CHAPTER THREE

Characterization of the Degree of Food Processing in Relation With Its Health Potential and Effects

Anthony Fardet[1]
Université Clermont Auvergne, INRA, UNH, Unité de Nutrition Humaine, CRNH Auvergne, Clermont-Ferrand, France
[1]Corresponding author: e-mail address: anthony.fardet@clermont.inra.fr

Contents

Abstract

Up today technological processes are intended to produce safe and palatable food products. Yet, it is also expected that processing produces healthy and sustainable foods. However, due to the dramatic increase of chronic diseases prevalence worldwide, i.e., obesity, type 2 diabetes, cardiovascular diseases, and some cancers, ultraprocessing has been pointed out as producing unhealthy foods, rich in energy and poor in protective micronutrients and fiber, i.e., "empty" calories. Indeed the 1980s saw massive arrivals of ultraprocessed foods in supermarkets, i.e., fractionated–recombined foods with added ingredients and/or additives. Epidemiological studies clearly emphasized that populations adhering the most to ultraprocessed foods,

Advances in Food and Nutrition Research, Volume 85
ISSN 1043-4526
https://doi.org/10.1016/bs.afnr.2018.02.002

e.g., processed meat, refined grains, ultraprocessed plant-based foods, and/or sweetened beverages, exhibited the higher prevalence of chronic diseases. This prompted researchers to classify foods according to their degree of processing as with the international NOVA classification (i.e., un/minimally processed, processed, and ultraprocessed foods). More and more studies showed that such a classification makes sense for health. Overall one distinguishes three categories of processes: mechanical, thermal, and fermentative treatments, this latter being the more favorable to food health potential. This chapter has therefore several ambitions: (1) to review association between degree of food processing and chronic disease risk prevalence; (2) to explore the impact of technological processes on food health potential considering both matrix and compositional effects; (3) to discuss the need for classifying food according to their degree of processing in future epidemiological studies; and (4) to analyze consequences of adhering to a more holistic paradigm in both food processing and nutrition.

1. INTRODUCTION: THE FOUR NUTRITIONAL TRANSITIONS

We are used to talk about the nutrition transition following the industrialization of our modern societies (Drewnowski & Popkin, 1997). It took place in the 18th century after the discovery of the steam engine that allowed mechanization at large scale of food production. But this is after the Second World War that industrialization became more intensive with the development of big cities and populations worldwide. For example, in France it became indispensable to reach food self-sufficiency, and agriculture began to be intensive to increase culture yields and to supply sufficient calories to the French population, and research—via the creation of INRA (French National Institute for Agricultural Research) in 1946—had the mission to address this increasing demand in calories. It followed, especially in developed countries, the replacement of traditional foods by processed ones, from minimally processed and monotonous plant-based foods to a diversified diet rich in (ultra)processed and meat-based foods containing lots of animal and "empty" calories (Glinsmann, Irausquin, & Park, 1986).

However, there were other food or nutrition transitions which are also very important for human being and that were almost never mentioned in scientific literature. The first one probably occurred between 500,000 and 1,000,000 years ago with the discovery and control of fire. Fire domestication has made it possible to cook food, and store smoked meat, thus reducing parasitosis, but also to increase the digestibility of food, favoring their metabolic efficiency, and increasing the cerebral volume (Wrangham, 2010).

Indeed, due to higher starch and protein digestibility, more energy became available to our brain and body. Thus, those that today advocate the return to the Paleolithic diet as the gold standard diet for humans, emphasizing that the Neolithic period has favored the production of new foods that our organism was not used to digest (i.e., dairy, breeding meat, and cereals) (Cordain, 2002), tend to forget this first transition to which our organism had also to strongly adapt. The second nutrition transition took place during the Neolithic period around 10,000–12,000 years ago with the settlement of human populations together with the development of agriculture. Indeed, at this time humans began to consume three kinds of foods in more significant amounts than previously, i.e., dairy, breeding meat-based, and cereal-based foods; all these foods cannot be massively consumed when the hunter–gatherer should move each day at another place to find foods. Some historians and researchers advance that both settlement and the high availability of food energy and animal proteins through these three food groups, e.g., cereals, are a high concentrate of both energy and nutrients (including fiber and micronutrients), and meat and dairy are a high concentrate of proteins, permitted the increase of worldwide human population and the advent of large cities. After the Neolithic transition came the so-called nutrition transition as evoked earlier. Finally there was a fourth nutrition transition that scientists never mentioned: the passage from processed to ultraprocessed products in the 1980s; in other word the era of fractionated–recombined foods added with numerous ingredients and additives… and that coincide with the explosion of the prevalence of metabolic chronic diseases of industrialization. This last transition has been omitted by scientists probably because foods were only considered as a sum of nutrients, and that ultraprocessing destroys the food matrix, a nutritional property only very recently studied (Fardet, Souchon, & Dupont, 2013).

As we can see, human organism through ages has to constantly adapt to a new food environment, not only one: from crude to cooked foods, from wild to cultivated foods, from traditional to processed foods, and from processed to ultraprocessed foods. And probably we will in the future meet other nutrition transition(s), maybe after succeeding in conquering space and other planets? But what is particularly noticeable in the last nutrition transition is that first processing was at the benefit of foods to render them more healthy, palatable, and edible—as in the case of canning or fermentation at their debut—, whereas with ultraprocessing (i.e., food fractionation, then ingredients/nutrient recombination to produce "artificial" foods added with numerous additives) foods became at the benefit of technology for gaining profit and time. Health food potential has progressively becoming a secondary issue. Let us just have a look at our bread: first we were used to consume wholemeal leavened bread with a high nutrient density and a low glycemic index, and today kneading intensity has been increased, leaven was replace by rapid yeast fermentation, flour was refined and more and more additives, and vital gluten was added to formulation to produce bread resistant to freezing, as in supermarket. The resulting airy white bread has lost all its nutritional properties, being devoid of protective micronutrients and fiber, being no more satiating and a source of rapid carbohydrates because there is no more protection for starch to be slowly digested (Rémésy, Leenhardt, & Fardet, 2015). The same is true for tomatoes, milks, meats, fruits, etc.: they were modified to adapt to technological and profit constraints, leaving tasteless and micronutrient-poor food products.

Therefore, until recent time processing was almost only concerned by food palatability (organoleptic properties) and security (safe products), not really by food health potential, still less by its environmental footprint. So today technologists are confronted with a quadruple food constraint: to produce palatable, secure, but also healthy and sustainable foods, which is a huge and tough challenge for the years to come. For example, concerning cereal-based foods to produce less refined flours and more natural whole grain foods will require the whole change of cereal sector, notably the milling process. Therefore, today whole grain cereal-based foods are first recombined whole grain foods, not natural one … because, instead, this will require to completely change basic paradigm, and this is too difficult and will cost lot of money. Yet a recombined whole grain food has not the same nutritional value that a natural whole grain food (Fardet, 2014c) because food is largely more than the sum of its parts as we will discuss later (Fardet & Rock, 2014b).

Thus, the role of processing on food health potential is a rather recent preoccupation by food scientists and nutritionists. Contrary to what we thought we knew we know only a little about the impact of processing on health properties of foods, and the relation between both has never been objectively characterized. Why? Probably because food scientists, technologists, and nutritionist scientists have been used to work in isolation: nutrition scientists have limited knowledges in food processing and food scientists and technologists a few knowledges in human nutrition; but also because the reductionist paradigm is at the basis of our scientific culture, i.e., the whole is equal to the sum of the parts, which has lead us to fractionate and crack foods in a multitude of isolated ingredients that we after recombined in an infinity of food recombination; but to the detriment of our health (Fardet, 2015c; Fardet & Rock, 2014a, 2014b, 2015).

This chapter has therefore several ambitions: (1) to review in scientific literature the association between degree of food processing and chronic disease risk prevalence; (2) to explore the impact of technological processes on food health potential considering both matrix and compositional effects; (3) to discuss the need for classifying food according to their degree of processing in future epidemiological studies; and (4) to analyze the consequences of adhering to a more holistic paradigm in both processing and food health potential. In these different parts, references to my recent works about the development of a quantitative and holistic food index, and of the relation between degree of processing, satiety, and glycemic potentials, will be made.

2. FOOD PROCESSING AND CHRONIC DISEASE RISKS

2.1 Epidemiological Studies

2.1.1 Binary Comparisons

The degree of food processing has rarely been taken into consideration in epidemiological studies (Fardet et al., 2015). Epidemiologists are used to classify foods into usual groups like fruits, vegetables, cereals, legumes, dairy, nuts, white and red meats, fish, and seafood. The only mention of processing were the comparisons: "red vs processed meats" (thermal and mechanical treatments), "whole vs skimmed milks" (mechanical treatment removing fat fraction), or "refined vs whole grains" (mechanical treatment removing bran and germ fraction). However, these rough comparisons give a first interesting view of the impact of processing on chronic disease and mortality risks.

Considering cereal-based foods, it has been quite consistently shown that higher whole grain-based food consumption has been associated with significantly lower risks of all-cause mortality (Aune et al., 2016; Li et al., 2016; Zong, Gao, Hu, & Sun, 2016), type 2 diabetes (Aune, Norat, Romundstad, & Vatten, 2013; Chanson-Rolle et al., 2015), cardiovascular diseases (Aune et al., 2016; Li et al., 2016; Mellen, Walsh, & Herrington, 2008; Zong et al., 2016), cancer mortality (Zong et al., 2016), colorectal cancer (Aune et al., 2011), and lower fasting blood glucose and insulin levels (Nettleton et al., 2010), and to a lesser extent with reduced weight gain (Cho, Qi, Fahey, & Klurfeld, 2013; Lutsey et al., 2007) and risk of metabolic syndrome (Esmaillzadeh, Mirmiran, & Azizi, 2005; Sahyoun, Jacques, Zhang, Juan, & McKeown, 2006), whereas higher consumption of refined cereals is either neutral (Aune et al., 2016; Aune, Norat, et al., 2013; Esmaillzadeh et al., 2005; Mellen et al., 2008) or deleterious (Fardet & Boirie, 2014; Sahyoun et al., 2006) toward chronic disease risks. For example, it has been shown in a prospective study within a cohort of around 200,000 South Korean men and women that brown unrefined rice is more protective against type 2 diabetes (36% lower risk) than white refined rice, this latter leading to significantly higher prevalence of type 2 diabetes (+17%) when regularly consumed (Sun et al., 2010). In another study authors detailed subtypes of cereal-based foods and calculated a pooled risk of coronary heart disease of 0.83 (0.75–0.92) for whole grain bread and 1.07 (0.86–1.34) for white bread, 0.72 (0.64–0.82) for whole grain breakfast cereals and 1.15 (0.79–1.67) for refined grain breakfast cereals (Aune et al., 2016).

Overall these studies suggested that refining deteriorates cereal-based food health potential. However, in these studies there was no distinction between natural whole grain-based foods and recombined/reconstituted whole grain-based foods from bran, germ, and/or cereal fiber. Thus, an ultraprocessed food added with fat and/or sugar may be considered as whole grain foods if recombined from white refined flour, bran, and germ, whereas it is not really healthy.

Considering red vs processed meats, there are also, as for cereals, lots of epidemiological studies that have been pooled in meta-analyses for cancer, cardiovascular disease, obesity, and type 2 diabetes risks (Alexander, Mink, Cushing, & Sceurman, 2010; Alexander, Morimoto, Mink, & Cushing, 2010; Aune, Chan, et al., 2013; Becerra-Tomás et al., 2016; Chan et al., 2011; Chen, Lv, Pang, & Liu, 2013; Choi, Song, Song, & Lee, 2013; Huang, Han, Xu, Zhu, & Li, 2013; Larsson & Wolk, 2012; Micha, Wallace, & Mozaffarian, 2010; Rouhani, Salehi-Abargouei, Surkan, & Azadbakht, 2014; Wallin, Orsini, & Wolk, 2011; Xu et al., 2013; Zhao et al., 2016; Zhao, Yin, & Zhao, 2017). There is less study for metabolic syndrome (Becerra-Tomás et al., 2016). In these studies red and processed meat were generally shown to be either neutral or to increase risk of these chronic diseases, confirming our previous systematic review of systematic reviews and meta-analyses (Fardet & Boirie, 2014). Notably processed meat was classified as carcinogenic to humans by the International Agency for Research on Cancer (IARC, 2015). However, one meta-analysis reported no association between red/processed meats and prostate cancer (Alexander, Mink, et al., 2010). Concerning the distinction between red (minimally processed) and processed meat (including ultraprocessed meat), meta-analyses did not really show clear distinct effects, notably for breast cancer (Alexander, Morimoto, et al., 2010), colorectal adenomas (Aune, Chan, et al., 2013; Xu et al., 2013) and cancer (Chan et al., 2011), esophageal adenocarcinoma (Huang et al., 2013) and cancer (Choi et al., 2013), ovarian cancer (Wallin et al., 2011), gastric cancer (Zhao et al., 2017), stroke (Chen et al., 2013; Micha et al., 2010), and Barrett's esophagus (Zhao et al., 2016); except for pancreatic cancer (Larsson & Wolk, 2012), coronary heart disease (Micha et al., 2010), type 2 diabetes mellitus (Micha et al., 2010) where processed meat was associated with increased risk but not red meat. However, processed meats may gather very various type of meats, from traditional delicatessen to ultraprocessed meat with various added ingredients and additives. Such a distinction is never made.

Considering whole vs semiskim vs skimmed milk there are also lots of epidemiological studies. In a previous systematic review of systematic reviews and meta-analyses we showed there was no clear distinction between each type of milk toward obesity and cancer risks (Fardet & Boirie, 2014). Concerning cancers, low-fat/skim milk was shown to be not associated with ovarian cancer (pooled OR = 0.925 [0.789–1.085]), whereas whole milk was positively associated (pooled OR = 1.228 [1.031–1.464]) (Liu et al., 2015); the same was observed for bladder cancer with pooled OR of 2.23 (1.45–3.00) for whole milk and 0.47 (0.18–0.79) for skim milk (Qi-Qi et al., 2011). For the influence of thermal treatment on milk health potential toward chronic disease risks there is no prospective study.

Concerning fruits we can also mention the comparison between whole fruits and fruit juices against deregulation of carbohydrate metabolism. Indeed while fruits were shown to be quite neutral toward type 2 diabetes risk (Fardet & Boirie, 2014), fruit juices, when regularly consumed, have been shown to increase this risk (Imamura et al., 2016; Xi et al., 2014). Indeed, fruit juices supply free sugars because, the fiber network surrounding cells being either removed or destroyed during fruit pressing and/or refining, sugars are more readily available for absorption and become a source of rapid carbohydrates that may lead to type 2 diabetes when regularly consumed.

Concerning vegetable a recent prospective study confirms the deleterious effect of ultraprocessing on vegetable health potential (Satija et al., 2017). In pooled multivariable analysis, higher adherence to healthful plant-based diet (whole grains, fruits/vegetables, nuts/legumes, oils, tea/coffee) was inversely associated with coronary heart disease risk (HR: 0.75; 95% CI: 0.68–0.83; $P_{\text{trend}}=0.001$), whereas unhealthful plant-based diet (juices/sweetened beverages, refined grains, potatoes/fries, sweets) was positively associated with coronary heart disease risk (HR: 1.32; 95% CI: 1.20 to 1.46; $P_{\text{trend}}=0.001$). These results suggest that is not sufficient to say: "Eat five fruits and vegetable a day," we should add: "natural or minimally processed."

Concerning other food products, i.e., legumes, nuts, and white meat, there are no epidemiological study dedicated to the influence of processing on human health. Concerning pathologies the most studied were obesity, type 2 diabetes, cardiovascular diseases, and cancers, but nothing about sarcopenia, osteoporosis, mental health, chronic kidney, and liver diseases (such as nonalcoholic steatohepatitis).

In these binary comparisons from epidemiological studies, such as whole grain vs refined grains, whole vs skimmed milk, and red vs processed meat, there is no specific distinction about the degree of processing, notably the comparison between processed and ultraprocessed foods as we will discuss in Section 3.

