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Review: use of fruits and vegetables in processed foods: consumption trends and technological impacts.

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Abstract

According to FAO information, during the last decades great efforts have been made by authorities and specialists for the development of public policy and to spread the benefits of adopting healthy diets and physical activities, aiming to reduce the incidence of non-transmissible chronic diseases, which are the main cause of death worldwide. In spite of its healthy status, the consumption of vegetable products (fruits, vegetables, grains, and plants) has been staying below the expected level in most countries, forcing the public policy makers to implement ways to encourage consumers to include more vegetable products in their diets. Aware of this reality, the food industry continuously seeks for innovative ways of contributing to increase the consumption of fruits and vegetables. This review proposes to show the consequences of functionality and nutrition macrotrends for fruit and vegetable consumption, and the technological challenges and alternatives found for the development of processed products containing such raw materials.

Keywords: food industry; healthy food; macrotrends; technological innovation.

Practical Application: This review presents the macrotrends for the consumption of fruits and vegetables, having as practical application the development of processed products containing such raw materials.

1 Introduction

There has been an increasing concern about the negative impact of modern diet on the planet's and people's health. While global population keeps growing, we have to feed everyone without irreparably harming the environment. In addition, processed food must have accessible, convenient, safe, nutritive, and sustainable features (McClements, 2020).

Diets rich in fruits and vegetables are widely recommended for their health-promoting properties. Fruits and vegetables have historically taken a place in food guidelines due to their vitamin and mineral contents. More recently the presence of phytochemicals was highlighted (Yahia et al., 2019), mainly the antioxidants. Furthermore, fruits and vegetables are recommended as a source of food fiber (Slavin & Lloyd, 2012; Food and Agriculture Organization of the United Nations, 2020).

Fruits are a natural source of energy, vitamins, minerals, and fibers. Typically fruits have between 10% and 25% of carbohydrates, less of 1.0% of proteins, and a very small amount (less of 0.5%) of fat. Important minerals are present in fruits, such as Ca, Mg, Na, K, P, Cl, and S, in addition to micro-quantities of Fe, Cu, Co, Mn, Zn, I, and Mo. Potassium is the most abundant mineral in fruits, followed by calcium (Orrego et al., 2014). Vegetables are an important component of diets, being traditionally served with a source of protein and carbohydrate. They give not only a variety of color and texture to meals, but also important nutrients. Vegetables are poor in fat and calories and relatively poor in proteins, but rich in carbohydrates and fibers, adding significant levels of micronutrients to diet (Carvalho et al., 2006).

One barrier to increase the fruit and vegetable consumption is the time required for their preparation, as well as their availability, the reduced shelf-life of *natural* products and other factors, such as culture, education, lifestyle changes, urbanization, etc. (McMullin et al., 2019).

Fruits and vegetables provide functional compounds that bring benefits to one or more organic functions, besides basic nutrition, contributing to improve the health status and well-being and/or to reduce the risk of diseases (Carvalho et al., 2006; Wallace et al., 2020), which meets the growing demand from consumers of healthy, natural, and convenient foods, and plant-based foods are becoming more and more popular (Sun-Waterhouse et al., 2010b; Salehi, 2020). Healthy nutrition has become popular, with most consumers looking for foods and drinks that meet the health and well-being, ethics, and sustainability increasing requirements (Wiley, 2019).

Natural, organic and, whole-grain foods, which are rich in fiber, proteins, vitamins, and minerals are seen by consumers as healthy. The allergen-free and non-GMO food and those that have low or no content of sugar, saturated fat, trans fat and sodium also are seen likewise. For fulfilling several of these requirements, fruits and vegetables meet the consumers' wish for healthy products. In addition, the scientific literature includes several works associating the fruit and vegetable

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consumption with a reduction in mortality (Olaya et al., 2019), cardiovascular diseases (Spence, 2019) and even some types of cancer (Cicco et al., 2019; Lin et al., 2019), although many works call these associations into question, especially regarding cancer and diabetes (Food and Agriculture Organization of the United Nations, 2020). Notwithstanding the scientific debate, which is common to all areas of knowledge, fruits and vegetables should be part of people's daily diet because most of them they have low caloric density and are rich in fibers, antioxidants, vitamins, and minerals, among other nutrients.

Although considered as healthy, fruits and vegetables are below the expected consumption level in many countries. Several initiatives have been conducted worldwide aiming to include these raw materials in diets. Among such initiatives we have the food industry continuously seeking for innovative ways of contributing to increase the consumption of fruits and vegetables in their several forms: natural, dehydrated, frozen, freeze-dried, as juice or extract, or even as isolated ingredients used to enrich all kinds of products (Salehi & Aghajanzadeh, 2020). Liu (2013) highlights the importance of food variety for the diet, since it enables the occurrence of synergic effects among several phytonutrients.

