuring adequate nutrition by recommending nutrient-dense food groups and on maintaining a healthy body weight, preventing obesity and reducing the risk of degenerative disorders(1).

The ever-evolving dietary approach to reducing the prevalence of metabolically related and degenerative diseases has long been focused on identifying macro- and micro-nutrients, foods and, most recently, dietary patterns with relevant and well-defined health effects, whose adoption should then be promoted to the population. Special attention must also be paid to energy intake, to minimise imbalance between calorie intake and expenditure, because excess energy intake is likely to be the primary cause of weight gain and obesity irrespective of other dietary considerations(1).

However, recently, excessive consumption of highly processed or ultra-processed food (UPF) has been gaining significant attention as an alternative explanation for the rates of high BMI/obesity and poor health(2). There are several proposals that promote classification schemes for UPF(3), but the NOVA system is probably the most commonly cited and allocates foods into one of four categories, in terms of degree of processing: (a) unprocessed or minimally processed foods, (b) processed culinary ingredients, (c) processed foods and (d) ultra-processed foods. The UPF category is quite large, encompassing the vast majority of foods and beverages produced by the food industry, and specifically singles out 'products obtained from formulations of several ingredients like salt, sugar, oils, and fats, and substances like flavors, colours, sweeteners, emulsifiers', which are often highly calorie dense(2,4).

* **Corresponding author:** Francesco Visioli, email francesco.visioli@unipd.it

The preferential use of foods from the first categories and the reduction (or even banning) of foods from the fourth one is presented as an effective tool in preventing weight gain or obesity, and preserving health[2]. However, we believe that this classification and its associated use in the formulation of public health policies need to be more critically analysed.

UPF classification: food processing pitfalls and inconsistencies

First and foremost, the concepts of 'processing' and 'ultra-processing', which are crucial to the NOVA classification, are – in our opinion – not objectively defined. No independent, objectively measurable or precise reference parameters exist that account for the wide range of methods by which foods are processed. Ill-defined terms such as 'often', 'in many cases' and 'normally' are constantly used in the NOVA classification; definitions such as 'highly profitable' or 'intensely appealing' have also been linked to UPF, making it very difficult to objectively and unequivocally classify foods[5]. Furthermore, the classification has often been changed for unclear reasons. The modifications to NOVA criteria have been thoroughly reviewed[6].

According to NOVA, it makes a major difference whether a food is industrially prepared or prepared at home. Furthermore, despite the subjective and opaque nature of these terms, the presence in foods of ingredients 'not traditionally used in culinary preparations' or with 'no domestic equivalents' forces their immediate allocation to the UPF group[4].

Notable too, NOVA introduces into its classification the concept of 'purpose'. For example, authors contributing to the NOVA classification state that 'The overall purpose of ultra-processing is to create branded, convenient (durable, ready to consume), attractive (hyper-palatable) and highly profitable (low-cost ingredients) food products designed to displace all other food groups.'[5]. In other words, inherent in its rationale, NOVA classifies foods according to the assumed 'purpose' for which they have been designed and produced. This approach introduces a subjective (perhaps ideological) bias in the food classification process that should be, on the contrary, as independently objective as possible.

In fact, the theoretical, biologically based grounds for the NOVA classification are also uncertain. The basic idea appears to be that nature is intrinsically friendly to humans and that, therefore, natural foods are intrinsically 'good', while any human intervention (with the exception of preparing foods at home) will alter this optimal situation. Since humans themselves are an integral part of nature on Earth, the logic is surely at least debatable.

Little scientific evidence currently supports this notion. Human food processing interventions throughout the course of human history, as the NOVA authors themselves admit, do not necessarily translate into worse nutritional characteristics, and industrial-scale food treatments, faulted by NOVA, are not inherently worse than their domestic counterparts, which NOVA strongly favours. Parameters such as cooking temperatures, critical for mechanisms such as acrylamide synthesis, are often less controllable at home. Moreover, minimally processed foods are supposed to be inherently safe, but might contain pathogen-associated molecular patterns that increase cardiometabolic risk[7].

Indeed, it is difficult to understand the rationale for why a large portion of a homemade, butter-rich sugar-rich cake should have a more favourable classification (and purported health effects) than a similar, size-controlled (and hence with controlled energy content) industrially prepared product.