2.1.2 The International NOVA Classification

In 2010 some Brazilian epidemiologists were concerned by the rapid increase of obesity and type 2 diabetes prevalence in Brazilian population, especially among children and adolescents, which prompted them to develop a new food classification based on the degree of food processing, i.e., international NOVA classification (Monteiro, Levy, Claro, de Castro, & Cannon, 2010; Moubarac, Parra, Cannon, & Monteiro, 2014). We will come back to it in details in Section 3. Briefly they cluster foods in raw/minimally processed, processed culinary ingredients, processed and ultraprocessed (Monteiro, Cannon, Levy, et al., 2016). Since then, several recent epidemiological studies have been carried out using their NOVA classification, and clustering populations in quartiles or quintiles of calories coming from ultraprocessed foods. They showed that populations adhering the most to ultraprocessed foods, irrespective of food groups, presented the highest prevalence of obesity (Canella et al., 2014; Louzada, Baraldi, et al., 2015), metabolic syndrome (Tavares, Fonseca, Garcia Rosa, & Yokoo, 2012), and dyslipidemia (Rauber, Campagnolo, Hoffman, & Vitolo, 2015). Besides a recent epidemiological study based on household availability of ultraprocessed foods in 19 European countries unraveled a significant positive association with obesity, and each percentage point increase in the household availability of ultraprocessed foods resulted in an increase of 0.25% points in obesity prevalence (Monteiro, Moubarac, et al., 2018).

2.2 Interventional Studies

2.2.1 Meta-Analyses of Whole- vs Refined Grains

There are lots of intervention studies about the effect of food processing on some human biomarkers: our aim is not to review all of them here. In the most recent meta-analysis of the 14 studies testing the acute effects of whole grain (vs refined grains) foods, significant reductions of the postprandial values of the glucose iAUC (incremental Area Under response Curve, 0–120 min) by −29.71 mmol min/L (95% CI: −43.57, −15.85 mmol min/L), the insulin iAUC (0–120 min) by −2.01 nmol min/L (95% CI: −2.88, −1.14 nmol min/L), and the maximal glucose and insulin response were shown (Marventano et al., 2017). However, in 16 medium- and long-term randomized controlled trials, effects of whole grain foods on fasting glucose and insulin and homeostatic model assessment-insulin resistance (HOMA-IR) values were not significant (Marventano et al., 2017). In the second meta-analysis whole grain intake did not show any effect on body weight (weighted difference: 0.06 kg; 95% CI: −0.09, 0.20 kg, $P = 0.45$) and waist circumference (weighted difference: −0.10 cm; 95% CI: −0.25, 0.04 cm; $P = 0.15$), but a small effect on the percentage of body fat was observed (weighted difference: −0.48%; 95% CI: −0.95, −0.01; $P = 0.04$) compared with that for a control composed of refined grains (Pol et al., 2013).

2.2.2 Glycemic and Satiety Impacts: The "Matrix" Effect

Overall glycemic index is a good indicator of food processing because the more foods are processed, the higher their glycemic index tend to be and the lower their satiety potential (Fig. 1; Fardet, 2016; Fardet, Méjean, Labouré, Andreeva, & Féron, 2017). Indeed highly processed foods are generally unstructured, fractionated, and added with free glucose and sucrose rendering glucose more available for absorption and increasing blood glycemic response. Probably one of the first study emphasizing the role of processing on carbohydrate metabolism was made on apple (Haber, Heaton, Murphy, & Burroughs, 1977). Raw whole apple, apple purée, and apple juice were compared for their glycemic and insulinemic index, and for their impact on satiety in healthy human subjects. Main results showed that the peak of plasma hypoglycemia after 90 min was higher with

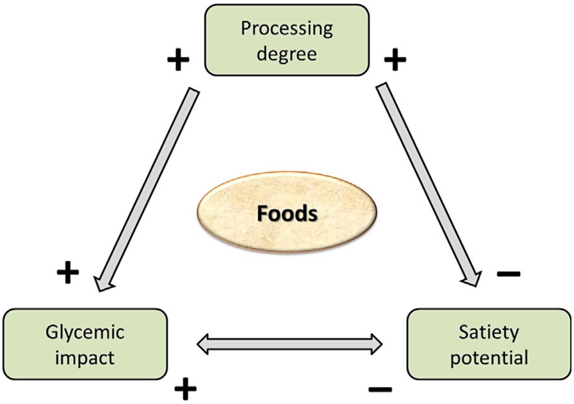


Fig. 1 Transitivity relation between degree of processing, glycemic index, and satiety potential.

juice, then purée, and finally whole apple; and the more apple was unstructured the higher its insulinemic peak 30 min after meal and the lower its satiety score (Haber et al., 1977). Later Holt et al. obtained similar results by modulating cereal particle size (fine flour, coarse flour, cracked grains, and whole grains) and observing that the finer the cereal-based food structure, the higher the area under the glucose curve and the lower the area under the satiety curve (Holt & Miller, 1994). In the same way, whole carrots (fiber and structure), blended carrots (fiber but no structure), or carrot nutrients (no fiber or structure) were compared for their satiety potential within a meal, and as expected meals with whole and blended carrots resulted in significantly ($P < 0.05$) higher satiety that nutrients from carrot, emphasizing the matrix effect of carrot on satiety (Moorhead et al., 2006). More specifically variations in a process have been studied with breads baked with different conditions, showing that some varieties of French bread (Traditional Baguette) have lower insulinemic index in healthy subjects, and lower glycemic index in type 2 diabetic subjects, than that of the other varieties (Rizkalla et al., 2007). According to authors, these results would be due to differences in bread processing rather than to the fiber content, suggesting again a matrix effect due to processing. Similar to Rizkalla et al. (2007), Granfeldt, Bjorck, and Hagander (1991) had studied the influence of pasta processing (i.e., spaghetti and three varieties of fresh roll-sheeted linguine—including thin and thick linguine) on carbohydrate metabolism, but only minor differences appeared in glucose, insulinemic, and C-peptide plasma responses.

Our objective here is not to review all studies but to point out that when degree of processing is considered in interventional studies significant differences in various parameters of human metabolism could have been measured, apparently mainly in response to fractionation and/or refining of initial complex foods which impacts both food matrix and composition.

3. FOOD PROCESSING AND FOOD HEALTH POTENTIAL

3.1 The Different Types of Generic Processes Used in Food Industry

Overall in agrofood industry, but also at home, we can distinguish three main categories of technological processes that are mechanical, thermal, and fermentative treatments (Box 1). However, a ready-to-eat food is rarely the result of only one treatment, especially in industry. The food may be submitted to a combination of several treatments. For example, a fresh

BOX 1 The different categories of technological processes

1. Primary technological treatments

Mechanical treatments

- Fractionating, refining (flours, ingredients, etc.), grinding (e.g., fruit purées and compotes):
  - o Reducing particle size
  - o Vitamins, minerals, and fiber losses
  - o Disintegrating food matrix: destruction of protein and fibrous networks
  - o Increasing glycemic index
  - o Decreasing satiety potential
- Extraction with or without change of state (e.g., crystallization, distillation/pressing, centrifugation, decantation, skimming, dry cleaning):
  - o Oxidations
  - o Selection of macronutrient fractions
- Mixing processes (e.g., kneading):
  - o Influencing glycemic index
  - o Reorganizing nutrient interactions
- Flaking, rolling (e.g., breakfast cereals, vegetable flakes, corn petals):
  - o Influencing glycemic index through modifying food form (e.g., thickness)
- Filtration (e.g., microfiltration and ultrafiltration):
  - o Selection of macro- and micronutrient fractions
- Emulsion/expansion:
  - o Oxidations

Continued

BOX 1 The different categories of technological processes—cont'd

Thermal treatments: starch gelatinization, water content reduction/increase, vitamin denaturation, modification of fiber properties, destruction/appearance of antioxidants, newly formed compounds (e.g., heterocyclic amines):

- Cooking: boiling in water, steam cooking, oven, oil frying, microwaves, warm air, infrared, ohmic
  - o Vitamin and mineral losses
  - o Increasing glycemic index
- Dehydration: drying (freeze-drying, zeodration, atomization, microwaves, warm air, fluidized bed)
  - o Vitamin losses
- Extrusion cooking
  - o High increase of glycemic index
  - o Vitamin losses
- Sterilization, pasteurization, UHT, and canning
  - o Modifying protein digestibility
  - o Occurrence of newly formed compounds such as acrylamides and melanoidins (Maillard reaction → loss of nutritive value of proteins, e.g., blocked lysine), and nitrosamines

Fermentative treatments: increasing nutrient density, modifying food texture, predigesting certain macronutrient fractions, solubilizing fibers, releasing bound fractions of vitamins and polyphenols, degrading antinutritional factors (e.g., tannins and phytic acid), consumption of growth factors, gas production, degradation of proteins, sugars, and so on

- Alcoholic (e.g., fruits, cereals)
- Acetic (e.g., vinegar)
- Lactic (e.g., cabbage, soya, onions, yogurts)
- Propionic (e.g., some cheeses)
- Malolactic (e.g., wine)
- Butyric (e.g., some cheeses)

2. Secondary technological treatments

Enzymatic treatments

- Malting
- Other hydrolyses (e.g., starch, lactose, proteins, pectin, β-glucans)

Packaging and conservation treatments

- Modified atmosphere packaging
- Canning
- Vacuum packaging
- Confection and salting

Decontamination treatments

- Ionization (crosslinking of molecules, appearance of neoforms)
- Pascalization, bridgmanization, high-pressure processing, or high hydrostatic pressure (e.g., coagulation of proteins)

yogurt is fermented from (semi)skimmed and sterilized milk, therefore including at least three treatments; and more when ingredients and additives are added such as in ultraprocessed dairy products. Breakfast cereals for children are also the result of mechanical treatments (flour refining), thermal treatment to gelatinize starch, e.g., extrusion cooking with high pressures and temperatures, grinding, and addition of salt, sugars, fat, and/or numerous additives. These products are called "ultraprocessed foods" (Monteiro, Cannon, et al., 2018). Generally at home we use more classic culinary ingredients such as oils, butter, salt, sucrose, and spices, more classic cooking methods such as steam or water cooking, more classic mechanical treatments such as grinding, sectioning, hulling, and/or peeling, and classic fermentations such as alcoholic or lactic acid fermentations, notably when doing one's own yogurt or breads.

Otherwise processing impacts both nutritional composition and food matrix. However, it is very difficult to evaluate the real impact of processing on food health potential due to a double complexity:

(1) While some processes are denaturing, others improve the health potential, e.g., fermentation processes. However, the foods we consume are very often the result of a series of several treatments applied, and it is therefore very difficult to separate the respective share of each of these processes on the health potential of foods: while a first treatment may diminish this potential, the following one can increase it.

(2) In addition, food matrices are generally complex: thus while one treatment can negatively affect a nutrient, it can at the same time positively affect another nutrient. It is therefore also difficult to evaluate the specific action of each nutrient into the health potential of foods as a result of technological processes.

The impact of processing on food matrix has only been a little taken into consideration. Why? Probably because foods have been most of the time considered as an only sum of nutrients according to a reductionist perspective, and considering that all calories are the same and interchangeable from one food to another.

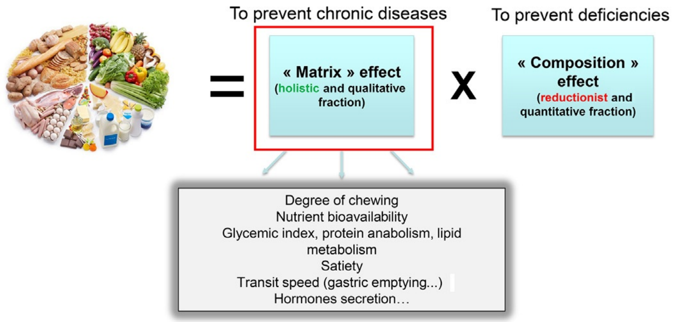
3.2 Redefining Food Health Potential: Toward a More Holistic Paradigm

3.2.1 What Is Food Health Potential?

To get better insight into the impact of processing on food health potential it is necessary to clearly define what "food health potential" is. This appears obvious but in reality this is not. Up today, or at least up to the end of the 20th century, food potential was essentially defined by its composition via a reductionist approach considering that the whole food was equal to the sum of its nutrient. With such a view or paradigm foods were interchangeable, and a calorie from food A was equal to a calorie from food B. Yet, science has today clearly shown that food is more than the sum of its nutrients (quantitative and reductionist aspect): it is also a structure or matrix that determines very important nutritional properties such as satiety potential, hormonal secretions, and nutrient bioavailability (qualitative and holistic aspects) (Fig. 2). It is only to observe that ground almond particles of smaller size have more fractured cells and thereby greater nutrient release (bioaccessibility) than larger particles, although nutritional composition is exactly the same (Grundy, Wilde, Butterworth, Gray, & Ellis, 2015).

3.2.2 Composition Tables, Nutritional Indices, and Their Limits

Today there are numerous food composition tables from various countries such as France (ANSES-Afssa, 2008), USA (U.S. Department of Agriculture, 2008), Germany (Souci, Fachmann, & Kraut, 2008), or India (National Institute of Nutrition, 2017). All these tables are obviously useful for several purposes such as calculating nutrients supplied by a specific diet, notably in reference to the recommended daily allowances, and for preventing nutritional deficiencies. But they have many drawbacks: they tell nothing about nutrient bioavailability within human organism and the fraction really used by organism, the additives used, the glycemic index, the satiety potential, these latter being related to food matrix structure.



With identical composition in nutrients and calories, two foods with different physical structures will not have the same health potential

1 calorie food A ≠ 1 calorie food B

Consuming 500 kcal from minimally processed foods does not have the same effect on health as 500 kcal from ultra processed food

Fig. 2 Definition of food health potential.

Indeed two foods of almost identical composition have not obligatory the same health potential. In the end these tables tell nothing about the degree of food processing.

The same is true for the many nutritional indices as the nutrient-rich food index (Drewnowski & Fulgoni, 2008) or the NDS/LIM index (Darmon, Vieux, Maillot, Volatier, & Martin, 2009), most of them based on some nutrients to encourage and those to limit on a calorie basis and as regards with daily recommended amount of nutrients. Although they can partially reflect degree of processing as shown with the NDS/LIM scores (Darmon et al., 2009), they are very limited and are reductionist indices not including very important nutritional parameters such as satiety, bioavailability, number of additives, and degree of processing of added ingredients. There is a real need for more holistic index taken into consideration both matrix and compositional effects because both are involved in health effects in humans. We have initiated such a work through measuring water activity (a_w), number of ingredients and/or additives, and textural characteristics (shear and compression stress), and we showed that is possible to define more holistic and integrative food index (Fardet, Lakhssassi, & Briffaz, 2018).

This raises the important issue of developing food table of physicochemical characteristics including parameters related to the matrix effect, e.g., nutrient bioavailable percentage, hardness, a_w, porosity, shelf life, nutrient quality (*trans*-fatty acids, fructose), newly formed compounds, etc. Such tables do not exist but there is undoubtedly lots of data to collect worldwide.

Such a paradigm shift is indispensable to approach the real food health potential and to objectively study its association with the degree of processing. In this way international tables of glycemic index (Foster-Powell, Holt, & Brand-Miller, 2002) are relevant because this latter generally varied according to food structure parameters, i.e., degree of starch gelatinization/crystallinity, particle size, food thickness, presence of amylose–lipid complexes, presence of fibrous/protein networks, and/or food density.

3.3 Impact of Processing on Food Composition

Among food nutritional properties the most studied and well known is the antioxidant potential, which is regularly measured on ready-to-eat foods (Carlsen et al., 2010). Beyond antioxidant potential, there is also, among other, the PRAL index that measures alkalinity of foods, the lipotropic potential that measures the potential of a food to prevent liver steatosis (Fardet & Chardigny, 2013; Fardet, Martin, & Chardigny, 2011b), and the fullness factor that measured the satiety potential of foods (Fardet, 2016; Fardet, Méjean, et al., 2017). It is therefore interesting to observe from these data how processing modifies these functional nutritional food indices.

Concerning the antioxidant potential, it is clear and unambiguous that refining decreases it by removing germ and bran fractions rich in antioxidants (more than 34 compounds have antioxidant potential in whole grain wheat: polyphenols, vitamins, minerals, etc.) (Fardet, 2010). If we looked at the table by Carlsen et al. (2010) for the antioxidant content by main food groups first animal-based foods are largely poorer in antioxidants than plant-based foods (median around ninefold less), and second processed and ultraprocessed products—such as confectionary, salty and sugary snacks, infant foods, mixed food entrees, soups, sauces gravies, dressing, and biscuits—present significantly lower antioxidant potential than fresh and raw foods—such as fruits, vegetables, spices, and herbs (Carlsen et al., 2010).