Due to their wide diversity, fruits and vegetables have many nutritional functions and bring benefits to all body systems in different stages of life. They can be placed in the functionality and nutrition macrotrends (Table 1), which can be unfolded in two trends: natural functionality, represented by generic qualities of fruits and vegetables and their use in order to reduce the risk of diseases; and personalized nutrition, which involves directing the fruit and vegetable consumption to specific market groups, looking for the best option of diet and functionality to each situation. For the first trend, the following generic application innovation platforms are being considered: increased nutritional density, reduced calorie density, antioxidants, fibers, micronutrients, and proteins, as well as those of specific application: cardiovascular health, brain, eyes, digestive system, etc., in which specific bioactive or functional ingredients are used. For the second trend, an approach of specific consumer groups is made: life cycle (pregnancy, child, teenager, adult, and elderly), gender, and restrictive diets (intolerance and allergy).

2 Natural Functionality

2.1 Products to increase nutritional density and reduce calorie density

Since most of fruits and vegetables have low calorie density, the direct consumption of this kind of food instead of others or its incorporation in product formulation causes a reduction in calorie density, therefore being an interesting strategy in diet balancing. This topic is discussed by Vialta (2014a), who also emphasizes that fruits and vegetables have a healthy status and their addition to products is a way of making a diet healthier or increasing the nutritional density of products, as they are rich in fibers, antioxidants, vitamins, and minerals. Because these substances are involved in the entire human metabolism, they play important roles in several organs and systems: cardiovascular, digestive, etc.

Mytton et al. (2014) consider it would be unlikely that promoting the increased consumption of fruits and vegetables without specific advices to reduce the consumption of other kinds of food could cause weight gain in the short term, and it could also help in the maintenance or even loss of weight. However, they highlight that more studies or the application of other methods are required to understand the long-term effects on weight maintenance and loss. Similarly, Guyenet (2019) concluded that fruit consumption does not contribute to obesity and it may assist in the prevention and management of excess of adiposity. On the other hand, Wang et al., 2019 stated that an elevation of body mass index and body weight could be mitigated by increasing the ingestion of fruits and vegetables, with such effect being more accentuated in subjects at higher genetic susceptibility to obesity.

Considering the relevance of obesity, many studies have been conducted with the purpose of finding ways of fighting it. One example is the discovery that non-digestible compounds present in apples change the ratio of bacteria in gut microbiota of obese rats to a similar pattern observed in thin rats, what may help to prevent some of the obesity-associated disorders, such as chronic inflammation, which may result in diabetes (Nutrition Insight, 2014c). In another study (Nutrition Insight, 2014a), rats fed with a high-fat diet and drinking diluted grapefruit juice gained less weight and had a 13

Table 1. Functionality and nutrition macrotrend and its potential innovation platforms.

MacrotREND	HIGHLIGHTED TRENDS	INNOVATION PLATFORM
Functionality and nutrition	**Natural functionality** (Search for functionalities naturally present in fruits and vegetables, aiming healthiness and reduction in risk of diseases)	Vegetable products with high nutritional density (proteins, vitamins, etc.)
		Super fruits and vegetables
		Vegetable products with high functional power (antioxidants, fibers, omega 3, etc.)
		Products with bioactive or functional ingredients specific for cardiovascular health, brain, eyes, digestive system, etc.
	Personalized functionality (Consumption of fruits and vegetables by specific consumer groups, looking for the best option of diet and functionality to each situation)	Products specific for nutrition of pregnant women, children, teenagers, adults (men and women), and elderly
		Products for restrictive diets (food intolerance, allergies, ideology, etc.)

to 17% reduction in blood glucose levels, besides showing higher sensitivity to insulin, considering the amount of such hormone has diminished three times. Many of the works recently published have used as a strategy to fight obesity the study of vegetable functional compounds modulating gut microbiota (Cao et al., 2019). Boccellino & D'Angelo (2020) have studied the anti-obesity effect of polyphenols and verified that, although some results are conflicting, probably due to the different design and duration of studies, divergences among people and different chemical formulas of dietary polyphenols used, data obtained until this moment promote the conduction of new clinical trials to validate the benefits of polyphenols for obese subjects.