One of the pillars of the NOVA classification is indeed combining, under the umbrella of 'ultra-processing', several industrial processing steps (extrusion, refining, frying or sterilisation) together with formulation strategies (number and type of ingredients, use of colourants, thickeners and flavor). Such combinations, far from being defensible on a scientific basis or comprehensive[8], are likely to be indirectly misleading, making it impossible to understand precisely which, if any, factors might potentially be responsible for the negative health consequences being attributed to ultra-processed foods as a composite category.

Combining formulation/composition and processing, moreover, is an approach that is demonstrably inaccurate in many ways[9]. Indeed, formulation may surely impact the health profile of a food product, since the choice of ingredients and the composition of macro- and micro-nutrients is directly connected with any formulation decision. As a matter of fact, several nutritional scoring systems assessing the health impact of food products based on food formulations have been developed[3,10,11]. Although the principles behind these scores can be fiercely debated, they are recognised by the scientific community as meaningful tools to correlate the intake of certain food products with health outcomes[12]. On the other hand, the overall idea of correlating food processing *per se* with negative health outcomes lacks a fundamental, biologically founded rationale.

Other examples of mismatches between UPF classifications and most published nutrition science are saturated fat and sodium. Their content does not, in fact, automatically increase along with the degree of food processing[6]. Homemade (or unprocessed) foods are not inherently less salty and less rich in fat than those undergoing so-called ultra-processing. Consequently, the preferential use of the former will not necessarily be associated with an improvement in two of the major criteria – salt and saturated fat reduction – usually considered to characterise a balanced, heart-friendly diet[13]. Reformulation of foods also plays an important role in public health campaigns such as the reduction of salt intake. As salt not only adds flavour, but is also important for functionality (e.g. in bread and cheese) and shelf life, the reduction of salt content in foods often requires a considerable amount of additional 'processing'[14]. Free sugars, conversely, are actually more abundant in NOVA-defined UPF than in non-UPF, but this is an unsurprising observation, since the addition of sugars to formulations is one of the definitional criteria used for classifying foods as UPF[15].

Food processing from ancient times to today

Food processing is the means through which humankind throughout its history has treated raw materials to obtain better (e.g. more digestible) or safer (e.g. to remove toxins) food products. Through the ages, humans have treated raw commodities they have hunted, gathered, grown or derived through domestication of animals to reduce spoilage and extend shelf life, to improve their palatability and to create safer food products. It is abundantly evident that human survival and evolution were unquestionably aided by the ability to process foods[16].

Thus, food processing does not necessarily translate into poorer nutritional properties. Actually, historically, the opposite is true, as shown by some classical examples. Corn, or maize, was first domesticated by the Indigenous people living in what is now central Mexico around 7000 BCE. Around 1500 BCE, Mesoamericans developed a process called nixtamalisation, which made maize more palatable (in fact, improved palatability is likely to have been the only reason why the procedure was developed). The process involves drying maize kernels and then soaking them in warm water mixed with an alkali, such as ash or slaked lime. Nixtamalisation partially breaks down maize cell walls, making it easier to chew and digest. Because maize is high in non-absorbable niacin (vitamin B3), most people who relied on unprocessed maize as a primary food source suffered from niacin deficiency (pellagra) whose clinical manifestations include the classical triad of dermatitis, diarrhea and delusions. Nixtamalisation makes niacin – and some limited aminoacids – bioavailable; therefore, following the development of nixtamalisation, cases of niacin deficiency dropped, and the region's first major civilisations started to develop.

Another example is canned food, which represented a major advance enabling the French troops to endure longer campaigns[17], and – to this day – canning provides people worldwide with nutritious and bacteriologically safe foods, concomitantly reducing waste[18]. The same line of reasoning applies to food safety, which is greatly enhanced by food processing such as pasteurisation, other forms of heat processing and the like.

Cassava (*Manihot esculenta* Crantz) is an important tropical root crop providing energy to a large proportion of the world's population. However, raw cassava contains at least two cyanogenic glycosides, linamarin and lotaustralin, that limit its use as food or feed. Since early times, processing techniques in cassava production have been developed and greatly reduce cyanide in tubers and leaves. The most widely used methods to reduce cyanide in cassava are drying via exposure to sunlight (which reduces cyanide better than oven drying owing to a prolonged interaction between linamarase and the glucosides) and soaking followed by boiling[19]. Soaking and boiling is also used to inactivate lectins in legumes such as soyabeans and red kidney beans[20,21].