Concerning the lipotropic potential, we also showed that overall processing decreases it by around 20%, thermal (median change of −16%) and refining (−33%) being more drastic than fermentations (−5%) (Fardet, Martin, & Chardigny, 2011a). More specifically fermentations increased betaine (median change of +32%) and choline (+34%) densities, and canning and boiling vegetables increased choline densities (+26%). On Fig. 3 is the PCA plot for processed vs raw food for their lipotropic potential showing that processed foods (in blue) are clustered on the left-hand side characterized by the lowest lipotropic potential.

Concerning the alkalinizing potential, there is no study measuring influence of processing. However, by looking at PRAL index of several foods no difference is observed according to the degree of processing, differences being more in relation with food groups and animal-based vs plant-based foods (Piquet, 2012).

Finally concerning the satiety potential Holt et al. first showed in healthy humans that minimally processed foods are more satiating that processed and ultraprocessed foods such as confectionary, snacks, and breakfast cereals (Holt, Miller, Petocz, & Farmakalidis, 1995). We confirmed these results on 378 ready-to-eat foods classified according to their degree of processing (Fardet, 2016; Fardet, Méjean, et al., 2017). In summary ultraprocessed fractionated/recombined foods are poorly satiating.

It is clear from these observations that processing negatively impacts food antioxidant, lipotropic, and satiety potential by removing micronutrients and the most satiating macronutrients that are fiber and proteins, ultraprocessed

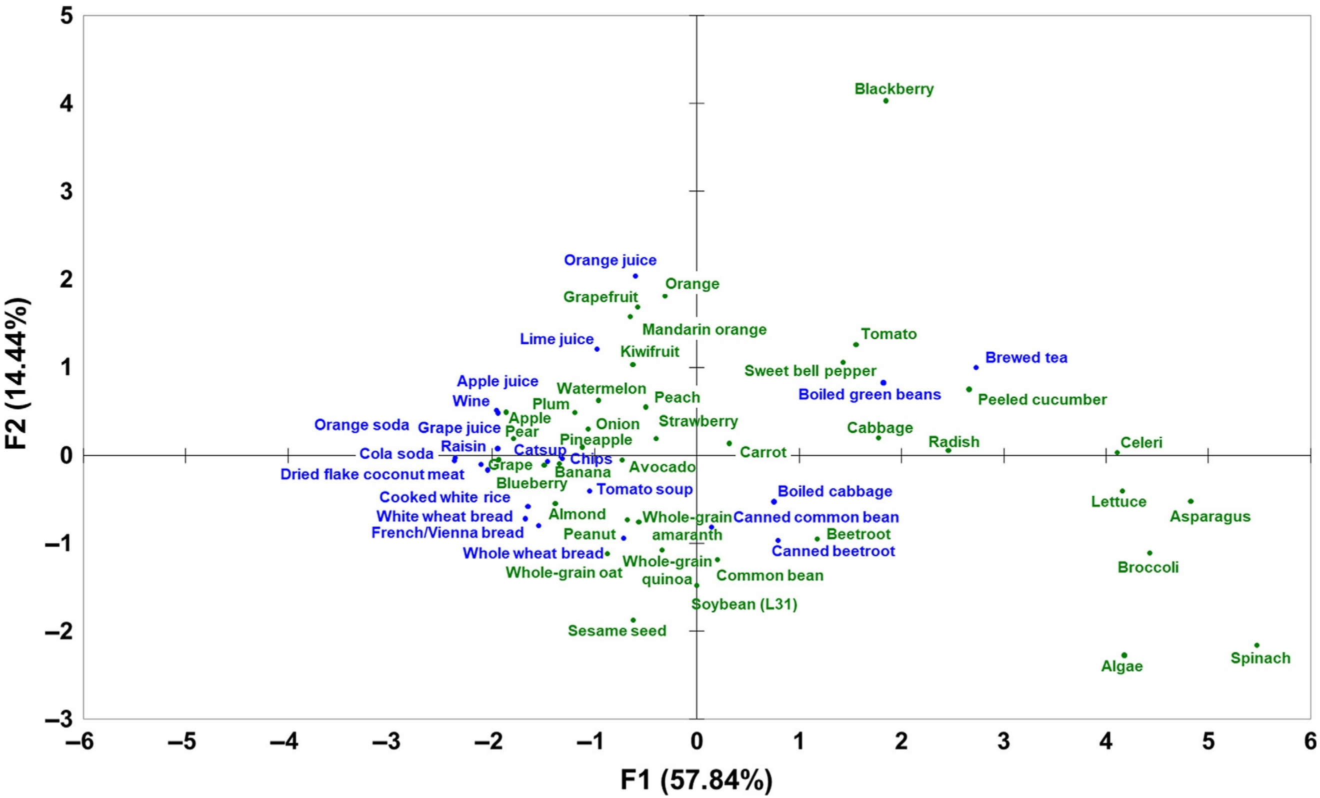


Fig. 3 PCA score plot of processed (*blue* or *gray*) and raw (*green* or *black*) foods for their lipotropic potential. *From Fardet, A., Martin, J.-F., & Chardigny, J.-M. (2011). Thermal and refining processes, not fermentation, tend to reduce lipotropic capacity of plant-based foods.* Food & Function, 2*(8), 483–504 with permission of The Royal Society of Chemistry©.*

foods being richer in fat and sugars, especially when added. Indeed it is well known that fiber and protein fractions are more satiating than fat and sugars.

3.4 Impact of Processing on Food Matrix

Processing not only influences food composition but also food matrix (Fardet, 2014a). Food matrix can be defined as the support, architecture, or the structure of the food resulting from nutrient interactions, giving to it its form, thickness, density, hardness, porosity, color, and crystallinity. Therefore, each food has its own matrix, and this latter determines the bioavailable fraction of each food nutrient, but also the food satiety potential as solid foods are more satiating than semisolid and liquid foods (Chambers, 2016). Thus, glycemic index, and macronutrients, vitamin, trace element, and mineral bioavailable fractions are determined by food matrix. This has been well demonstrated in scientific literature, but this is not the scope of this review to detail it here.

Previously, it was cited a study by Haber et al. (1977) showing that the more apple is unstructured the lower its satiety effect and the higher its insulinemic response; and similar results were obtained with carrots (Moorhead et al., 2006) and cereals (Holt & Miller, 1994). The matrix effect of foods has been only seriously studied from the beginning of the years 2000. Since then many studies have been carried out on various foods, be animal-based or plant-based foods. Notably the effect of almond structure has been thoroughly investigated. For example, grinding almonds clearly increases the degree of almond cell disruption, favoring cell wall breakdown (Mandalari et al., 2008). Then by comparing raw almond emulsion, chewed raw almond, and raw almond intact cells Grundy et al. very well emphasized the matrix effect, but also the influence of chewing that seems to break cell wall allowing oil bodies to be released from cell and subjected to lipolysis (Fig. 4; Grundy et al., 2015).

In vitro gastric digestion of different processed apples (raw vs freeze, freeze-dried, and convective dried *Granny* apple) was also studied (Dalmau, Bornhorst, Eim, Rosselló, & Simal, 2017). Before digestion raw apples are composed of many well-arranged pores in a heterogeneous and anisotropic pattern; freeze apple by immersion in liquid nitrogen exhibited irregular shapes, cellular damage, and more intercellular spaces; freeze-dried apple exhibited heterogeneity of the pore structure similar to that of the raw apples, but a collapse of cell membranes was observed;

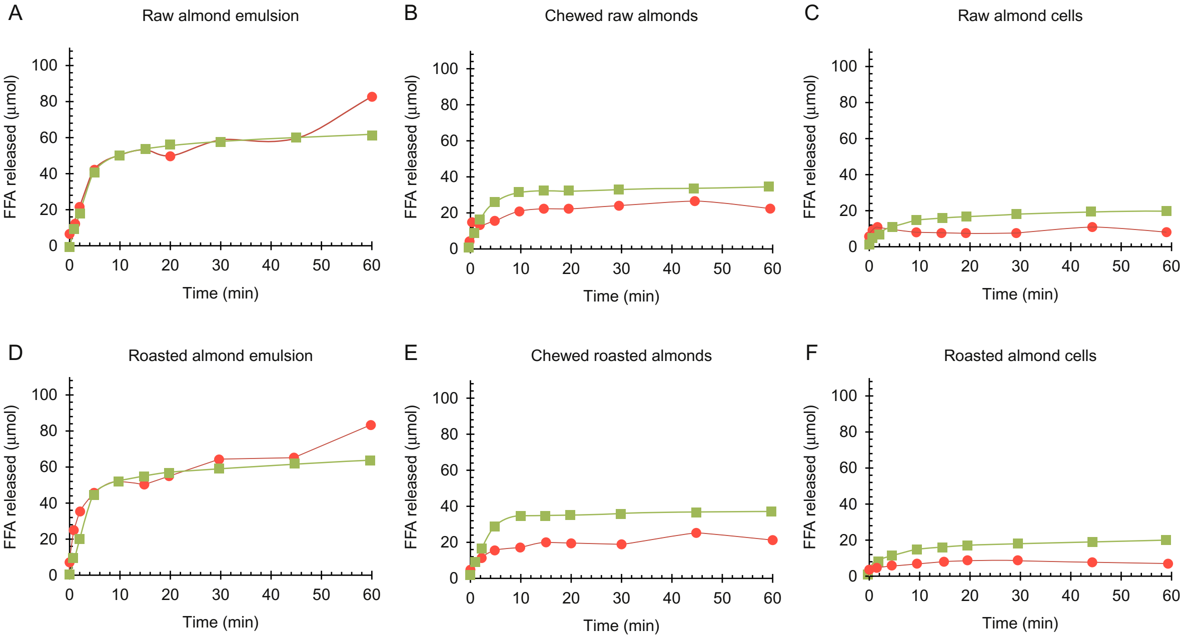


Fig. 4 Free fatty acid release (μmol) over a 60-min time period during duodenal digestion, using the pH-stat method (*green* or *gray line*) and gas chromatography analysis (*red* or *black line*, average values duplicates) for raw (A–C) and roasted (D–F) almonds; almond emulsions (A and D), chewed almonds (B and E), and separated almond cells (C and F). *Adapted from Grundy, M. M. L., Wilde, P. J., Butterworth, P. J., Gray, R., & Ellis, P. R. (2015). Impact of cell wall encapsulation of almonds on in vitro duodenal lipolysis.* Food Chemistry, 185, *405–412 with permission of Elsevier© under the terms of the Creative Commons Attribution License (CC BY).*

and in convective dried apples cells exhibited shrinkage, and there was a reduction in the number and size of pores as well as cellular collapse when compared to raw apples. Processing has therefore led to cellular destruction, but has also modified cell wall carbohydrate composition. During gastric digestion processed apples also showed faster decreases in soluble solids compared to raw apples. Finally, contrary to convective drying, freezing, and freeze drying resulted in decreases in total polyphenol content and antioxidant activity in apples.

Another well-known effect of processing is that on lycopene from tomato. Thus, in humans, the bioavailability of lycopene is greater from tomato paste than from fresh tomatoes (Gartner, Stahl, & Sies, 1997). According to Shi and Le Maguer food processing may improve lycopene bioavailability by breaking down cell walls, which weakens the bonding forces between lycopene and tissue matrix, thus making lycopene more accessible (Shi & Le Maguer, 2000).

Although all studies are not reviewed here, these results all together convincingly show that when processing fragment or destroy food structure this systematically leads to increased nutrient bioavailability, sometimes for beneficial effect, sometimes not, notably when this increases the proportion of rapidly available sugars.

4. FOOD PROCESSING AND RANKING OF FOODS

If processing has so relevant effect on food health potential, both on its structure and composition, it is naturally evident the need of ranking foods according to their degree of processing. It is not an easy task for several reasons: (1) unitary industrial processes are not given by agrofood industry, only a rough nutritional composition (generally without percentages of added fat, sugar, and salt); (2) human toxicity (on the long term) of the hundreds industrials ingredients and/or additives is not very well known; (3) the effect of processing on food structure is difficult to apprehend, all the more that there is no physicochemical food table; and (4) we still lack epidemiological studies for the association between processed foods and chronic disease risks.

4.1 The International NOVA Classification

4.1.1 Definition

The NOVA classification has been elaborated by Brazilian epidemiologists facing a dramatic increase in epidemics of obesity and type 2 diabetes, both in adolescents and adults (Monteiro et al., 2015). Carlos Monteiro, from

University of Sao Paulo (School of Public Health), came to the conclusion that "The issue is not food, nor nutrients, so much as processing" (Monteiro, 2009). He and his colleagues observed that this increase of obesity and type 2 diabetes prevalence was associated with an increased consumption of ultraprocessed foods (Monteiro, Levy, Claro, de Castro, & Cannon, 2011), mainly marketed by transnational Big Food companies (Monteiro & Cannon, 2012). This is within this context that they published in 2014 the first comprehensive NOVA classification of foods according to their degree of processing (Fig. 5 and Box 2; Moubarac, Parra, et al., 2014); and a few time later they also helped publishing the first national dietary guidelines including this new paradigm with technological pyramids instead of the usual food pyramids (Fig. 6; Ministry of Health of Brazil, 2014).

4.1.2 The Ultraprocessed Foods: A New Concept

The ultraprocessed products have invaded our supermarket shelves, fast food outlets, distributors, and other hot spots on the street, as shown in Brazil and Canada during the last decades (Martins, Levy, Claro, Moubarac, & Monteiro, 2013; Moubarac, Batal, et al., 2014). In New Zealand, it has been estimated that they are over 80% of food packaged in supermarkets (Luiten, Steenhuis, Eyles, Ni Mhurchu, & Waterlander, 2016). Main ultraprocessed foods are chocolate bars, dairy desserts, breakfast cereals for children, reconstituted fruit juices and sodas (i.e., sweetened beverages), industrial ready-to-eat meals, confectionary, salty, sugary and fatty snacks, industrial pastries and delicatessen, and so on.

Fig. 5 The NOVA classification according to the degree of food processing.

BOX 2 The NOVA classification (from Monteiro et al., 2016)

Group 1: Unprocessed or minimally processed foods

Unprocessed (or natural) foods are edible parts of plants (seeds, fruits, leaves, stems, roots) or of animals (muscle, offal, eggs, milk), and also fungi, algae, and water, after separation from nature.

Minimally processed foods are natural foods altered by processes such as removal of inedible or unwanted parts, drying, crushing, grinding, fractioning, filtering, roasting, boiling, pasteurization, refrigeration, freezing, placing in containers, vacuum packaging, or nonalcoholic fermentation. None of these processes adds substances such as salt, sugar, oils, or fats to the original food.

The main purpose of the processes used in the production of group 1 foods is to extend the life of unprocessed foods, allowing their storage for longer use, such as chilling, freezing, drying, and pasteurizing. Other purposes include facilitating or diversifying food preparation, such as in the removal of inedible parts and fractioning of vegetables, the crushing or grinding of seeds, the roasting of coffee beans or tea leaves, and the fermentation of milk to make yogurt.

Group 1 foods include fresh, squeezed, chilled, frozen, or dried fruits and leafy and root vegetables; grains such as brown, parboiled or white rice, corn cob or kernel, wheat berry or grain; legumes such as beans of all types, lentils, chickpeas; starchy roots and tubers such as potatoes and cassava, in bulk or packaged; fungi such as fresh or dried mushrooms; meat, poultry, fish, and seafood, whole or in the form of steaks, fillets and other cuts, or chilled or frozen; eggs; milk, pasteurized or powdered; fresh or pasteurized fruit or vegetable juices without added sugar, sweeteners, or flavors; grits, flakes or flour made from corn, wheat, oats, or cassava; pasta, couscous and polenta made with flours, flakes, or grits and water; tree and ground nuts and other oil seeds without added salt or sugar; spices such as pepper, cloves, and cinnamon; and herbs such as thyme and mint, fresh or dried; plain yogurt with no added sugar or artificial sweeteners added; tea, coffee, drinking water.

Group 1 also includes foods made up from two or more items in this group, such as dried mixed fruits, granola made from cereals, nuts, and dried fruits with no added sugar, honey or oil; and foods with vitamins and minerals added generally to replace nutrients lost during processing, such as wheat or corn flour fortified with iron or folic acid.

Group 1 items may infrequently contain additives used to preserve the properties of the original food. Examples are vacuum-packaged vegetables with added antioxidants, and ultrapasteurized milk with added stabilizers.