2.2 Products with raw materials of high nutritional content

Antioxidants

By using oxygen to get energy, cells produce reactive oxygen species (hydrogen peroxide, free radicals, hypochlorous acid, etc.) that could damage them seriously. This does not happen because these cells have antioxidant systems that use enzymes, such as catalase and superoxide dismutase, and substances like vitamins C and E, ubiquinol (coenzyme Q), and polyphenols. In plants, reactive oxygen species are also produced during photosynthesis, mainly under conditions of high light exposure, whose negative effects are in part avoided by the presence of carotenoids, a group of antioxidants that is part of polyphenols.

Polyphenols are the most common group of chemical substances in plants and the most abundant antioxidants in human diet. Flavonoids, which include thousands of compounds, are the most studied subgroup of polyphenols. Several studies have shown the protective action of these substances in humans (Rosas et al., 2019). Therefore, including fruits and vegetables in diet can be a way of minimizing the oxidative stress effects, which have been associated with many diseases.

Lima et al. (2014) showed the complexity of studying the effects of polyphenols on human health and emphasized the need of knowing the content and quality of this important group of antioxidant substances, whose physiological effects are difficult to evaluate, since one single food may contain a large number of different compounds, and their destination *in vivo* can hardly be measured. The authors highlight that more agronomy, biochemical and chemical studies should be performed to elucidate the role of these substances in plants and human beings.

As the human body produces reactive oxygen species in all of its cells, there is a general demand of antioxidants, both those synthesized by the body and those obtained from the diet. Thus, the presence of such compounds in products enables positioning in several ways. Hence, companies are constantly launching products containing various types of antioxidants. A recent trend consists of using fruits and vegetables with high antioxidant content in product formulations.

A research conducted by *Datamonitor* in 2014 with consumers from 20 countries (Felgate, 2014) already identified the "super" trend among the 8 greatest trends related to the fruit, vegetable, and grain sector. Such trend refers to consumers who prefer "superfoods" as a natural way of improving their health rather than using supplements and drugs. Many consumers believe a healthy diet can diminish the risk of diseases throughout life. Most fruits and vegetables have beneficial properties for health, such as high antioxidant content (blackberry, pomegranate), high iron content (kale), or even the ability of reducing blood pressure (cherry). "Superfruits" can be considered as a valuable source of functional ingredients based on their phytochemical composition and related antioxidant activity (Chang et al., 2019). The challenge for industry is using these healthiness claims in industrial products, usually counting on the help of advertising to promote "super" fruits and vegetables.

Ohr (2012) emphasized that non-alcoholic drinks containing "superfruits" were the category with the highest number of products launched, representing 40% of total, mainly in fruit-based drink and well-being drink segments. The author highlighted the following "superfruits": *açai*, Aronia berry or chokeberry, blueberry, cherry, cranberry, pomegranate, prickly pear, and raisin. The author mentions there is no acceptable definition for a "superfruit", but she says the term usually refers to fruits that have an exceptional nutritional value and high antioxidant content, a strong appeal for the consumer and tend to be more exotic.

The popularity of "superfruits" has promoted the antioxidant activity in subcategory of fruits, but there is room for disclosing the high antioxidant content of some vegetables such as kale, spinach, bell pepper, beet, etc. An interesting product line of McCain Defense Mix with carrots, peas, broccoli, and capsicum is being placed as a natural source of antioxidants, fibers, and vitamins A and C.

The perspective is the "superfruit" market, which has been growing on the last decade, shall continue following this trend for the next five years (Global Processed Superfruits Market, 2020).

Enriched Products

Fibers

Fruits and vegetables are rich in dietary fibers, whose ingestion brings several physiological benefits to digestive system. In addition, they reduce the blood glucose, fat, and cholesterol levels, contribute to increase the production of short-chain fatty acids, improve the absorption of minerals, and have prebiotic effects (Zacarchenco et al., 2014). This work describes in details the prebiotics and their beneficial effects for health.

Benito-González et al. (2019) conclude the scientific evidence available indicate that a significant ingestion of these cell wall polysaccharides considered as dietary fibers may lead to the prevention of diseases and improve intestinal health, thus promoting new studies in this fascinating area.

A well explanatory study about the importance of dietary fibers revealed that, if adult Americans increased to about 25 g their daily fiber intake, the health system could save USD 12.7 billion per year (Nutritional Insight, 2014j).

Micronutrients

Fruits and vegetables are rich and vitamins and minerals and can contribute to mitigate the problem of micronutrient malnutrition or "occult hunger," which, according to Muthayya et al. (2013) mentioned in Manus et al. (2014), affects around 2 billion people worldwide, with iron, zinc, vitamin A, iodine, and folic acid being the most prevalent deficiencies.