Infant formula is yet another example of how food technology improved the lives of millions of children worldwide. While is it indisputable that breast-feeding should be the preferred way of providing nutrients to a newborn[22], insufficient breast milk intake is frequent[23] and could lead to impaired growth. Moreover, despite recommendations, the majority of mothers in developed countries choose to switch their infants to predominantly formula intake by 6 months of age. Several formulas have been developed over the years and their composition is constantly improving, for example most recently by adding fructooligosaccharides[22], milk fat globule membranes[24] or long-chain omega 3 fatty acids[25]. Actually, such additions transform these formulas into so-called UPF. A similar line of reasoning applies to purposefully formulated foods aimed at lessening the burden of malnutrition (stunting and/or wasting) in developing countries[26].

Food fortification might also be responsible, according to NOVA, for shifting food items from one category to a worse one from a processing perspective. However, food fortification may be necessary in countries where micro-nutrient availability is reduced or impeded by inherent conditions. One pertinent example is that of vitamin D, low status of which is associated with poor usculo-skeletal health, and increased risk of rickets and osteomalacia. Since its discovery a century ago, fortification with vitamin D of foods such as milk in the United States and margarine in the UK has unquestionably contributed to near eradication of rickets[27], and has more recently been introduced in countries such as Finland, where food, especially milk product fortification, has greatly contributed to ameliorating low vitamin D status[28]. Folate-fortified grain products are, purportedly, ultra-processed foods in the NOVA classification, yet avoiding their use in the year prior to conception has been associated with a 30% increased risk of spina bifida[29] and wheat flour is now fortified with folic acid, by law, in numerous countries worldwide. Notably, vitamin D intake from unfortified foods or as derived from sunlight exposure and the folate contents of/intakes from vegetables are almost always inadequate[30] to produce similar health effects to fortified foods[31–33], meaning that national public health policies often focus on fortification and/or supplementation of diets[27,34]. Also worthy of mention are special foods for people who are lactose intolerant or living with coeliac disease or children with inborn genetic diseases, which are often lifesaving but require application of specialised food processing techniques[35].

Dietary fibre provides another example, where benefits for gut health, heart health[36] and protection against some forms of cancer are notable yet intakes often fall below dietary recommendations[37]. In westernised countries, cereal-derived fibre makes a major contribution to overall fibre intake and palatable fibre-rich products, such as whole-meal bread, pasta and cereals are often made by recombining wheat fractions, such as bran and white flour. Unfortunately, many high-fibre foods such as breakfast cereals and most whole-meal bread are adversely classified by NOVA and reducing their use simply because they are captured by the definition of being UPF would be expected to exacerbate already low fibre intakes[38].

Finally, reformulation of food products to reduce salt content, such as the UK salt reduction initiative as mentioned above[14], as well as saturated[36] and trans[39] fats and – recently – to lower sugar[40] is supported by all nutrition societies and public health bodies because it could greatly reduce the incidence of major NCDs worldwide[41]. Reformulation sometimes requires additional processing steps or the use of additives, but it is difficult to identify a scientifically based explanation of why consumption of UPF-categorised food products such as mixed vegetables with some sauce or seasoning, and gluten-free pasta, should be avoided.

Food processing: friend or foe?

Looking more closely, the main problem with the NOVA classification is that it is not really compatible with the classical

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evidence-based evaluation of food, based on composition and mode of consumption. According to NOVA, it is not important what (or how much) is eaten, but how it has been produced (processed) and by whom (home or industry)[5]. Thus, differing health effects of different amounts of different fats and carbohydrates are often overlooked, as are portion sizes. A large steak is allocated to group 1 (the optimal one), while many wholegrain products, a protein bar made with extruded legume flours or fruit-enriched yogurts are, instead, penalised. The consequent mismatch between NOVA and the classical nutrient-based classifications is striking at times, extending to 50% of considered food items in Australia[42].

In any case, it is useful to reflect on which one of the many technological steps involved in food processing might actually be responsible for the, allegedly, negative consequences. More specifically, it is necessary to investigate if the various processing steps are correlated with food characteristics such as accelerated eating rate, high energy density or high glycaemic index, which can easily be correlated with negative health outcomes[41]. For this purpose, in this context we scrutinised several industrial processing methods, considered their consequences on the nutritional value of the products, and assessed if they can cause alteration to the food matrix structure, disrupting the original tissue organisation and/or leading to the loss of food identity. The results of this exercise are summarised in Table 1.