Group 2: Processed culinary ingredients

These are substances obtained directly from group 1 foods or from nature by processes such as pressing, refining, grinding, milling, and spray drying.

BOX 2 The NOVA classification (from Monteiro et al., 2016)—cont'd

The purpose of processing here is to make products used in home and restaurant kitchens to prepare, season and cook group 1 foods and to make with them varied and enjoyable handmade dishes, soups and broths, breads, preserves, salads, drinks, desserts, and other culinary preparations.

Group 2 items are rarely consumed in the absence of group 1 foods. Examples are salt mined or from seawater; sugar and molasses obtained from cane or beet; honey extracted from combs and syrup from maple trees; vegetable oils crushed from olives or seeds; butter and lard obtained from milk and pork; and starches extracted from corn and other plants.

Products consisting of two group 2 items, such as salted butter, group 2 items with added vitamins or minerals, such as iodized salt, and vinegar made by acetic fermentation of wine or other alcoholic drinks, remain in this group.

Group 2 items may contain additives used to preserve the product's original properties. Examples are vegetable oils with added antioxidants, cooking salt with added antihumectants, and vinegar with added preservatives that prevent microorganism proliferation.

Group 3: Processed foods

These are relatively simple products made by adding sugar, oil, salt, or other group 2 substances to group 1 foods. Most processed foods have two or three ingredients. Processes include various preservation, fermentation, or cooking methods, and, in the case of breads and cheese, nonalcoholic fermentation.

The main purpose of the manufacture of processed foods is to increase the durability of group 1 foods, or to modify or enhance their sensory qualities.

Typical examples of processed foods are canned or bottled vegetables, fruits, and legumes; salted or sugared nuts and seeds; salted, cured, or smoked meats; canned fish; fruits in syrup; simple breads and cheeses.

Processed foods may contain additives used to preserve their original properties or to resist microbial contamination. Examples are fruits in syrup with added antioxidants, and dried salted meats with added preservatives.

When alcoholic drinks are identified as foods, those produced by fermentation of group 1 foods, such as beer, cider, and wine, are classified here in group 3.

Group 4: Ultraprocessed food and drink products

These are industrial formulations typically with five or more and usually many ingredients. Such ingredients often include those also used in processed foods, such as sugar, oils, fats, salt, antioxidants, stabilizers, and preservatives. Ingredients only found in ultraprocessed products include substances not commonly used in culinary preparations, and additives whose purpose is to imitate sensory qualities of group 1 foods or of culinary preparations of these foods, or to disguise undesirable sensory qualities of the final product. Group 1 foods are a small proportion of or are even absent from ultraprocessed products.

Continued

BOX 2 The NOVA classification (from Monteiro et al., 2016)—cont'd

Substances only found in ultraprocessed products include some directly extracted from foods, such as casein, lactose, whey, and gluten, and some derived from further processing of food constituents, such as hydrogenated or interesterified oils, hydrolyzed proteins, soy protein isolate, maltodextrin, invert sugar, and high-fructose corn syrup. Classes of additive only found in ultraprocessed products include dyes and other colors, color stabilizers, flavors, flavor enhancers, nonsugar sweeteners, and processing aids such as carbonating, firming, bulking and antibulking, defoaming, anticaking and glazing agents, emulsifiers, sequestrants, and humectants.

Several industrial processes with no domestic equivalents are used in the manufacture of ultraprocessed products, such as extrusion and molding, and preprocessing for frying.

The main purpose of industrial ultraprocessing is to create products that are ready to eat, to drink, or to heat, liable to replace both unprocessed or minimally processed foods that are naturally ready to consume, such as fruits and nuts, milk and water, and freshly prepared drinks, dishes, desserts, and meals. Common attributes of ultraprocessed products are hyperpalatability, sophisticated and attractive packaging, multimedia, and other aggressive marketing to children and adolescents, health claims, high profitability, and branding and ownership by transnational corporations.

Examples of typical ultraprocessed products are: carbonated drinks; sweet or savory packaged snacks; ice-cream, chocolate, candies (confectionery); mass-produced packaged breads and buns; margarines and spreads; cookies (biscuits), pastries, cakes, and cake mixes; breakfast "cereals," "cereal," and "energy" bars; "energy" drinks; milk drinks, "fruit" yogurts, and "fruit" drinks; cocoa drinks; meat and chicken extracts and "instant" sauces; infant formulas, follow-on milks, other baby products; "health" and "slimming" products such as powdered or "fortified" meal and dish substitutes; and many ready to heat products including pre-prepared pies and pasta and pizza dishes; poultry and fish "nuggets" and "sticks," sausages, burgers, hot dogs, and other reconstituted meat products, and powdered and packaged "instant" soups, noodles, and desserts.

When products made solely of group 1 or group 3 foods also contain cosmetic or sensory intensifying additives, such as plain yogurt with added artificial sweeteners, and breads with added emulsifiers, they are classified here in group 4. When alcoholic drinks are identified as foods, those produced by fermentation of group 1 foods followed by distillation of the resulting alcohol, such as whisky, gin, rum, vodka, are classified in group 4.

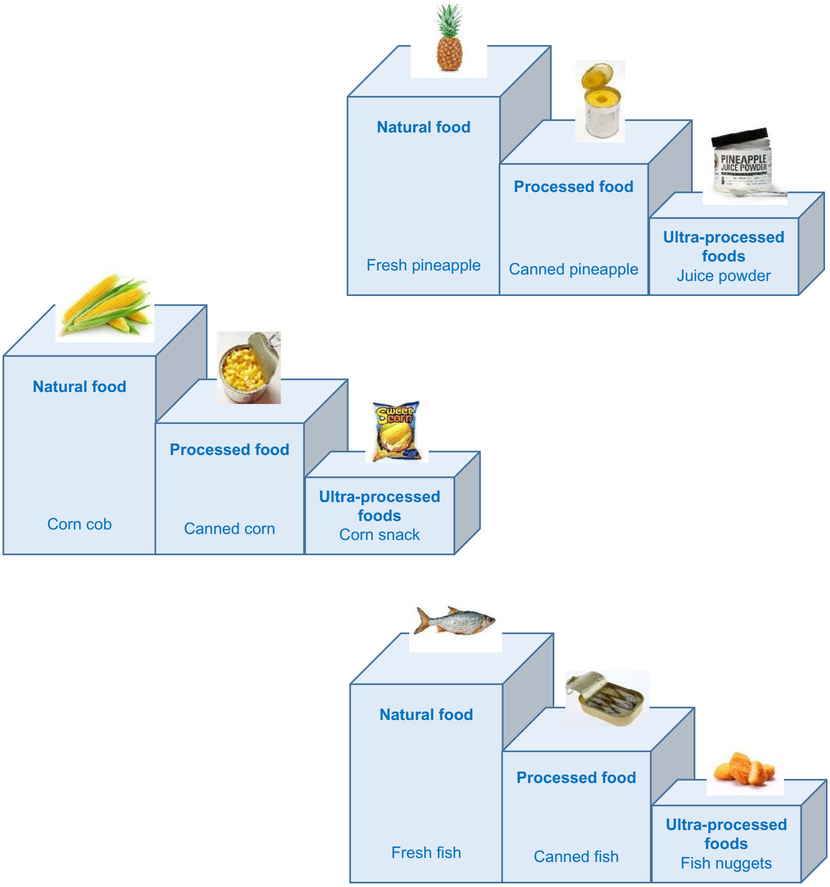


Fig. 6 Example of technological pyramids according to NOVA classification. *From Ministry of Health of Brazil, Secretariat of Health Care, Primary Health Care Department (2014).* Dietary guidelines for the Brazilian population. *São Paulo: Editora Senac.*

It is difficult to say exactly when ultraprocessed products have appeared in the shelves, probably their massive appearance dates back to the 1980s. They have been defined precisely only very recently by the scientific community. Epidemiologists at the University of Sao-Paulo have chosen several criteria (see details in Box 2; Monteiro et al., 2016):

(1) Industrial formulations made from typically five or more ingredients, most often very many;

(2) The purpose of the various additives and ingredients is to imitate the sensory qualities of unprocessed or little processed foods, and culinary preparations made from these foods or to mask the undesirable sensory qualities of the final products;

(3) The main objective of industrial ultraprocessing is therefore to create products that are ready for use or to be heated, subject to replacing both unprocessed and minimally processed foods that are naturally ready for consumption such as fruits and nuts, milk and water, drinks, dishes, desserts, and freshly prepared meals. The common attributes of ultraprocessed products are hyperpalatability, sophisticated and attractive packaging, health claims, high profitability, and generally belong to major brands of transnational companies.

In summary, an ultraprocessed food is an artificial food generally made of recombined ingredients and/or additives, or so much refined that one cannot any more recognize the original raw food. Thus, according to Brazilian researchers, milk drinks and yogurts that have been sweetened, colored, and flavored or bread with emulsifiers should be considered as ultraprocessed foods.

Even if they are decried and partly responsible for the increase in the prevalence of chronic diseases when consumed in excessive quantities, they have a useful place in the food supply when they are consumed in reasonable quantities for what they have been created. These foods can play a role in niche markets such as sweets, pastries, food for clinical purposes, survival rations, or exertion (army, sports, etc.), eating malnourished elderly or why not for food in space, so many situations, sports, festive, pathological … where ultraprocessed foods can be really useful. Ultraprocessed foods have "the right to exist," if only because they share the need for human creativity. The problem is that today they are not niche products, but are consumed to the point of constituting more than 50% of the caloric intake in many countries, especially in big cities. Besides, they are often poorer in protective micronutrients (Crovetto, Uauy, Martins, Moubarac, & Monteiro, 2014; Fardet, Méjean, et al., 2017; Louzada et al., 2015a; Martínez Steele et al., 2016; Moubarac, Batal, Louzada, Martinez Steele, & Monteiro, 2016) and energy-rich (calories) derived from sugars, fat (added) in particular. That is why some scientists talk about "empty" calories (McGill, 2014), so "empty" of bioactive protective micronutrients!

A Brazilian cross-sectional study has shown that beyond 13% of daily calories from ultraprocessed products the risk of obesity starts to increase significantly (Louzada, Baraldi, et al., 2015). Although other studies are needed to confirm the right percentage, it seems that we should not exceed 1 cal among 6 of ultraprocessed foods, and not 1 in 2 as it tends to become the case in South America (Pan American Health Organization, 2015), Western countries, especially Anglo-Saxon countries (Martínez Steele, Popkin, Swinburn, & Monteiro, 2017; Moubarac et al., 2016). France seems to resist better than other European countries (Monteiro, Moubarac, et al., 2018), probably because of its culinary tradition. However, a recent study realized in the French cohort NutriNet-Study reported that ultraprocessed foods contributed 18.4% of the foods consumed in weight and 35.9% of total energy intake (Julia et al., 2018), while obesity prevalence continues to increase concomitant with increased consumption of ultraprocessed foods (Monteiro, Moubarac, et al., 2018).

In addition, ultraprocessed products are less satiating and more hyperglycemic than un-, minimally-, or normally processed products when classified according to NOVA (Fardet, 2016; Fardet, Méjean, et al., 2017). The reason would that among ultraprocessed foods there are lots of semisolid and liquid foods that are less satiating than solid foods (Chambers, 2016); in consequence they required less chewing leaving a too short time for complete stimulation of satiety hormones (Chambers, 2016); and they contain less protein and fiber than minimally processed and raw foods, fiber, and protein being the most satiating nutrients.

The problem today is that ultraprocessed products are inexpensive to produce, therefore cheap and are thus more consumed by the underprivileged and poorest classes, most affected by obesity (Darmon & Drewnowski, 2015).

To conclude this section, ultraprocessed products are the symbols of the Western reductionist thinking, which tends to divide reality into isolated entities for better studying it. If the food is only a sum of nutrients then why not splitting or cracking the food then recombine the ingredients in endless combinations. It is however to forget that the whole is greater than the sum of the parts ($2 > 1 + 1$ or synergy). To return to a more holistic vision is thus to less split the food and apply less drastic technological treatments.

4.1.3 Use of NOVA in Epidemiological Studies

The NOVA classification is more and more used by researchers worldwide. Up today it has been used for several purposes (Monteiro et al., 2016): (1) association with chronic diseases such as obesity (Canella et al., 2014; Louzada, Baraldi, et al., 2015), metabolic syndrome (Tavares et al., 2012), and dyslipidemias (Rauber et al., 2015); (2) assessment of "the socioeconomic and demographic distribution of dietary patterns" (Monteiro et al., 2011; Sparrenberger, Friedrich, Schiffner, Schuch, & Wagner, 2015);

(3) "time changes in dietary patterns" (Louzada et al., 2015b; Martins et al., 2013); (4) "the impact of dietary share of ultraprocessed products on the dietary content of macro- and micronutrients" (Barcelos, Rauber, & Vitolo, 2014; Bielemann, Santos Motta, Minten, Horta, & Gigante, 2015; Louzada et al., 2015a; Martins et al., 2013); (5) study of "the relationship between household food purchase patterns and relative prices of ultraprocessed and all other food items" (Moubarac, Claro, et al., 2013); (6) "influence of the food environment (Costa, Claro, Martins, & Levy, 2013; Leite et al., 2012; Vedovato, Trude, Kharmats, & Martins, 2015) and of food advertising (Mallarino, Gomez, Gonzalez-Zapata, Cadena, & Parra, 2013) on the consumption of ultraprocessed products"; (7) evaluation of "the impact of a nutrition education intervention" (de Paula Franco Franco, Rosa, Luiz, & Oliveira, 2015); (8) assessment of the impact of ultraprocessed products on consumption of added sugar (Martínez Steele et al., 2016); (9) assessment of "the secular trends in national dietary patterns (Moubarac, Batal, et al., 2014), and the impact of ultraprocessed products on indicators of nutrient profile of diets" (Moubarac, Martins, et al., 2013); (10) study of "the relationship between household food purchase patterns and relative prices of ultraprocessed and all other food items" (Moubarac, Claro, et al., 2013); (11) estimation of "the potential for reduction of cardiovascular disease by reducing consumption of ultraprocessed products" (Moreira et al., 2015); (12) assessment of "the impact of the consumption of ultraprocessed products on the nutritional quality of diets" (Crovetto et al., 2014; Julia et al., 2018); (13) description of the nutrient profile of supermarket foods (Luiten et al., 2016); (14) correlation of time trends in consumption of ultraprocessed products with adult obesity (Juul & Hemmingsson, 2015); (15) study time trends in sales of ultraprocessed products in 79 low-middle, upper-middle, and high-income countries (Monteiro, Moubarac, Cannon, Ng, & Popkin, 2013), and also in 14 Asian countries (Baker, Kay, & Walls, 2014); (16) comparison of "the strategies used by the manufacturers of tobacco, alcohol, and ultraprocessed products, with implications for prevention and control of noncommunicable diseases" (Moodie et al., 2013); (17) analysis of "the association between changes in sales of ultraprocessed products and changes in population body mass in 15 Latin American countries" (Pan American Health Organization, 2015) or obesity in 19 European countries (Monteiro, Moubarac, et al., 2018).

In the end, as reported by Monteiro et al. (2016) "the proportion of dietary energy in ultraprocessed products has been recommended as an indicator of the quality of diets by the INFORMAS initiative (Vandevijvere et al., 2013). The utility of NOVA has been recognized in reports from the Pan American Health Organization (Pan American Health Organization, 2015) and the UN Food and Agriculture Organization (Food and Agriculture Organization of the United Nations, 2015). Also, the NOVA four food groups are the basis for the main recommendations of the current official Brazilian national food and nutrition guide (Ministry of Health of Brazil, 2014; Monteiro et al., 2015)."

4.2 The SIGA Classification: A Step Further

Although the NOVA classification, scientifically validated by numerous epidemiological and consumer studies worldwide, has the immense merit of having proposed a new paradigm of food classification that makes sense from the point of view of health, it has some weaknesses:

(1) Ultraprocessed foods will not disappear overnight in the agrofood industry; and they can also participate in a balanced meal provided that they do not constitute the basis of the diet: it is therefore desirable to distinguish several subgroups in the ultraprocessed products, from the best to the least healthy, to ensure the transition to less ultraprocessed products;
(2) In ultraprocessed foods the nature of the additives and the degree of processing of the ingredients is not taken into account;
(3) In processed foods the amount of added culinary ingredients is not considered: it is not the same to add one or five pieces of sugar in plain yogurt;
(4) This classification remains qualitative and does not reflect in the nuance of the intensity of certain technological treatments (e.g., intensity of temperatures and pressure) and the loss of the "matrix" effect of foods, e.g., whole fruit vs fruit juice.