Given the relevance of this topic, a strategy that has been used all around the world in order to increase the micronutrient availability is biofortification, a biotechnological process that changes plant or animal metabolism by making it produce higher amounts of a given nutrient or even making it produce a nutrient that was not produced before (Vialta, 2014b). According to several authors, biofortification would enable a higher bioavailability of nutrients and exempt their addition during processing. Table 2 shows foods biofortified through modern techniques of genetic improvement. However, there are many other examples of biofortification obtained with classical techniques, such as vitamin-enriched manioc developed by *Instituto Agronômico de Campinas* - IAC, which has 40 times more vitamin A than common manioc, and varieties of pumpkin, rice, sweet potato, bean, black-eyed peas, corn, manioc, and wheat developed by EMBRAPA, which are enriched with iron and zinc and have higher resistance to diseases and climate changes (Silveira, 2012).

Proteins

In addition to their nutritional importance, proteins increase satiety. Their participation in product formulation has grown in the last years and should continue growing, mainly soy protein isolates. However, since soy has a history of causing allergies in some people, the use of proteins from other sources has been also increasing, such as pear (Watrous, 2014), lentil, chickpea, and pea, which have been widely studied due to their abundant amount and for being alternative sources of animal protein, especially because of the growth of plant-based food market observed in the last years.

Fruit and vegetable consumption and cancer

In the American Association for Cancer Research meeting held in April 2014, Dr. Walter C. Willett, an experienced epidemiologist from Harvard, stated in the opening session of the event that evidence about fruits and vegetables having any protective effect on cancer is weak (Johnson, 2014).

There are many scientific studies supporting Dr. Willett statement. One example is the meta-analysis performed by Vieira et al. (2015), which, in contrast to the ideas suggested in prior studies, concludes there is no support for current evidence that fruits and vegetables may have any protective effect against bladder cancer, although the authors contemplate that an association with specific types of fruits or vegetables, such as citrus or cruciferous fruits, cannot be excluded. Another example is the cohort study conducted by Wang et al. (2014) demonstrating the increase in fruit and vegetable consumption has not reduced the risk of cancer mortality.

However, there are many scientific studies showing an association between fruit and vegetable consumption and a reduction in risk of certain types of cancer. The meta-analysis performed by Aune et al. (2011) suggests there is a weak but statistically significant non-linear inverse association between fruit and vegetable intake and the risk of colorectal cancer. In another meta-analysis, Li et al. (2015) concludes the intake of cruciferous vegetables may inversely associated with the risk of pancreatic cancer, but due to the limited number of studies included in this work, additional well-designed prospective studies are required to confirm such association. Another example is a new research revealing that women eating food containing flavonols and flavanones, both subclasses of flavonoids, significantly reduce their risk of developing epithelial ovarian cancer. In American Cancer Society Guideline for Diet, Physical Activity for Cancer Prevention (Rock et al., 2020), there are several reports of works showing a reduction in risk of some types of cancer through fruit and vegetable consumption.

Fruit and vegetable consumption and chronic diseases

Another factor that may be contributing to increase the prevalence of chronic diseases related to modern food supply is the change in food digestibility caused by extensive food processing (Gibney et al., 2017). Traditionally, fruits, vegetables, nuts, and grains were consumed in a less processed manner, and therefore they were digested slower by the human body, resulting in a slower release of nutrients in our bloodstream. With the introduction of processed food, many natural food structures, such as plant cell walls, are broken during the manufacturing process. As a result, macronutrients (such as fat and starch) are much faster released, digested, and absorbed in our gastrointestinal system, eliciting to "peaks" of nutrients in our bloodstream. The

Table 2. Examples of biofortified products and their functions.

ProduCts	FunCTIONs
Golden rice, rich in vitamin A	Fight blindness in Asia
Sorghum enriched with vitamins and amino acids and higher availability of iron and zinc	Fight malnutrition in Africa
Corn with provitamin A	Fight blindness
Corn producing L-lactic albumin	Increase protein content of corn
Tomato rich in flavonoids	Improve heart health
Tomato that produces a peptide acting as HDL cholesterol protein	Improve heart health
Soybean producing omega 3	A cheap source of omega 3
Grape with six times more resveratrol	Cardiovascular health
Lettuce rich in folic acid	Avoid fetal malformation

Adapted from Vialta (2014b).

most known example of this phenomenon is the glucose peak observed after eating quick digestion starchy food, such as white bread (Lennerz & Lennerz, 2018).