It is worth remembering that part of food processing operations derives from the need to eliminate harmful living microorganisms, to avoid food spoilage over time[43]. This is a major positive effect of food processing, helping ensure food safety and security worldwide[16]. Operations like freezing and drying have been known for millennia, and are currently carried out industrially with technologies that are now far more efficient than their purely natural counterparts, namely snow and sun. Moreover, freezing or oven drying have minimal effect on nutrient composition, and also minimal influence on the food matrix structure[44]. Freeze drying or spray drying can efficiently eliminate water from food, reducing the likelihood of food spoilage over time. However, these processes often produce food items in a powdered form[45], which might not then be perceived as 'real food' by many consumers[46].

Food fermentation is also one of the most ancient processing operations; according to NOVA, fermented products are not ultra-processed. However, as with other processing techniques, fermentation improves stability and digestibility of many animal- and vegetable-based products, causing profound changes in food structure, and basically creating new foods, such as bread from flour, cheese and yogurt from milk, beer from grain, wine from grapes, etc., whose familiarity depends on the consumer's culture. For instance, miso is clearly identified as a fermented soybean-based product in Japan, but it might be classified as an unknown (ultra)-processed product in Europe.

Many of the industrial processes involve thermal treatments or drying, with transfer of heat directly to the food by means of different time/temperature intensity (pasteurisation > UHT > retorting). In some cases, heat transfer is achieved by contact with hot oil, as in deep/air-frying, with temperatures being potentially very high and with incorporation of the used oil into the products, once again changing the nutritional composition[47]. Often, thermal treatment does not significantly modify the micro- and macronutrient content of foods[48], but in some cases, the formation of undesired compounds or the loss of fresh flavor occur. To reduce the negative consequence brought about by conventional thermal processing, new technologies, enabling control of microbial contamination without using heat, have been developed. High pressure, cold plasma and pulsed electric fields have the capacity to reduce bacterial content using pressure and electrical flow, respectively[49]. These techniques leave the food structure largely unaltered and can be seen as good examples of how processing technologies are evolving to fulfil the consumer's desire to have food products that are recognisable and with an intact structure[46].

Extrusion has often been considered to be a processing operation leading to the destruction of food structure and identity, supporting the assumption that extruded products are ultra-processed foods with a poor nutritional quality[5]. However, this is not always the case, if we take a closer look to at the available extrusion techniques. From the technological perspective, there are two different types of extrusion process depending on the amount of water in the final products. Low-moisture extrusion is often used in the production of breakfast cereals, puffed snacks and similar starchy products[50]. The quality of extruded food products mainly depends on the formulation strategy. Looking at nutritional consequences, the impact of extrusion is not much different from baking, and what you put in the dough is what you find in the final product. Low-moisture extrusion can also be used to design food products with a very healthy nutritional profile. There are plenty of products, such as protein bars, legume-based crisps or gluten-free biscuits, that are characterised by a lower energy density compared with conventionally baked products[51]. High-moisture extrusion is, on the other hand, a less familiar process that is now increasingly being applied in plant-based meat alternatives or gluten-free products. The process allows production of fibrous structures starting from ingredients which would not have the ability to create a strong texture if using conventional devices and methodologies[52]. High-moisture extrusion can therefore contribute to the production of new 'analogue' food products, such as surimi[53,54]. Although these might be perceived by some as 'artificial', such foods can, if nutrient dense, contribute to a balanced and healthy diet, providing options for those who wish to reduce consumption of meat and fish.

Another common processing step in the food industry is homogenisation. This process sometimes destroys the food identity (milk is an exception), while providing a creamy texture and drastically increasing eating rate especially with meat products, but also with vegetables and fruits (e.g. purees and smoothies compared with the produce from which they originate). Homogenisation is one of the main factors responsible for food 'hyper-palatability', one of the features leading to food overconsumption[55]. However, it is worth noting that homogenisation is not always an industrial processing step: it is often performed at a domestic level using a simple immersion (stick) blender or various other common home-kitchen aids.