A new qualitative approach is therefore necessary through improvement of the NOVA classification taking into account the nature, quantity, function, and degree of transformation of the ingredients and/or additives, and the loss of the "matrix" effect in order to achieve an even more holistic and realistic classification, notably as regards with "communication" with agrofood industry.

Thus, now eight technological groups can be differentiated, as shown in Fig. 7: A (un-/minimally processed), B (processed), and C (ultraprocessed) with the following subgroups: A0 (un-/minimally processed foods with

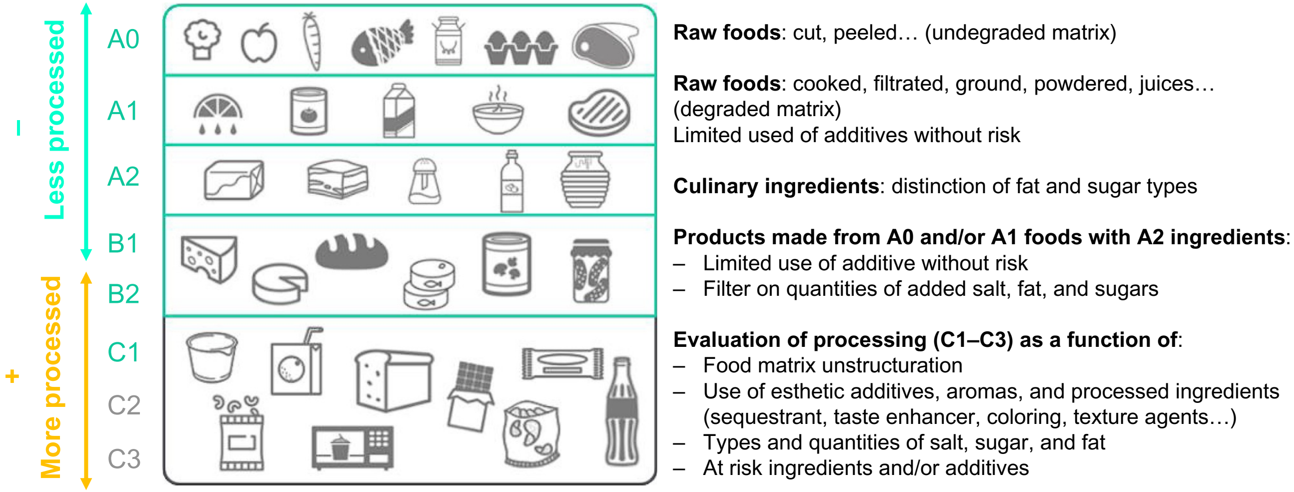


Fig. 7 The SIGA classification according to the degree of food processing.

intact raw initial matrix); A1 (un-/minimally processed foods with degraded raw matrix); A2 (culinary ingredients used at home); B1 (processed foods with added salt, sugars, and fat in proportions in agreement with official recommendations); B2 (processed foods with added salt, sugars, and fat in proportions above official recommendations); C1 (ultraprocessed foods with loose of matrix effect and/or with added unprocessed industrial ingredients and/or limited number of additives); C2 (ultraprocessed foods with loose of matrix effect and/or with added processed industrial ingredients and/or a high number of additives); C3 (ultraprocessed foods with loose of matrix effect and with added ultraprocessed industrial ingredients and/or a very high number of additives): in C group the quantity, number and function of ingredients and/or additives is also taken into consideration for dispatching foods within C1, C2, or C3.

Ultimately, the SIGA project proposes to classify food according to their degree of transformation according to holistic criteria in order to help the large distribution and the agrofood companies to improve their offer, in particular by proposing foods less transformed (change of the group C to groups A or B), or by improving their ultraprocessed products (switching of groups C3 and C2 to C1). However, one must keep in mind that, ultimately, the final objective of SIGA is not the reformulation of ultraprocessed foods to render them—in appearance—"healthier" such as in group C1 (Scrinis, 2015), but, rather, to develop a largely much higher supply in normally or minimally processed foods. Shift from C3–C2 to C1 is only a primary step.

4.3 The Need for a Quantitative Technological Index

In the future it will be also necessary to shift from qualitative to quantitative food classification according to their degree of processing through the development of a quantitative technological index (TI), including both "matrix" and "composition" effects, not only nutritional composition as it has been realized up today (Darmon et al., 2009; Drewnowski & Fulgoni, 2008). To realize it physicochemical parameters of foods in relation with food structure/matrix, and also other nutritional properties (e.g., PRAL, antioxidant, alkalinizing, satiety, and glycemic potentials or indices), should be included. In a recent study carried out on more than one hundred solid and semisolid ready-to-eat foods we showed that it is possible to include textural parameters (compression and shear stress) in addition to nutritional indices to develop a holistic TI reflecting degree of processing as compared to NOVA or SIGA qualitative classification (Fardet et al., 2018). Within the context of our selected parameters we reached the following formulae:

$\mathrm{TI} = (\mathrm{LIM} \times \mathrm{MS})/(\mathrm{NDS} \times \mathrm{SR})$

With LIM, LIM score; MS, Maximum Stress ($\mathrm{N/cm^2}$) which is the maximum force to compress food brought back to the section of the sample; NDS, Nutrient Density Score; and SR, Shear or Stress resistance ($\mathrm{N/cm^2}$) corresponds to the maximum force to cut the food into two pieces brought back to the section of the sample.

For example, the French NutriScore and other international indices developed for front-of-pack nutrition labeling, based on nutrients to encourage and those to limit in relation with recommended daily allowances, are reductionist nutritional indices which misclassify some food products in relation to health, and do not take into account added ingredients and/or additives, and the matrix effect (Crosetto, Lacroix, Muller, & Ruffieux, 2017; Julia et al., 2017). As a result, for example, traditional foods are not distinguished from industrial ones, as for traditional vs industrial delicatessen, traditional products generally not using additives.

5. FOOD PROCESSING: HOLISTIC VS REDUCTIONIST APPROACHES

5.1 Reductionism in Nutrition and Processing

5.1.1 The Nutritionism of Gyorgy Scrinis

Gyorgy Scrinis is an Australian lecturer from the University of Melbourne in the Science of Food and Nutrition Policy who authored a book entitled *Nutritionism: The Science and Politics of Dietary Advice* where the author explores how nutritional reductionism (i.e., Nutritionism) has shaped public health research and policy (Scrinis, 2013). The author divides the history of nutritional science and research into three periods:

(1) The period of "Quantifying Nutritionism" (about 1850–1950: period rather controlled by researchers). The main objective of scientists was to discover and quantify the nutrients in the food and the nutritional needs of the organism, in particular to fight diseases related to nutritional deficiencies. During this period, nutrition researchers discovered the role of carbohydrates, proteins, lipids, and vitamins. The discovery of the role of vitamins made it possible to fight illnesses that struck the population at that time, such as scurvy (due to vitamin C deficiency), xerophthalmia or dry eyes that could lead to blindness (vitamin A deficiency), beriberi (vitamin B1 deficiency), or pellagra (vitamin B3 deficiency).

Nutritional reductionism has therefore allowed saving many lives. But experts have come to consider foods as only sources of calories and macronutrients (lipids, carbohydrates, and proteins), and have compared and evaluated them on the basis of their energy content. The human body was perceived as a machine that spends energy and needs calories to function. Nutrition was perceived as simply bringing energy through food, regardless of the complexity of the food: A calorie from food A was equal to one calorie of food B and foods were easily interchangeable.

(2) The period of "Good-and-Bad Nutritionism" (began in the early 1960s: a period that was rather controlled by the government). Emphasis is placed on the nutrients to be avoided or reduced (bad) and those to be favored (good) in order to combat the development of chronic diseases. During this period, the researchers tried to understand the causes, and thus to identify the "responsible" for the development of chronic diseases. The 1970s were marked by a craze for low-carb diets (the most famous of which is the Atkins diet), and then the 1980s saw the wave of low-fat diets as if cutting down a single macronutrient could save your health. As Gyorgy Scrinis recalls, the explosion of overweight and obesity in the United States in the early 1980s coincided with the fashion of the "low-fat" diet. With this diet, we thought we were fighting against cardiovascular diseases, and that is the opposite effect we have achieved. As consumers reduced their intake of lipids, they also increased refined sugars consumption in such proportions that they increased in weight. Through this example, it can be seen that by having only a partial and reductive view of the food (here only the fat content is seen in the food), new problems are created. It is like a ball of string: you think you untangle the ball by pulling on a thread but at the same time the knots are accentuated elsewhere in the ball.

(3) The period of "Functional Nutritionism" (from the mid-1990s to the present: a period that is rather controlled by the agrofood industries). A functional food is a food that has a beneficial effect on one or more target functions of the body, so as to improve health and well-being and/or reduce the risk of disease. How did we enter the era of functional foods? Research has identified nutrients that improve a physiological function. Once the nutrient and improved function were identified, the approach was to isolate this nutrient and to enrich the usual foods with this compound. Industrialists quickly realized all the benefits they could derive from this approach. There are a multitude

> of functional foods marketed today such as margarines enriched with phytosterols, yogurts enriched with vitamin D, food fortified with fiber, and breakfast cereals enriched with vitamins and minerals. Unlike the previous period in which nutrients were finger-pointed negatively, the emphasis is instead on "positive" nutrients that are supposed to improve our health. It goes without saying that functional foods have in no way prevented the development of chronic diseases of industrialization (Fardet, 2015a, 2015b). For such purpose, it is not a food that will "save" your health but a global diet. Moreover, a function in the organism is supported by a multitude of nutrients, each nutrient generally acting on several functions (Fardet, 2017).

More recently, Gyorgy Scrinis goes even further in his analysis by showing how the nutrient approach has economically benefited from the agrofood industry (Scrinis, 2015; Scrinis & Monteiro, 2018). The health authorities, by advising to consume less sugars, salt, and fat (still a nutrient approach!), have stimulated the creativity of the agrofood industry which has begun to develop a myriad of new products. The industrialists have developed lightened, fortified, or reformulated foods and sell them by highlighting their improved health potential. But this is to forget the so-called matrix effect of foods.

5.1.2 Complex Natural Foods vs Fractionated/Recombined Foods

Nutrition reductionism that leads to fractionate foods into isolated ingredients and/or nutrients considers that a food is the only sum of nutrients (i.e., $2 = 1 + 1$) (Fardet & Rock, 2014b). Consequently, nutraceuticals, functional foods, ultraprocessed foods made of recombined ingredients and nutritional supplements are all the fruit of the reductionist thought. They are intended to improved health but they do not, as can be seen by the explosions of obesity and type 2 diabetes epidemics worldwide. The case of foods enriched with phytosterols is a good example of the reductionist paradigm applied to health (Fardet, Morise, Kalonji, Margaritis, & Mariotti, 2017).

Plant phytosterols are known to reduce blood cholesterol levels by 10%–15% (EFSA, 2012; Ras et al., 2013). And a too high level of blood cholesterol has been associated with a significantly higher risk of developing cardiovascular disease (Kritchevsky & Chen, 2005). Since phytosterols have this property, agrofood industrialists isolated them and enriched food with them at high doses. This reductionist reasoning greatly underestimates the role of the synergy of action of the constituents and presents gaps. First of all, it is not because phytosterols decrease the level of blood cholesterol that one can deduce hastily and "by transitivity" that they significantly reduce the risk of cardiovascular diseases. In addition, the daily doses of phytosterols to be ingested in order to reduce this rate of 10%–15% can reach up to 3–6 g/day, which is enormous and largely supranutritional. What is known about the long-term use of such high doses of phytosterols in 10, 20, or 30 years? Nothing. The intervention studies available are short-term studies carried out under hypercontrolled conditions that are often far from the "real" life (Fardet, Morise, et al., 2017). Worse, many have found a deleterious effect of such consumption of phytosterols, especially on the absorption of fat-soluble vitamins or their precursors such as β-carotene (carotenoid precursor of vitamin A) (Fardet, Morise, et al., 2017). Actually, phytosterols compete with these compounds, and the absorption of β-carotene may be decreased by 24% (Fardet, Morise, et al., 2017). Such a decrease may increase the risk of cardiovascular disease (Kohlmeier & Hastings, 1995; Kritchevsky, 1999; Palace, Khaper, Qin, & Singal, 1999; Voutilainen, Nurmi, Mursu, & Rissanen, 2006). For this reason, regular consumers of products fortified with phytosterols are recommended to increase their concomitant consumption of fruits and vegetables rich in carotenoids. In short, we do not get away!

5.1.3 The Reductionism Applied to the Manufacture of Cereal Products

In food technology, reductionism has led technologists to split foods and then isolate ingredients and then recombine them by adding salt, fat, simple sugars, and many additives—in order to restore their taste, color, and texture that were lost during the fractionation–recombination processes of the original foods. The manufacture of cereal products thus perfectly illustrates this process of fractionation–recombination:

- The millers split the cereals into "white" refined flours, bran, and germ;
- The starch producers fractionate the cereals in the same way but go much further in the fractionation. From the flour they also produce starch, modified starch, glucose syrup, maltodextrins, dextrose, polyols (sorbitol, mannitol, maltitol, etc.), coloring caramels, and gluten vital.

This extreme cracking of cereals led to the production of more and more white breads and a multitude of ultraprocessed cereal products, such as wholemeal soft white bread, in which the whole wheat flour is artificially reconstituted (white flour + bran) or these wholemeal wheat rusks with a quite long list of ingredients and additives (Box 3). We see here that several ingredients derived from the cracking of wheat were used to make this food. In order to give it a particular taste, appearance, and

BOX 3 Ingredients list of wholemeal wheat rusk

Wheat flour 49.77%, whole grains 40.6% (wholemeal wheat flour 32.9%, crushed whole wheat grain, malted wheat flakes), glucose–fructose syrup, palm oil, yeast, wheat germ, wheat gluten, salt, flour-treating agent (ascorbic acid), emulsifier (sunflower lecithin).

texture, they were added with salt, fat, simple sugars, and two additives (ascorbic acid, soya lecithin). This fractionation–recombination process gives rise to highly energetic cereal products, virtually devoid of protective fibers and micronutrients, cereal products of poor nutritional quality, poorly satiating, and hyperglycemic (high glycemic index).

But the ingredients derived from the cracking of cereals are not only part of the cereal products. Starch, modified starch, and gluten are used for technological purposes in many other products. Gluten is found in delicatessen, cooked meals, breaded foods, spices, soy sauce, etc. In this case, gluten is a texturing agent; it allows tying the sauces, gives a more homogeneous texture.

Otherwise reductionism affects biodiversity. To improve the quality of bread, geneticists have selected varieties of wheat that are rich in protein source of gluten. These varieties of wheat are better sold because they give bread dough that is richer in gluten, leading to more airy breads. However, such selection has considerably reduced the biodiversity of cereals, so that in France 10 varieties of wheat cover about half of the national wheat area, whereas there are more than several hundred varieties of wheat (Fardet, 2014b).

Reductionist researchers see cereals as an assemblage of starch, protein, fiber, minerals, vitamins, polyphenols, and other phytonutrients (Fardet, 2014c). As many epidemiological studies highlight the protective role of whole grains in the health of cereals, in particular with respect to cardiovascular diseases, type 2 diabetes, and certain cancers of the digestive tract, this role has been first attributed to fibers, then minerals, vitamins, and antioxidants (Fardet, 2010; Fardet & Boirie, 2014). The researchers studied these compounds one by one and associated one physiological effect with one compound. They were first interested in fibers, then with resistant starch (with digestion), with minerals like magnesium, then with phenolic acids, and with phytic acid. More recently, betaine and choline have also been considered potentially protective compounds of health (Fardet & Chardigny, 2013). Perhaps the next decade will highlight another class of cereal compounds, who knows? However, it is likely that the combination of several bioactive compounds is responsible for the protective effect of whole grains (Fardet, 2014c).

Fig. 8 is showing a diagram that models all the protective effects of cereals highlighted by reductionist research (Fardet, 2010). As you can see, these protective mechanisms are extremely complex. Unfortunately this pattern is probably still fragmentary because the reality is infinitely still more complex. This complexity can never be grasped by a reductionist approach. Here, we are dealing with the limits of reductionism. Actually, these limits are quite logical if one reflects on them:

– First, human cells are never in contact with a single bioactive compound at once, but with a cocktail of nutrients that interact and can act in synergy to have a particular health effect. This is the case for antioxidants, for example.
– The effect of a food on the body and therefore on the long term on health does not depend solely on its nutritional composition. It also depends on its physical structure, its "matrix." At similar nutritional composition, two foods of different structure do not lead to the same effect on blood glucose and satiety.
– Cereal products are rarely eaten alone. Most of the time, they are consumed within a global diet that incorporates other foods that also have effects on the body.
– Finally, it must be taken into account that humans have different levels of physical activity, that they have a different genome, and that therefore the same food may have a different effect in a given person.

Considering these different levels of complexity, one may ask why continuing to concentrate research on isolated compounds, why continuing to split the cereal grains into refined ingredients and flours and select cereal varieties based on a single criterion? It seems that we do not take the problem at the right end.

Today, some complex questions require complex answers and the research must be placed in a global and integrated perspective (Fardet & Rock, 2014b). Food and the human organism are complex entities that cannot be studied with only a reductionist approach (Fardet & Rock, 2014a, 2015). In the face of a complex issue, we must first try to respond to them through a holistic approach. Then, in a second stage, we will emerge more specific questions to which we can respond via a reductionist approach

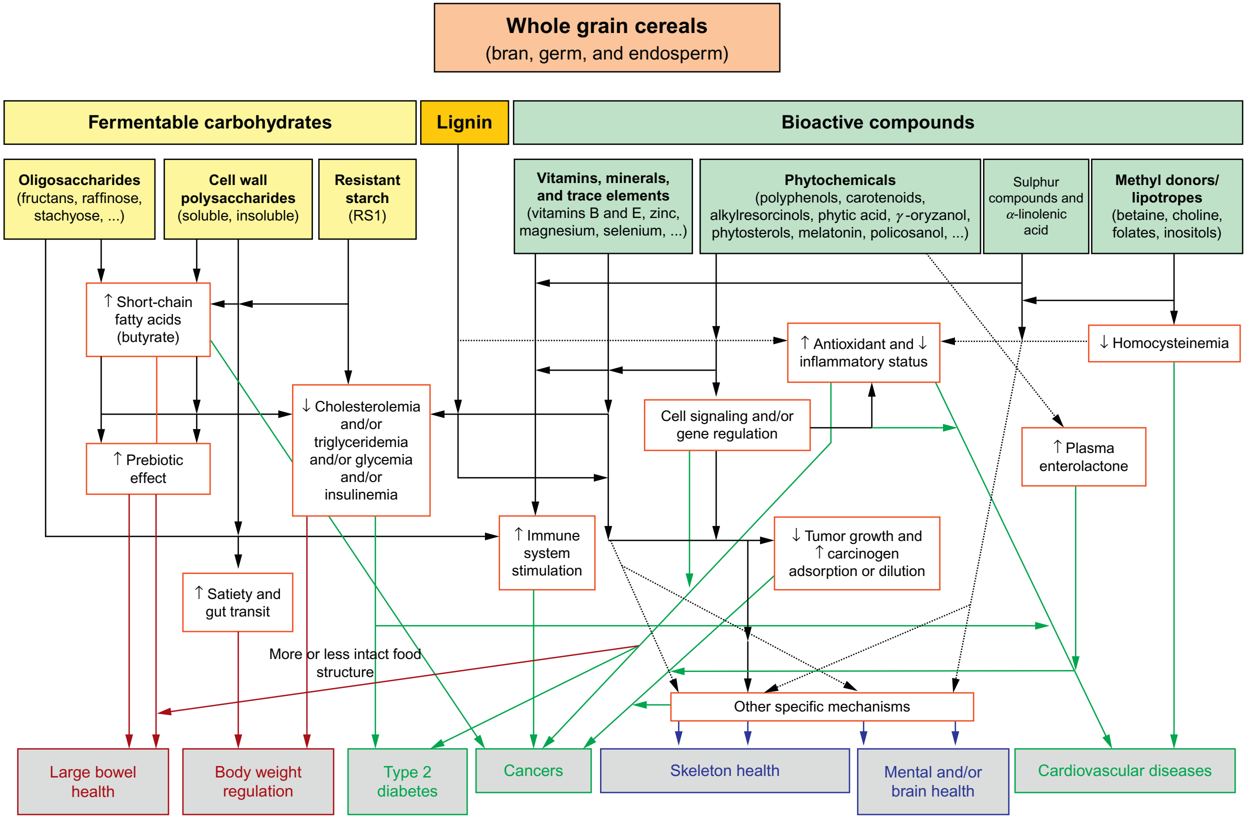


Fig. 8 Protective mechanisms of whole grain cereals as unraveled through a reductionist approach. *From Fardet, A. (2010). New hypotheses for the health-protective mechanisms of whole-grain cereals: What is beyond fibre?* Nutrition Research Reviews, 23*(1), 65–134 with permission of Cambridge University Press©.*

(Fardet & Rock, 2015). Unfortunately, for decades, in the science of cereals, research has been carried out in the opposite direction (Fardet, 2014c). Looking back, it is obvious that we have gone wrong. It is time to review the way we work and to refine our research methods.

First, whole grain cereals should be considered "packages" of nutrients and micronutrients (food package) (Fardet, 2010). In whole grain wheat, there are more than 30 compounds having an antioxidant effect, each having a specific mode of action (Fardet, 2010). It therefore seems more useful to develop the concept of "package" of antioxidants. Numerous studies show that the bioactive compounds act synergistically and that the sum of the whole does not correspond to the sum of the parts (i.e., $2 > 1 + 1$). This has been clearly demonstrated for antioxidants (Parker, Miller, Myers, Miguez, & Engeseth, 2010). The concept of "package" can be extended to antiinflammatory, anticarcinogenic, hypolipidemic, and hypoglycemic compounds. Second, on the basis of a top-down approach, it would be instructive to study the metabolic response of a whole grain cereal-based diet over a very long term compared to a refined cereal-based diet. High-throughput approaches such as metabolomics, transcriptomics, proteomics, and genomics are well suited to this type of study and would allow us to know which metabolic pathways are activated after each type of meal and how it evolves in time, as we did in the rat (Fardet et al., 2007). Such approaches without a priori are very useful for generating new research hypotheses that can then be explored further via a reductionist approaches.

A holistic approach would also involve studying the effect of cereal biodiversity. It would be interesting to study how several associated varieties of cereals influence the antioxidant status of the organism (compared to only one). A holistic approach would also involve studying the effect of food structure on health. To date, the effect of the food structure has been little studied, especially on satiety. One could compare, for example, the health effects of mueslis (flaked cereals) with those of cooked-extruded and puffed refined cereals, whole wheat bread with white bread, breads with more or less dense crumbs, etc. The literature tends to show that the more the food structure of cereal products is destroyed, the less the resulting food product is healthy (Fardet, 2014c, 2016; Fardet, Méjean, et al., 2017). The food structure also plays a role in the rate of release of nutrients into the blood, and on human health on a long term. At present time this question has been studied mainly for glucose (all the research works on the glycemic index), and less for protein, lipids, and micronutrients. It therefore deserves to be extended to these other nutrients.

5.2 Holism in Nutrition and Processing

5.2.1 The "Wholism" of Colin T. Campbell

It is amazing that when Gyorgy Scrinis published his book "Nutritionism" in Australia (Scrinis, 2013), in the United States T. Colin Campbell and Howard Jacobson published a similar reflection in "Whole: Rethinking the Science of Nutrition" (Campbell & Jacobson, 2013). T. Colin Campbell is a researcher in nutrition and biochemistry who had therefore been educated, if I may say so, in the culture of nutritional reductionism, since it is what is taught on the benches of universities and high schools. However, his researches led him to discover the health potential of a diet based on complex and little-processed plant products, called the Whole Plant-Based Diet (WPBD). With this discovery, he developed the concept of "Wholism" by making a play on words in English with "Whole" and "Holism." Some of his ideas that seem to be fundamental to improve the nutritional situation on a sustainable basis are brought here.

T. Colin Campbell understood, like Gyorgy Scrinis, that we have entered for several decades into the era of the exclusive, even dogmatic, concept of reductionism. By dogma, it is meant a truth, an assertion considered as fundamental, incontestable, and intangible by a political, philosophical, or religious authority. Here, nutritional reductionism is the truth that no longer truly accepts disputes or other visions of things. The problem stems from the fact that other points of view are no longer accepted as scientific, and that reductionism is considered "absolute truth." Yet, both approaches, reductionism and holism, must coexist harmoniously, but this is not the case today. Nutrition research, especially in the West, is essentially reductionist.

T. Colin Campbell and Howard Jacobson (Campbell & Jacobson, 2013) explain very well that we are stuck in a "vicious reductionist circle in the service of economic profit" when we should move toward a "holistic virtuous circle in the service of the humans" (Fig. 9). In the vicious reductionist circle, all research is oriented to produce short-term partial reductionist results that can be quickly exploited by the agrofood and pharmaceutical industries—but also by the medical sector as is the case in the United States Medical, e.g., equipment for hospitals. The whole system is shaped like this: it is there to heal with ever more sophisticated products in the technological processes implemented and the formulation, and the provision of adapted materials. But what motivates the system is no longer public health, it is the economy generated by a supposed correction of the precarious health of the population. There are solutions to improve the health of our fellow

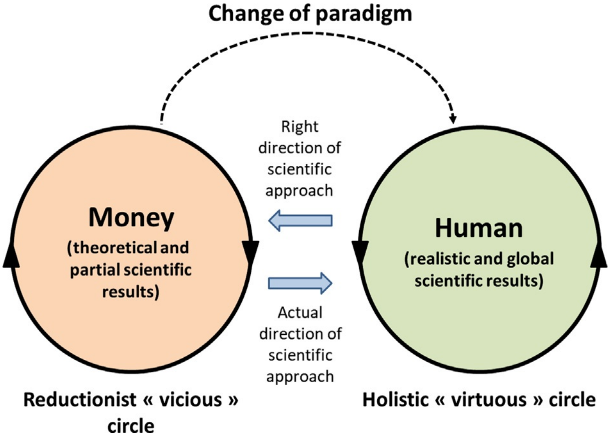


Fig. 9 Holistic and reductionist circles.

citizens in a sustainable way, but these holistic solutions do not really interest the three actors mentioned earlier. Thus, promoting a plant-based diet—such as focusing on the degree of food processing—does not interest these industries because it is synonymous with less profits. Adhering to the low-processed plant regime is a holistic, healthy, and sustainable solution for our planet, but if people adhere to it, rates of industrialization disease will decline, people will get better, they will buy less processed food, they will have less need to buy functional foods and get treatment. The irony is that even in scientific research, massive funding will be given priority to reductionist research that fuels the system: there is little room for holistic scientific projects. Why? Because reductionist research will produce results that are immediately exploitable by the industry and can therefore be converted into profit and innovation. Even the decision-making bodies that allocate funds for research projects are reductionist and prefer to finance reductionist projects that sound more "scientific" and "more brilliant." The researchers themselves have also entered, without necessarily being aware of it, in this vicious circle, to be promoted, to have funds, to be able to publish their work in the most prestigious scientific journals. Yet, Nalin Chandra Wickramasinghe, an eminent professor of applied mathematics and astronomy at Buckingham University, explains that we have entered an era in which cross-disciplinary and generalist researchers are sorely lacking (Wickramasinghe & Ikeda, 2011). One could compare the situation to a piece of tissue that is held by the presence of horizontal and vertical fibers in a tight mesh: hyperspecialized reductionist researchers would then correspond to the vertical mesh, while generalist holistic researchers would correspond to the horizontal mesh. Today the mesh size is low because of the preponderance of vertical fibers, the reductionist researchers.

On the other hand, as T. Colin Campbell also points out, reductionism has led to considering preventive nutrition from a pharmacological perspective and nutrients much like drugs that could be isolated and administered in high doses. The pattern of nutritional intervention studies in humans is modeled on that of pharmacological studies, i.e., randomized controlled trials, which certainly allow a very good control of the conditions of the study (and thus isolate the only effect of the nutritional factor studied), but which are far removed from the "real" life. It is not surprising that these controlled randomized studies produce only minor and often contradictory effects: the underlying postulate being partial, it can produce only partial results that cannot be extrapolated. We are a bit like those blind people who want to explain the whole elephant from its ear, paw, or trunk. And yet industrialists give immense credit to these studies to market functional foods or food supplements. They do it most often without even taking the time to study the effect of these products over the long term.

Besides, there is only to find that the EFSA Panel on dietetic products, nutrition, and allergies rejected most of the health claims petitions due to lack of enough scientific evidences. According to my opinion, such a reject indirectly reflects the limits of reductionist nutrition producing only partial and contradictory results.

5.2.2 From a Reductionist Vicious Circle to a Holistic Virtuous Circle

T. Colin Campbell therefore maintains that it is necessary to move from a vicious reductionist circle in favor of money to a holistic virtuous circle for the benefit of humans (Fig. 9). For this, it is a whole paradigm (or "software") that must be changed.

Finally, T. Colin Campbell and Howard Jacobson (Campbell & Jacobson, 2013) developed another analysis: in the reductionist approach, solutions appear magical, easy, infallible, and rapid; in the holistic approach, the solutions are realistic, take time to be elaborated, are complex, and require efforts to be implemented. Why? Because reductionism focuses on partially correcting effects, while holism arrests root causes of negative effects over the long term and does not exacerbate the situation.

6. CONCLUSIONS AND PERSPECTIVES

Processing is indispensable. It allows producing safe, edible, tasty, and healthy foods. However, ultraprocessing is less indispensable because it globally produces unhealthy foods, except in some cases for special nutritional purposes, e.g., designed foods for sportsmen, ill people, some elderly populations, or simply for some occasion where we need to eat rapidly with practical foods or for special social events such as festive events. But these foods should not be the norm. In addition, fractionating or cracking natural complex foods, then reassembling nutrients and ingredients is energy consuming and not really sustainable, and with a disappointing result. Yet we are progressively entering or coming back to an era of minimal processing based on ancient traditional processes such as prefermentation, soaking, sprouting, and more modern ones such as the use of ultraviolet-C, modified atmospheres, heat shocks, and ozone treatments.

Populations worldwide are more and more unhealthy with dramatic increase in epidemics of obesity, type 2 diabetes, and cardiovascular diseases to the point that these chronic diseases are today more prominent in some emerging and developing countries than infectious diseases. Science is clear on this point: diets rich in animal-based and ultraprocessed foods calories are unhealthy and all associated with increased risk of industrialization diseases; and all diet based on minimally processed plant-based foods calories are healthy and protective.

Therefore, the future of researches in processing and nutrition should move toward more holistic approaches, notably by investigating the effect of minimal processing and plant-based foods on health in subjects followed in real-life conditions. This is not to say that reductionism is useless, but instead that it should enroll in the framework of holistic scientific issues.

REFERENCES

Alexander, D., Mink, P., Cushing, C., & Sceurman, B. (2010). A review and meta-analysis of prospective studies of red and processed meat intake and prostate cancer. *Nutrition Journal*, *9*, 50. https://doi.org/10.1186/1475-2891-9-50.

Alexander, D. D., Morimoto, L. M., Mink, P. J., & Cushing, C. A. (2010). A review and meta-analysis of red and processed meat consumption and breast cancer. *Nutrition Research Reviews*, *23*(02), 349–365.

ANSES-Afssa, Centre d'information sur la qualité des aliments (2008). Table CIQUAL. Composition nutritionnelle des aliments.

Aune, D., Chan, D. S. M., Lau, R., Vieira, R., Greenwood, D. C., Kampman, E., et al. (2011). Dietary fibre, whole grains, and risk of colorectal cancer: Systematic review and dose-response meta-analysis of prospective studies. *BMJ*, *343*, d6617.

Aune, D., Chan, D. S. M., Vieira, A. R., Rosenblatt, D. A. N., Vieira, R., Greenwood, D. C., et al. (2013). Red and processed meat intake and risk of colorectal adenomas: A systematic review and meta-analysis of epidemiological studies. *Cancer Causes & Control*, *24*(4), 611–627.

Aune, D., Keum, N., Giovannucci, E., Fadnes, L., Boffetta, P., Greenwood, D. C., et al. (2016). Whole grain consumption and the risk of cardiovascular disease, cancer, and all-cause and cause-specific mortality—A systematic review and dose-response meta-analysis of prospective studies. *BMJ*, *353*, i2716.