Food fractionation and refining of ingredients, examples being soy protein isolates, refined oils or purified starches, are often the base ingredients of modern industrial food systems,

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Table 1. Influence of food processing techniques on nutritional characteristics of foods and effect of the different processes on the physical characteristics of the food structure

Processing type	Purpose	**Nutritional effects***	**Structural effects***
Deep freezing	Preservation	No effect on macronutrients. No or very limited effect on vitamins or phytochemicals	Using accurate freeze–thawing procedure, the cell structure remains unaltered, but slow freezing or fast thawing can damage the original structure of the plant or animal tissues
Oven drying	Preservation	Depending on the temperature of drying, limited or severe degradation of thermally labile compounds has been reported	A well-conducted drying does not alter tissue structure and preserves the identity of plant and animal products. Inappropriate drying results in burning and fragmentation of the products
Freeze drying	Preservation	It is considered the most gentle way to eliminate water from a food product. No nutrient loss was reported	In most cases, the final product of the freeze drying process is a powder; therefore, the identification of original food is not possible
Spray drying	Preservation	It can be used only for some foods and ingredients. Despite the high processing temperature in most cases, only a limited reduction in thermally labile compounds has been found	Spray-drying processing implies the passage of a solution (or a suspension through a small nozzle); therefore, the tissue is usually damaged. The final product is a powder; therefore, the identification of original food is not possible
Acid, sugar and salt addition	Preservation	All these ancient preservation methods cause limited changes in the nutrient composition of the original food. The addition of salt and sugar is not a positive nutritional feature	In all cases, these methods preserve the identity of the food products, which remain recognisable. The cell structure is often damaged by the osmotic shock
Fermentation	Preservation and new products	Fermentation usually improves the nutritional features of the original material. It improves protein and lipid digestibility, generates bioactive metabolites and reduces sugar content	In most cases, fermentation generates new products and the identification of the original material is based only on aquired knowledge and experience. There is often a massive change in food structure, usually towards the formation of softer and smoother products
Thermal treatments	Preservation and cooking	The thermal load (i.e. the time–temperature ccombination) and the amount of water are the key factors determining the degradation of micro-nutrients, the protein denaturation and the starch gelatinisation Usually, food thermal treatments improve digestibility and bioaccessibility	Depending on the conditions, severe damage to the original tissue can occur, related to the quick loss of water. In most cases, food texture changes becoming softer in high-moisture foods and crunchy in low-moisture products
Deep, vacuum and air frying	Cooking	Conventional deep frying in oil is a severe thermal treatment causing a strong reduction in thermally labile micro-nutrients and an increase in fat content. Milder alternatives, such as vacuum frying (lower temperature) or air frying (much less oil) have been proposed	Frying usually preserves the food's identity, but it causes tissue breakdown. It can create crispier and harder texture
High-pressure treatments	Preservation	This non-thermal technique is meant to avoid micro-nutrient degradation, and it can induce a significant change in protein structure. Contrasting effects on protein digestibility were observed depending on the food products	In most cases, the food structure is preserved during the treatment. High pressure is used mainly with juices and purees, so this feature is not actually visible
Pulsed electric field	Preservation	This non-thermal technique is meant to avoid micro-nutrient degradation, although depending on the machine setting, some heating can occur and thermally labile compounds might be degraded	Pulsed electric field causes minor visible changes to the food structure, but preserves its identity. At the cellular level, the cell membrane becomes more permeable, potentially favouring micro-nutrient bioaccessibility
Low-moisture extrusion	Structuring	This is a severe thermal treatment (so micro-nutrient degradation, protein denaturation and lipid oxidation occur), combined with a shearing force, which alters the fibrous structure	Completely changes the food identity, but it can be used to design crunchy and new puffed cereal-based or vegetable-based products
High-moisture extrusion	Structuring	The thermal load is lower owing to the presence of water. Degradation of micro-nutrients depends on time/temperature of the process. Large protein denaturation and alteration of fibrous structure result	Completely changes food identity, creating a fibrous-like structure using plant proteins and hydrocolloids
Homogenisation	Structuring	No degradation of micro-nutrients occurs. Facilitates the digestion of protein and fats, breaking down food structure and increasing their exposure to digestive enzymes	It breaks down the food to a liquid puree or juice. It changes its identity, with the notable exception of foods that are already liquid before homogenisation, such as milk
Fractionation and refining	Ingredient functionality	This process is meant to separate the original food material into different components. During the process, many valuable nutritional compounds are degraded	By definition, frationaction and refining lead to loss of food identity and of the original functional properties
Hydrogenation	Change in fat texture and functionality	It is perfomed on vegetable oils, increasing the proportion of saturated fatty acids; if not complete or performed inaccurately, it may also generate 'trans' unsaturated fatty acids. Note that use of the technique has diminished considerably over the years	It changes the nature of liquid fats, changing their functionality and enabling production of 'solid' margarine or spreads