Aune, D., Norat, T., Romundstad, P., & Vatten, L. J. (2013). Whole grain and refined grain consumption and the risk of type 2 diabetes: A systematic review and dose-response meta-analysis of cohort studies. *European Journal of Epidemiology*, *28*(11), 845–858.

Baker, P., Kay, A., & Walls, H. (2014). Trade and investment liberalization and Asia's non-communicable disease epidemic: A synthesis of data and existing literature. *Globalization and Health*, *10*, 66.

Barcelos, G. T., Rauber, F., & Vitolo, M. R. (2014). Produtos processados e ultraprocessados e ingestão de nutrientes em crianças. *Revista Ciência & Saúde*, 7(3), 155–161.

Becerra-Tomás, N., Babio, N., Martínez-González, M. Á., Corella, D., Estruch, R., Ros, E., et al. (2016). Replacing red meat and processed red meat for white meat, fish, legumes or eggs is associated with lower risk of incidence of metabolic syndrome. *Clinical Nutrition*, *35*(6), 1442–1449.

Bielemann, R. M., Santos Motta, J. V., Minten, G. C., Horta, B. L., & Gigante, D. P. (2015). Consumption of ultra-processed foods and their impact on the diet of young adults. *Revista de Saude Publica*, *49*, 28.

Campbell, C. T., & Jacobson, H. (2013). *Whole: Rethinking the science of nutrition*. Dallas, Texas, USA: BenBella Books352 pages.

Canella, D. S., Levy, R. B., Martins, A. P. B., Claro, R. M., Moubarac, J. C., Baraldi, L. G., et al. (2014). Ultra-processed food products and obesity in Brazilian households (2008–2009). *PLoS One*, *9*(3), e92752.

Carlsen, M. H., Halvorsen, B. L., Holte, K., Bøhn, S. K., Dragland, S., Sampson, L., et al. (2010). The total antioxidant content of more than 3100 foods, beverages, spices, herbs and supplements used worldwide. *Nutrition Journal*, *9*(1), 3.

Chambers, L. (2016). Food texture and the satiety cascade. *Nutrition Bulletin*, *41*(3), 277–282.

Chan, D. S. M., Lau, R., Aune, D., Vieira, R., Greenwood, D. C., Kampman, E., et al. (2011). Red and processed meat and colorectal cancer incidence: Meta-analysis of prospective studies. *PLoS One*, *6*(6), e20456.

Chanson-Rolle, A., Meynier, A., Aubin, F., Lappi, J., Poutanen, K., Vinoy, S., et al. (2015). Systematic review and meta-analysis of human studies to support a quantitative recommendation for whole grain intake in relation to type 2 diabetes. *PLoS One*, *10*(6), e0131377.

Chen, G. C., Lv, D. B., Pang, Z., & Liu, Q. F. (2013). Red and processed meat consumption and risk of stroke: A meta-analysis of prospective cohort studies. *European Journal of Clinical Nutrition*, *67*(1), 91–95.

Cho, S. S., Qi, L., Fahey, G. C., & Klurfeld, D. M. (2013). Consumption of cereal fiber, mixtures of whole grains and bran, and whole grains and risk reduction in type 2 diabetes, obesity, and cardiovascular disease. *American Journal of Clinical Nutrition*, *98*(2), 594–619.

Choi, Y., Song, S., Song, Y., & Lee, J. E. (2013). Consumption of red and processed meat and esophageal cancer risk: Meta-analysis. *World Journal of Gastroenterology*, *19*(7), 1020–1029.

Cordain, L. (2002). The nutritional characteristics of a contemporary diet based upon Paleolithic food groups. *JANA—Journal of American Nutraceutical Association*, *5*(3), 15–24.

Costa, J. C., Claro, R. M., Martins, A. P., & Levy, R. B. (2013). Food purchasing sites. Repercussions for healthy eating. *Appetite*, *70*, 99–103.

Crosetto, P., Lacroix, A., Muller, L., & Ruffieux, B. (2017). Modification des achats alimentaires en réponse à cinq logos nutritionnels. *Cahiers de Nutrition et de Dietetique*, *52*, 129–133.

Crovetto, M. M., Uauy, R., Martins, A. P., Moubarac, J. C., & Monteiro, C. (2014). Household availability of ready-to-consume food and drink products in Chile: Impact on nutritional quality of the diet. *Revista Médica de Chile*, *142*(7), 850–858.

Dalmau, M. E., Bornhorst, G. M., Eim, V., Rosselló, C., & Simal, S. (2017). Effects of freezing, freeze drying and convective drying on in vitro gastric digestion of apples. *Food Chemistry*, *215*, 7–16.

Darmon, N., & Drewnowski, A. (2015). Contribution of food prices and diet cost to socioeconomic disparities in diet quality and health: A systematic review and analysis. *Nutrition Reviews*, *73*, 643–660.

Darmon, N., Vieux, F., Maillot, M., Volatier, J.-L., & Martin, A. (2009). Nutrient profiles discriminate between foods according to their contribution to nutritionally adequate diets: A validation study using linear programming and the SAIN, LIM system. *American Journal of Clinical Nutrition*, *89*(4), 1227–1236.

de Paula Franco Franco, E., Rosa, G., Luiz, R. R., & Oliveira, G. M. M. D. (2015). Assessment of the quality of hypoenergetic diet in overweight women. *International Journal of Cardiovascular Science*, *28*(3), 244–250.

Drewnowski, A., & Fulgoni, V. (2008). Nutrient profiling of foods: Creating a nutrient-rich food index. *Nutrition Reviews*, *66*(1), 23–39.

Drewnowski, A., & Popkin, B. M. (1997). The nutrition transition: New trends in the global diet. *Nutrition Reviews*, *55*(2), 31–43.

EFSA. (2012). Scientific opinion of the panel on dietetic products, nutrition and allergies on a request from Unilever PLC and Unilever NV, related to the scientific substantiation of a health claim related to 3 g/day plant sterols/stanols and lowering blood LDL-cholesterol and reduced risk of (coronary) heart disease pursuant to article 19 of regulation (EC) No 1924/2006. *The EFSA Journal*, *10*(5), 2693.

Esmaillzadeh, A., Mirmiran, P., & Azizi, F. (2005). Whole-grain consumption and the metabolic syndrome: A favorable association in Tehranian adults. *European Journal of Clinical Nutrition*, *59*(3), 353–362.

Fardet, A. (2010). New hypotheses for the health-protective mechanisms of whole-grain cereals: What is beyond fibre? *Nutrition Research Reviews*, *23*(1), 65–134.

Fardet, A. (2014a). Foods and health potential: Is food engineering the key issue? *Journal of Nutritional Health & Food Engineering*, *1*(4), 1–2.

Fardet, A. (2014b). How can both the health potential and sustainability of cereal products be improved? A French perspective. *Journal of Cereal Science*, *60*(3), 540–548.

Fardet, A. (2014c). New approaches to studying the potential health benefits of cereals: From reductionism to holism. *Cereal Foods World*, *59*(5), 224–229.

Fardet, A. (2015a). Complex foods versus functional foods, nutraceuticals and dietary supplements: Differential health impact (part 1). *Agro Food Industry Hi-Tech*, *26*(1), 20–24.

Fardet, A. (2015b). Complex foods versus functional foods, nutraceuticals and dietary supplements: Differential health impact (part 2). *Agro Food Industry Hi-Tech*, *26*(3), 20–22.

Fardet, A. (2015c). A shift toward a new holistic paradigm will help to preserve and better process grain product food structure for improving their health effects. *Food & Function*, *6*(2), 363–382.

Fardet, A. (2016). Minimally processed foods are more satiating and less hyperglycemic than ultra-processed foods: A preliminary study with 98 ready-to-eat foods. *Food & Function*, *7*(5), 2338–2346.

Fardet, A. (2017). Chapter 16—New concepts and paradigms for the protective effects of plant-based food components in relation to food complexity. In F. Mariotti (Ed.), *Vegetarian and plant-based diets in health and disease prevention* (pp. 293–312). San Diego: Elsevier/Education, Reference and Continuity.

Fardet, A., & Boirie, Y. (2014). Associations between food and beverage groups and major diet-related chronic diseases: An exhaustive review of pooled/meta-analyses and systematic reviews. *Nutrition Reviews*, *72*(12), 741–762. https://doi.org/10.1111/nure.12153.

Fardet, A., Canlet, C., Gottardi, G., Lyan, B., Remesy, C., Mazur, A., et al. (2007). Whole grain and refined wheat flours show distinct metabolic profiles in rats as assessed by a 1H NMR-based metabonomic approach. *Journal of Nutrition*, *137*(4), 923–929.

Fardet, A., & Chardigny, J.-M. (2013). Plant-based foods as a source of lipotropes for human nutrition: A survey of in vivo studies. *Critical Reviews in Food Science and Nutrition*, *53*(6), 535–590.

Fardet, A., Lakhssassi, S., & Briffaz, A. (2018). Beyond nutritional-based food indices: A data mining approach to search for a quantitative holistic index reflecting the degree of food processing and including physicochemical properties. *Foods & Function*, *9*, 561–572.

Fardet, A., Martin, J.-F., & Chardigny, J.-M. (2011a). Thermal and refining processes, not fermentation, tend to reduce lipotropic capacity of plant-based foods. *Food & Function*, *2*(8), 483–504.

Fardet, A., Martin, J.-F., & Chardigny, J. M. (2011b). Lipotropic capacity of raw plant-based foods: A new index that reflects their lipotrope density profile. *Journal of Food Composition and Analysis*, *24*(6), 895–915.

Fardet, A., Méjean, C., Labouré, H., Andreeva, V. A., & Féron, G. (2017). The degree of processing of foods which are most widely consumed by the french elderly population is associated with satiety and glycemic potentials and nutrient profiles. *Food & Function*, *8*(2), 651–658.

Fardet, A., Morise, A., Kalonji, E., Margaritis, I., & Mariotti, F. (2017). Influence of phytosterol and phytostanol food supplementation on plasma liposoluble vitamins and provitamin A carotenoid levels in humans: An updated review of the evidence. *Critical Reviews in Food Science and Nutrition*, *57*(9), 1906–1921.

Fardet, A., & Rock, E. (2014a). The search for a new paradigm to study micronutrient and phytochemical bioavailability: From reductionism to holism. *Medical Hypotheses*, *82*(2), 181–186.

Fardet, A., & Rock, E. (2014b). Toward a new philosophy of preventive nutrition: From a reductionist to a holistic paradigm to improve nutritional recommendations. *Advances in Nutrition*, *5*(4), 430–446.

Fardet, A., & Rock, E. (2015). From a reductionist to a holistic approach in preventive nutrition to define new and more ethical paradigms. *Healthcare*, *3*(4), 1054–1063.

Fardet, A., Rock, E., Bassama, J., Bohuon, P., Prabhasankar, P., Monteiro, C., et al. (2015). Current food classifications in epidemiological studies do not enable solid nutritional recommendations to prevent diet-related chronic diseases: The impact of food processing. *Advances in Nutrition*, *6*(6), 629–638.

Fardet, A., Souchon, I., & Dupont, D. (2013). *Structure des aliments et effets nutritionnels* (1st ed.). Versailles: Quae.

Food and Agriculture Organization of the United Nations. (2015). *Guidelines on the collection of information on food processing through food consumption surveys*. Rome. http://www.fao.org/3/a-i4690e.pdf.

Foster-Powell, K., Holt, S. H., & Brand-Miller, J. C. (2002). International table of glycemic index and glycemic load values: 2002. *American Journal of Clinical Nutrition*, *76*(1), 5–56.

Gartner, C., Stahl, W., & Sies, H. (1997). Lycopene is more bioavailable from tomato paste than from fresh tomatoes. *American Journal of Clinical Nutrition*, *66*(1), 116–122.

Glinsmann, W. H., Irausquin, H., & Park, Y. K. (1986). Evaluation of health aspects of sugars contained in carbohydrate sweeteners: Report of sugars task force, 1986. *The Journal of Nutrition*, *116*(11 Suppl), S1–216.

Granfeldt, Y., Bjorck, I., & Hagander, B. (1991). On the importance of processing conditions, product thickness and egg addition for the glycaemic and hormonal responses to pasta: A comparison with bread made from 'pasta ingredients'. *European Journal of Clinical Nutrition*, *45*(10), 489–499.

Grundy, M. M. L., Wilde, P. J., Butterworth, P. J., Gray, R., & Ellis, P. R. (2015). Impact of cell wall encapsulation of almonds on in vitro duodenal lipolysis. *Food Chemistry*, *185*, 405–412.

Haber, G. B., Heaton, K. W., Murphy, D., & Burroughs, L. F. (1977). Depletion and disruption of dietary fibre. Effects on satiety, plasma-glucose, and serum-insulin. *Lancet*, *2*(8040), 679–682.

Holt, S. H., & Miller, J. B. (1994). Particle size, satiety and the glycaemic response. *European Journal of Clinical Nutrition*, *48*(7), 496–502.

Holt, S. H., Miller, J. C., Petocz, P., & Farmakalidis, E. (1995). A satiety index of common foods. *European Journal of Clinical Nutrition*, *49*(9), 675–690.

Huang, W., Han, Y., Xu, J., Zhu, W., & Li, Z. (2013). Red and processed meat intake and risk of esophageal adenocarcinoma: A meta-analysis of observational studies. *Cancer Causes & Control*, *24*(1), 193–201.

IARC Working Group, & International Agency for Research on Cancer. (2015). *Consumption of red meat and processed meat*. IARC. Monographs, Press Release No 240.

Imamura, F., O'Connor, L., Ye, Z., Mursu, J., Hayashino, Y., Bhupathiraju, S. N., et al. (2016). Consumption of sugar sweetened beverages, artificially sweetened beverages, and fruit juice and incidence of type 2 diabetes: Systematic review, meta-analysis, and estimation of population attributable fraction. *British Journal of Sports Medicine*, *50*(8), 496–504.

Julia, C., et al. (2018). Contribution of ultra-processed foods in the diet of adults from the French NutriNet-Santé study. *Public Health Nutrition*, *21*(1), 27–37.

Julia, C., Péneau, S., Buscail, C., Gonzalez, R., Touvier, M., Hercberg, S., et al. (2017). Perception of different formats of front-of-pack nutrition labels according to sociodemographic, lifestyle and dietary factors in a French population: Cross-sectional study among the NutriNet-Santé cohort participants. *BMJ Open*, *7*(6), e016108.

Juul, F., & Hemmingsson, E. (2015). Trends in consumption of ultra-processed foods and obesity in Sweden between 1960 and 2010. *Public Health Nutrition*, *18*(17), 3096–3107.

Kohlmeier, L., & Hastings, S. B. (1995). Epidemiologic evidence of a role of carotenoids in cardiovascular disease prevention. *American Journal of Clinical Nutrition*, *62*(6 Suppl), 1370S–1376S.

Kritchevsky, S. B. (1999). Beta-carotene, carotenoids and the prevention of coronary heart disease. *Journal of Nutrition*, *129*(1), 5–8.

Kritchevsky, D., & Chen, S. C. (2005). Phytosterols—Health benefits and potential concerns: A review. *Nutrition Research*, *25*(5), 413–428.

Larsson, S. C., & Wolk, A. (2012). Red and processed meat consumption and risk of pancreatic cancer: Meta-analysis of prospective studies. *British Journal of Cancer*, *106*(3), 603–607.

Leite, F. H., Oliveira, M. A., Cremm, E. C., Abreu, D. S., Maron, L. R., & Martins, P. A. (2012). Availability of processed foods in the perimeter of public schools in urban areas. *Jornal de Pediatria*, *88*(4), 328–334.

Li, B. L., Zhang, G. X., Tan, M. W., Zhao, L. B., Jin, L., Tang, X. J., et al. (2016). Consumption of whole grains in relation to mortality from all causes, cardiovascular disease, and diabetes dose-response meta-analysis of prospective cohort studies. *Medicine*, *95*(33), e4229.

Liu, J., Tang, W., Sang, L., Dai, X., Wei, D., Luo, Y., et al. (2015). Milk, yogurt, and lactose intake and ovarian cancer risk: A meta-analysis. *Nutrition and Cancer*, *67*(1), 68–72.

Louzada, M. L., Baraldi, L. G., Steele, E. M., Martins, A. P., Canella, D. S., Moubarac, J. C., et al. (2015). Consumption of ultra-processed foods and obesity in Brazilian adolescents and adults. *Preventive Medicine*, *81*, 9–15.