Table 1. *(Continued)*

Processing type	Purpose	Nutritional effects*	Structural effects*
Acid hydrolysis	Breakdown of proteins/ fibres	It is done to degrade proteins, usually on food byproducts, deriving amino acids and peptides. Improves digestibility, but it can produce toxic compounds such as 2- and 3-MPCD	The consequence of acid-driven protein hydrolysis is a complete loss of food structure and identity
Enzymatic hydrolysis	Breakdown of proteins/ fibres/lactose	Many different nutritional purposes: faster absorption of nutrients, generation of pre-biotic oligosaccharides, allergen degradation, lactose hydrolysis	In most cases with mild enzymatic treatment, the food identity is preserved (dairy, meat, bakery applications) while sensory/mechanical properties (texture) are modified
Packaging	Preservation information	Well-designed packaging can prevent spoilage and a decrease in some nutrients during the shelf life	Packaging cannot change the food structure or identity, although it strongly influences consumer perception

* *The table provides summary information: more details and literature references are given in the text.*

enabling standardisation of production processes; however, such processes alter many characteristics originally present in the starting material[56]. This is an important and now very well-recognised pitfall in current food production. Many research projects on cereal, legume, nut and plant food production chains are now in progress, aiming to achieve the reduction or elimination of these refining steps, to obtain ingredients maintaining the original food identity along with the desired functionalities. Despite these efforts, the extensive use of refined ingredients in the formulation of many manufactured food products remains a contentious issue[57]. Additionally, refining steps also require energy and resources, affecting sustainability from an environmental perspective[58]. Conversely wholegrain products are subject to rancidity, shorter shelf lives and longer fermentation times, thereby increasing waste. Additives in grains increase shelf life, in turn benefiting the planet[59,60].

Enzymatic and chemical treatments are also processing steps, often performed, together with refining, by food manufacturers. In many cases, these treatments are needed for specific categories of consumers (e.g. proteases to obtain hypo-allergenic formulations) or to improve technological quality and palatability (e.g. xylanase in brown bread or proteases for meat tenderness) or to obtain ingredients for production of specific foods (e.g. to bring foods based on plant-derived proteins to the market)[61,62]. Hydrogenation and hydrolysis of proteins and fibres are used to change the texture and to produce protein hydrolysates (amino acids and peptides) to be used as food ingredients[63]. Although some of these treatments could surely be abandoned, it would be speculative to judge all these treatments as being the same, as many of them are actually able to fulfil important consumer needs, such as the use of lactase in the manufacture of lactose-free dairy products[64].

Finally, packaging is also mentioned in the NOVA classification, as a criterium criterion for identifying UPF. This decision is difficult to understand because packaging does not change food composition or structure; actually, it often improves shelf life and ensures better hygienic conditions. Modified atmosphere packaging may help to avoid or minimise food spoilage due to, for example, oxidative phenomena, thus limiting the degradation of the food itself, extending its shelf life, reducing waste and increasing sustainability[65].

The considerable current effort to design and create sustainable recyclable food packaging solutions will strengthen the use of packaging as a continued means to provide consumers useful nutritional information[66].

The role of food additives

Some of the desired effects pursued by food processing may also be obtained with the use of specific additives[4]. The NOVA classification highlights the possible negative health effects of these compounds, but the beneficial effects of authorised additives in maintaining the nutrients and the safety and preservation of foods should not be dismissed[67]. Furthermore, the extension of shelf life and, consequently, the reduction of wastage associated with appropriate use of authorised additives has an

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indisputable effect on environmental preservation/sustainability, and reduces the overall impact of food systems.

The safety of additives, moreover, is thoroughly and continuously evaluated by authoritative institutions, such as the European Food Safety Authority (EFSA), the Food and Drug Administration (FDA) and the Joint FAO/WHO Expert Committee on Food Additives (JECFA), and their use is strictly regulated and monitored[68]. Such use is usually controlled by the precautionary principle, which leads to their elimination from the market when plausible doubts appear regarding any possible negative effect on consumers' health[68]. Consequently, the use of additives should not be *a priori* perceived as negative. Nevertheless, according to a recent paper, their presence seems to be even more important than technological processing in defining a food as an UPF in the NOVA classification system[4].

NOVA classification and poor prognosis in epidemiological studies

Beyond the specific criticism of the NOVA classification system and of its theoretical background, it is important to remember that the use of such a classification in observational (or cohort) epidemiological studies must be interpreted with caution and in the context of the general limitations typical of this type of study design[69]. These include the relative inability of the dietary intake assessment methods used in such studies to determine accurately and precisely the intake of individual foods (and, therefore, nutrients), the relationships among these individual constituents and the health outcomes resulting from their consumption[70,71] No matter how well such epidemiological studies are carried out and how few residual confounders remain in the analyses[72], they can never prove causality[73]; intervention trials are required to provide this type of evidence alongside supporting information from mechanistic studies[69].

Nevertheless, several cohort studies have associated the risk of non-communicable diseases (NCDs), such as atherosclerotic cardiovascular diseases and cancer, with a high intake of UPF, comparing groups with high or low intakes of these food[3]. Below we highlight a few points which may help to interpret properly the results of the available epidemiological observations.

The NOVA classification is neither the first nor the only categorisation scheme of food processing. Other published methods include that of the International Agency for Research on Cancer (IARC)[74,75], that of the International Food Information Council (IFIC)[76,77], and the method formulated by the University of North Carolina (UNC)[78].

Interestingly, the choice of food classification methodology markedly influences the association between UPF consumption and cardiometabolic risk markers. In a recent study by Martinez-Perez *et al.*[3], the highest UPF consumption in Spain was observed using the IARC classification (45·9%) and the lowest with NOVA (7·9%). A direct association between UPF consumption and BMI emerged only when using the NOVA classification to identify food considered to be ultra-processed, while an association with systolic and diastolic blood pressure and blood glucose was observed only using the University of North Carolina (UNC) classification system. Blood cholesterol levels, on the other hand, were negatively associated with UPF intake only when NOVA and UNC criteria were used. These differences suggest that the basic concept of ultra-processing (common to all the classification methods mentioned) is unlikely to be the major explanation of the association recorded between intake in UPF food and NCD risk factors. Secondly, the identification of a specific and plausible biological mechanism linking the consumption of UPF with the health effects observed in cohort studies should be considered an essential requirement[79]. An example of this is provided by the SUN study[3]. The increase in non-cardiovascular and non-cancer mortality observed in the SUN study in association with high intakes of ultra-processed foods (but also with lowest versus highest vegetable intake, indicator of overall diet quality), which strongly contributed to the association between total mortality and UPF consumption in that study, lacks such plausibility and should be interpreted cautiously.

Third, the possibility that unidentified residual confounders, such as the characteristics of the consumers of the so-called UPF (usually much younger, and often of lower socio-economic status than non-consumers), may play a role in the described association between UPF and health outcomes should also be convincingly ruled out. The fact that practically any NCD has been found to be increased among high-UPF consumers (an association not easy to explain in terms of plausible biological mechanisms) could be an important alarm bell in this regard.

Another pertinent example is that of so-called discretionary foods and beverages, that is, foods and drinks that are not necessary to provide the nutrients the body needs but that may still be consumed (occasionally and in limited amounts) to add variety to the diet. Of note, many of these are high in saturated fatty acids, sugars and/or alcohol, and are therefore described as energy dense[80]. Their routine consumption is discouraged by most guidelines and can provide an important residual confounder when UPFs are investigated in observational (or cohort) studies[81]. Discretionary foods, such as cakes, pastries, sweets and sugar-sweetened drinks, are typically relatively low in essential nutrients and relatively high in energy density, but we contend that their health effects, if consumed in excess, in relation to NCD and obesity risk are most likely due to their actual composition rather than to the way they are produced and processed.

The characteristics of the association observed between the incidence of diseases purportedly correlated with the consumption of these discretionary foods and their consumption rate in the population should also be analysed and considered in detail.

The risk of such diseases does indeed increase with UPF intake within populations but, importantly, not across populations. In countries such as the United Kingdom or Ireland, where their level of consumption exceeds 50% of total food, the incidence of UPF-associated NCDs should be much higher than in countries like Italy, where instead it only slightly exceeds 10%[82], but this is not the case.