Louzada, M. L., Martins, A. P., Canella, D. S., Baraldi, L. G., Levy, R. B., Claro, R. M., et al. (2015a). Impact of ultra-processed foods on micronutrient content in the Brazilian diet. *Revista de Saude Publica*, *49*, 1–8.

Louzada, M. L., Martins, A. P., Canella, D. S., Baraldi, L. G., Levy, R. B., Claro, R. M., et al. (2015b). Ultra-processed foods and the nutritional dietary profile in Brazil. *Revista de Saude Publica*, *49*, 38.

Luiten, C. M., Steenhuis, I. H., Eyles, H., Ni Mhurchu, C., & Waterlander, W. E. (2016). Ultra-processed foods have the worst nutrient profile, yet they are the most available packaged products in a sample of New Zealand supermarkets. *Public Health Nutrition*, *19*(3), 530–538.

Lutsey, P. L., Jacobs, D. R., Kori, S., Mayer-Davis, E., Shea, S., Steffen, L. M., et al. (2007). Whole grain intake and its cross-sectional association with obesity, insulin resistance, inflammation, diabetes and subclinical CVD: The MESA study. *British Journal of Nutrition*, *98*(02), 397–405.

Mallarino, C., Gomez, L. F., Gonzalez-Zapata, L., Cadena, Y., & Parra, D. C. (2013). Advertising of ultra-processed foods and beverages: Children as a vulnerable population. *Revista de Saude Publica*, *47*(5), 1006–1010.

Mandalari, G., Faulks, R. M., Rich, G. T., Lo Turco, V., Picout, D. R., Lo Curto, R. B., et al. (2008). Release of protein, lipid, and vitamin E from almond seeds during digestion. *Journal of Agricultural and Food Chemistry*, *56*(9), 3409–3416.

Martínez Steele, E., Baraldi, L. G., Louzada, M. L. D. C., Moubarac, J.-C., Mozaffarian, D., & Monteiro, C. A. (2016). Ultra-processed foods and added sugars in the US diet: Evidence from a nationally representative cross-sectional study. *BMJ Open*, *6*(3), e009892.

Martínez Steele, E., Popkin, B. M., Swinburn, B., & Monteiro, C. A. (2017). The share of ultra-processed foods and the overall nutritional quality of diets in the US: Evidence from a nationally representative cross-sectional study. *Population Health Metrics*, *15*(1), 6.

Martins, A. P. B., Levy, R. B., Claro, R. M., Moubarac, J. C., & Monteiro, C. A. (2013). Increased contribution of ultra-processed food products in the Brazilian diet (1987–2009). *Revista de Saude Publica*, *47*(4), 656–665.

Marventano, S., Vetrani, C., Vitale, M., Godos, J., Riccardi, G., & Grosso, G. (2017). Whole grain intake and glycaemic control in healthy subjects: A systematic review and meta-analysis of randomized controlled trials. *Nutrients*, *9*(7), 769.

McGill, A.-T. (2014). The sugar debate and nutrition: Obesity and 'empty calories'. *The New Zealand Medical Journal*, *127*(1392), 6–11.

Mellen, P. B., Walsh, T. F., & Herrington, D. M. (2008). Whole grain intake and cardiovascular disease: A meta-analysis. *Nutrition, Metabolism and Cardiovascular Diseases*, *18*(4), 283–290.

Micha, R., Wallace, S. K., & Mozaffarian, D. (2010). Red and processed meat consumption and risk of incident coronary heart disease, stroke, and diabetes mellitus a systematic review and meta-analysis. *Circulation*, *121*(21), 2271–2283.

Ministry of Health of Brazil, Secretariat of Health Care, & Primary Health Care Department. (2014). *Dietary guidelines for the Brazilian population*. São Paulo: Editora Senac.

Monteiro, C. A. (2009). Nutrition and health. The issue is not food, nor nutrients, so much as processing. *Public Health Nutrition*, *12*(05), 729–731.

Monteiro, C. A., & Cannon, G. (2012). The impact of transnational "big food" companies on the south: A view from Brazil. *PLoS Medicine*, *9*(7), e1001252.

Monteiro, C., Cannon, G., Levy, R. B., et al. (2016). The star shines bright. *World Nutrition*, *7*(1–3), 28–38.

Monteiro, C. A., Cannon, G., Moubarac, J.-C., Levy, R. B., Louzada, M. L. C., & Jaime, P. C. (2018). The UN decade of nutrition, the NOVA food classification and the trouble with ultra-processing. *Public Health Nutrition*, *21*, 5–17. https://doi.org/10.1017/S1368980017000234.

Monteiro, C. A., Cannon, G., Moubarac, J. C., Martins, A. P., Martins, C. A., Garzillo, J., et al. (2015). Dietary guidelines to nourish humanity and the planet in the twenty-first century. A blueprint from Brazil. *Public Health Nutrition*, *18*(13), 2311–2322.

Monteiro, C. A., Levy, R. B., Claro, R. M., de Castro, I. R. R., & Cannon, G. (2010). A new classification of foods based on the extent and purpose of their processing. *Cadernos de Saúde Pública*, *26*(11), 2039–2049.

Monteiro, C. A., Levy, R. B., Claro, R. M., de Castro, I. R. R., & Cannon, G. (2011). Increasing consumption of ultra-processed foods and likely impact on human health: Evidence from Brazil. *Public Health Nutrition*, *14*(1), 5–13.

Monteiro, C. A., Moubarac, J. C., Cannon, G., Ng, S. W., & Popkin, B. (2013). Ultra-processed products are becoming dominant in the global food system. *Obesity Reviews*, *14*(Suppl. 2), 21–28.

Monteiro, C. A., Moubarac, J.-C., Levy, R. B., Canella, D. S., Louzada, M. L. D. C., & Cannon, G. (2018). Household availability of ultra-processed foods and obesity in nineteen European countries. *Public Health Nutrition*, *21*, 18–26. https://doi.org/10.1017/S1368980017001379.

Moodie, R., Stuckler, D., Monteiro, C., Sheron, N., Neal, B., Thamarangsi, T., et al. (2013). Profits and pandemics: Prevention of harmful effects of tobacco, alcohol, and ultra-processed food and drink industries. *Lancet*, *381*(9867), 670–679.

Moorhead, S. A., Welch, R. W., Barbara, M., Livingstone, E., McCourt, M., Burns, A. A., et al. (2006). The effects of the fibre content and physical structure of carrots on satiety and subsequent intakes when eaten as part of a mixed meal. *British Journal of Nutrition*, *96*(3), 587–595.

Moreira, P. V. L., Baraldi, L. G., Moubarac, J.-C., Monteiro, C. A., Newton, A., Capewell, S., et al. (2015). Comparing different policy scenarios to reduce the consumption of ultra-processed foods in UK: Impact on cardiovascular disease mortality using a modelling approach. *PLoS One*, *10*(2), e0118353.

Moubarac, J.-C., Batal, M., Louzada, M. L., Martinez Steele, E., & Monteiro, C. A. (2016). Consumption of ultra-processed foods predicts diet quality in Canada. *Appetite*, *108*, 512–520.

Moubarac, J. C., Batal, M., Martins, A. P., Claro, R., Levy, R. B., Cannon, G., et al. (2014). Processed and ultra-processed food products: Consumption trends in Canada from 1938 to 2011. *Canadian Journal of Dietetic Practice and Research*, *75*(1), 15–21.

Moubarac, J. C., Claro, R. M., Baraldi, L. G., Levy, R. B., Martins, A. P., Cannon, G., et al. (2013). International differences in cost and consumption of ready-to-consume food and drink products: United Kingdom and Brazil, 2008–2009. *Global Public Health*, *8*(7), 845–856.

Moubarac, J. C., Martins, A. P. B., Claro, R. M., Levy, R. B., Cannon, G., & Monteiro, C. A. (2013). Consumption of ultra-processed foods and likely impact on human health. Evidence from Canada. *Public Health Nutrition*, *16*(12), 2240–2248.

Moubarac, J.-C., Parra, D. C., Cannon, G., & Monteiro, C. A. (2014). Food classification systems based on food processing: Significance and implications for policies and actions: A systematic literature review and assessment. *Current Obesity Reports*, *3*(2), 256–272.

National Institute of Nutrition. (2017). *Indian food composition tables*. Hyderabad, India.

Nettleton, J. A., McKeown, N. M., Kanoni, S., Lemaitre, R. N., Hivert, M.-F., Ngwa, J., et al. (2010). Interactions of dietary whole-grain intake with fasting glucose- and insulin-related genetic loci in individuals of European descent a meta-analysis of 14 cohort studies. *Diabetes Care*, *33*(12), 2684–2691.

Palace, V. P., Khaper, N., Qin, Q. I., & Singal, P. K. (1999). Antioxidant potentials of vitamin A and carotenoids and their relevance to heart disease. *Free Radical Biology and Medicine*, *26*(5–6), 746–761.

Pan American Health Organization. (2015). *Ultra-processed food and drink products in Latin America: Trends, impact on obesity, policy implications*. Washington, DC.

Parker, T. L., Miller, S. A., Myers, L. E., Miguez, F. E., & Engeseth, N. J. (2010). Evaluation of synergistic antioxidant potential of complex mixtures using oxygen radical absorbance capacity (ORAC) and electron paramagnetic resonance (EPR). *Journal of Agricultural and Food Chemistry*, *58*(1), 209–217.

Piquet, F. (2012). *Guide de l'équilibre acide-base*. Vergèze: Thierry Souccar Editions.

Pol, K., Christensen, R., Bartels, E. M., Raben, A., Tetens, I., & Kristensen, M. (2013). Whole grain and body weight changes in apparently healthy adults: A systematic review and meta-analysis of randomized controlled studies. *American Journal of Clinical Nutrition*, *98*(4), 872–884.

Qi-Qi, M., Yun, D., Yi-Wei, L., Jie, Q., Li-Ping, X., & Xiang-Yi, Z. (2011). Milk consumption and bladder cancer risk: A meta-analysis of published epidemiological studies. *Nutrition and Cancer*, *63*(8), 1263–1271.

Ras, R. T., Hiemstra, H., Lin, Y., Vermeer, M. A., Duchateau, G. S. M. J. E., & Trautwein, E. A. (2013). Consumption of plant sterol-enriched foods and effects on plasma plant sterol concentrations—A meta-analysis of randomized controlled studies. *Atherosclerosis*, *230*(2), 336–346.

Rauber, F., Campagnolo, P. D. B., Hoffman, D. J., & Vitolo, M. R. (2015). Consumption of ultra-processed food products and its effects on children's lipid profiles: A longitudinal study. *Nutrition Metabolism and Cardiovascular Diseases*, *25*(1), 116–122.

Rémésy, C., Leenhardt, F., & Fardet, A. (2015). Donner un nouvel avenir au pain dans le cadre d'une alimentation durable et préventive. *Cahiers de Nutrition et de Dietetique*, *50*(1), 39–46.

Rizkalla, S. W., Laromiguiere, M., Champ, M., Bruzzo, F., Boillot, J., & Slama, G. (2007). Effect of baking process on postprandial metabolic consequences: Randomized trials in normal and type 2 diabetic subjects. *European Journal of Clinical Nutrition*, *61*(2), 175–183.

Rouhani, M. H., Salehi-Abargouei, A., Surkan, P. J., & Azadbakht, L. (2014). Is there a relationship between red or processed meat intake and obesity? A systematic review and meta-analysis of observational studies. *Obesity Reviews*, *15*(9), 740–748.

Sahyoun, N. R., Jacques, P. F., Zhang, X. L., Juan, W., & McKeown, N. M. (2006). Whole-grain intake is inversely associated with the metabolic syndrome and mortality in older adults. *American Journal of Clinical Nutrition*, *83*(1), 124–131.

Satija, A., Bhupathiraju, S. N., Spiegelman, D., Chiuve, S. E., Manson, J. E., Willett, W., et al. (2017). Healthful and unhealthful plant-based diets and the risk of coronary heart disease in U.S. adults. *Journal of the American College of Cardiology*, *70*(4), 411–422.

Scrinis, G. (2013). *Nutritionism—The science and politics of dietary advice*. New York: Columbia University Press.

Scrinis, G. (2015). Reformulation, fortification and functionalization: Big food corporations' nutritional engineering and marketing strategies. *The Journal of Peasant Studies*, *43*(1), 17–37.

Scrinis, G., & Monteiro, C. A. (2018). Ultra-processed foods and the limits of product reformulation. *Public Health Nutrition*, *21*(1), 247–252. https://doi.org/10.1017/S1368980017001392.

Shi, J., & Le Maguer, M. (2000). Lycopene in tomatoes: Chemical and physical properties affected by food processing. *Critical Reviews in Biotechnology*, *20*(4), 293–334.

Souci, S. W., Fachmann, W., & Kraut, H. (2008). *Food composition and nutritional tables* (7th ed.). Stuttgart: Medpharm Scientific Publishers, Taylor & Francis, a CRC Press Book. 1364 pages.

Sparrenberger, K., Friedrich, R. R., Schiffner, M. D., Schuch, I., & Wagner, M. B. (2015). Ultra-processed food consumption in children from a basic health unit. *Jornal de Pediatria*, *91*(6), 535–542.

Sun, Q., Spiegelman, D., van Dam, R. M., Holmes, M. D., Malik, V. S., Willett, W. C., et al. (2010). White rice, brown rice, and risk of type 2 diabetes in US men and women. *Archives of Internal Medicine*, *170*(11), 961–969.

Tavares, L. F., Fonseca, S. C., Garcia Rosa, M. L., & Yokoo, E. M. (2012). Relationship between ultra-processed foods and metabolic syndrome in adolescents from a Brazilian Family Doctor Program. *Public Health Nutrition*, *15*(01), 82–87.

U.S. Department of Agriculture, Agricultural Research Service, & Nutrient Data Laboratory . (2008). *USDA nutrient database for standard reference, Release 27*. .

Vandevijvere, S., Monteiro, C., Krebs-Smith, S. M., Lee, A., Swinburn, B., Kelly, B., et al. (2013). Monitoring and benchmarking population diet quality globally: A step-wise approach. *Obesity Reviews*, *14*, 135–149.

Vedovato, G. M., Trude, A. C., Kharmats, A. Y., & Martins, P. A. (2015). Degree of food processing of household acquisition patterns in a Brazilian urban area is related to food buying preferences and perceived food environment. *Appetite*, *87*, 296–302.

Voutilainen, S., Nurmi, T., Mursu, J., & Rissanen, T. H. (2006). Carotenoids and cardiovascular health. *American Journal of Clinical Nutrition*, *83*(6), 1265–1271.

Wallin, A., Orsini, N., & Wolk, A. (2011). Red and processed meat consumption and risk of ovarian cancer: A dose-response meta-analysis of prospective studies. *British Journal of Cancer*, *104*, 1196–1201.

Wickramasinghe, C., & Ikeda, D. (2011). *Buddhism and science: A dialogue*. Paris, France: L'Harmattan. 284 pages.

Wrangham, R. (2010). *Catching fire: How cooking made us human*. New York, USA: Basic Books. 320 pages.

Xi, B., Li, S. S., Liu, Z. L., Tian, H., Yin, X. X., Huai, P. C., et al. (2014). Intake of fruit juice and incidence of type 2 diabetes: A systematic review and meta-analysis. *PLoS One*, *9*(3), e93471.

Xu, X., Yu, E., Gao, X., Song, N., Liu, L., Wei, X., et al. (2013). Red and processed meat intake and risk of colorectal adenomas: A meta-analysis of observational studies. *International Journal of Cancer*, *132*(2), 437–448.

Zhao, Z. W., Pu, Z. S., Yin, Z. F., Yu, P. F., Hao, Y. M., Wang, Q., et al. (2016). Dietary fruit, vegetable, fat, and red and processed meat intakes and Barrett's esophagus risk: A systematic review and meta-analysis. *Scientific Reports*, *6*, 27334.

Zhao, Z., Yin, Z., & Zhao, Q. (2017). Red and processed meat consumption and gastric cancer risk: A systematic review and meta-analysis. *Oncotarget*, *8*, 30563–30575.

Zong, G., Gao, A., Hu, F. B., & Sun, Q. (2016). Whole grain intake and mortality from all causes, cardiovascular disease, and cancer—A meta-analysis of prospective cohort studies. *Circulation*, *133*(24), 2370–2380.