On the basis of available published data, 'ultra-processed foods' accounted for 57·9% of energy intake, and contributed 89·7% of the energy intake from added sugars in the United States[83]. Since no study demonstrated that added sugar derived

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from the so-called UPF is more 'harmful' than added sugar derived from unprocessed or minimally processed foods, it seems reasonable to conclude that the excessive energy intake reported has to be limited regardless of the source of the food, industrialised or not. Shifting attention to blame industrially produced food as the real villain for high caloric intake confuses consumers and detracts from the real problem of large portion size and the energy density of dietary choices, regardless of their mode of production.

In other words, experimental mechanistic research is needed to help define the individual role of each of the steps of each complex industrial process, to evaluate its real impact on consumer health parameters or, if necessary, in suitable models.

UPF, food technology and life expectancy

More generally speaking, given the reported association between UPF and disease incidence, it is also difficult to explain why the progressive increase in consumption levels of these foods in recent decades, with the sole exclusion of the COVID period, has been accompanied by a continuous and constant increase in life expectancy at birth, both in industrialised countries and in the rest of the world. All statistics indicate that part of this increase in life expectancy is due to the ever-increasing availability of nutritious and safe foods[84–86], in addition to many other improvements in, for example, hygiene and health care. There is, of course, much room for improvement, but perhaps this simple observation suggests that the overall health contribution of industrial food production (even if it is obvious that such an effect would be difficult to disentangle from that of the other changes observed in our societies in the last century) is unlikely to have been negative.

Palatability – taste and overall 'pleasantness' – is also recognised as a major determinant of consumer choice and so, inevitably, is a key aspect of product development and reformulation[87]. Therefore, food technology applied to palatability would increase the consumption of nutritious foods. Wholegrain cereals may be a pertinent example, especially in the light of the GBD data, which indicate the need to increase the intake of these foods[1].

The assumption that the on-average high palatability of industrially produced foods may contribute to the excessive energy intake (or higher energy intake rate)[88] observed in many developed countries and, therefore, to the tendency to overweight is, on the other hand, also scientifically plausible.

However, the proposal to use a regulatory intervention to limit companies' innovation and research in this area (i.e. their tendency to produce and market more and more palatable food), which is often implicit in the debate on industrially produced foods, fails to acknowledge the realities of the determinants of food choice and is likely doomed to fail, at least in a free market economy. The issue of food palatability and its health impact appears to be unresolved to date, and perhaps it has not yet even been addressed in an objective, prejudice-free way.

One last, but not trivial untoward consequence of all UPF classifications is the public understanding of the concept of 'ultra-processing'. This classification is already being decoded as 'factory-produced' and conflated with 'junk food', with obvious negative consequences, such as slowing the transition to a more plant-based diet, which the NOVA authors themselves declare they do not want to happen[5]. Confusion about UPF leads to not recognising that their nutrient contribution can vary considerably, and that some processed foods classified by NOVA as 'ultra-processed' are recommended in dietary guidelines around the world[89]. Finally, consumers do not know how to use the NOVA scheme to construct a healthy diet, and field tests are required (in a fashion similar to that of front-of-pack labels)[90,91].

Conclusions

We are convinced that the purported association between UPF, excess weight, obesity and poor metabolic health needs to be more rigorously approached and investigated.

Food classification approaches may, in principle, have merits, namely those of increasing public awareness about dietary choices, pioneering an understandable (by the lay public) way to discriminate foods and encouraging the food industry towards the production of less energy-dense products [92–94].

Yet, all things considered, the overall biological plausibility of the NOVA system should be considered weak at best [79,95,96]. For example, it is difficult to comprehend how consumption of UPF *per se*, irrespective of portion size and recognising the wide spectrum in the nutritional composition of foods captured in the categorisation, should be *intrinsically* less favourable in public health terms than uncontrolled intake of unprocessed or, in particular, minimally (at home) processed food.

At this stage of understanding, the conclusion that these foods must be avoided is not scientifically supportable and may easily lead to undesired consequences[96]. The use of the NOVA classification in the formulation of public health policies needs, therefore, to be critically reconsidered, and any such classification should evolve from the mere sum of processing steps to the overall nutritional value of food items, in the context of global diet.

Authorship

F.V., F.M. and A.P. planned the paper and wrote the first draft. All other authors equally added sections and revisions, and edited the paper.

None.

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