2.3 Products containing specific bioactive or functional ingredients

Table 3 shows the importance of fruits and vegetables and their derivatives and ingredients in functional product sector.

Cardiovascular Health – CVH

A study showed that people who eat fruits daily has a 25-40% lower risk of experiencing cardiovascular diseases – CVD than those who never eat them, being able to establish a dose-response relationship between fruit consumption frequency and CVD risk (FRUIT..., 2014). The cohort study conducted by Wang et al. (2014) gives evidence that a higher fruit and vegetable consumption is related to a lower risk of all-cause mortality, mainly from cardiovascular diseases.

As shown in Table 3, the consumption of fruits and vegetables rich in omega 3, fibers, and antioxidants is recommended in order to reduce the risk of cardiovascular diseases – CVD, and so is the consumption of soy protein, beta-glucans, glucomannan, and psyllium fibers, polyphenols, vitamins, arginine, betaine, and magnesium. A detailed discussion of ingredients used for CVH can be found in Vialta (2014c).

Agência Nacional de Vigilância Sanitária (2016) [National Health Surveillance Agency] approved the claim that omega 3 assists in maintaining healthy levels of triglycerides. According to the meta-analysis published in *American Journal of Hypertension* and ordered by The Global Organization for EPA & DHA Omega-3 – GOED (New..., 2014), consumption of DHA and EPA omega-3 fatty acids may also reduce systolic and diastolic blood pressure. On the other hand, EMA (European Medicines Agency) has confirmed that omega-3 fatty acid medicines containing a combination of an ethyl ester of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) at a dose of 1 g per day are not effective in preventing further problems with the heart and blood vessels in patients who have had a heart attack (European Medicines Agency, 2019). This is the outcome of a re-examination requested by some of the companies that market the medicines concerned, following EMA's original recommendation in December 2018.

Table 3. Use of fruits and vegetables and their derivatives and ingredients in functional products.

PRODUCTS / INGREDIENTS	CARDIOVASCULAR HEALTH	DIGESTIVE SYSTEM HEALTH	IMMUNE SYSTEM	COGNITIVE PERFORMANCE	EYE HEALTH	SKIN HEALTH
Fruits and vegetables in their several forms, parts, and extracts	Rich in omega 3 (linseed, chia seeds, etc.), fibers and antioxidants (blueberries, pomegranate, olive leaf and grape seed extract, green tea, apple)	Rich in soluble and insoluble fibers	Rich in micronutrients	Rich in omega 3 (linseed, chia seeds, etc.) and antioxidants (*Ginkgo biloba, Panax ginseng*, saffron, guarana, cocoa, pomegranate, açai, grape)	Rich in antioxidants, especially carotenoids, lutein, zeaxanthin, and beta-carotene	Rich in antioxidants (açai, mangosteen, pomegranate, melon extract, etc.), omega 3 (linseed, chia seeds, etc.), anti-inflammatory (carotenoids, curcumin, etc.), and photoprotective effect (lycopene, phytoene and phytofluene, and fern extract *Polypodium leucomotos*)
Proteins	Soy protein					
Soluble fibers	Beta-glucans, glucomannan, *Psyllium*	Inulin, fructo-oligosaccharides, galacto-oligosaccharides, lactulose, polydextrose, maltodextrin, sorbitol, mannan	Yeast beta-glucans			
Insoluble fibers	*Psyllium*	Cellulose, hemicellulose, lignin, quitin				
Antioxidants	Polyphenols / stilbene (resveratrol, pterostilbene), Polyphenols / flavonoids (catechins)		Mainly vitamins C and E	Flavonoids CoQ10	Flavonoids / carotenoids (lutein, zeaxanthin, beta-carotene, and lycopene)	Beta-carotene, CoQ10, enzymes (superoxide dismutase – SOD, catalase, and glutathione peroxidase), lycopene, lutein, curcumin, etc.
Micronutrients	Vitamins K, K2, B1, B6, B12, E and niacin, L-arginine, betaine, magnesium		Vitamins A, B6, B9, B12, folic acid, selenium, zinc, iron, copper, manganese, essential amino acids, glutamine	Vitamin A, B-complex, C, D, E, tryptophan, L-theanine, taurine, choline, acetylcholine, phosphatidylcholine, phosphatidylserine, dimethylaminoethanol – DMAE, zinc, manganese, iron, and iodine	Vitamins A, C, E and selenium	Vitamins A, B-complex, C and E, selenium, zinc, copper, and choline
Other ingredients / nutrients	Isoflavones, omega 3			GABA, melatonin, L-carnitine, omega 3	omega 3	ceramides

Adapted from Vialta and Rego (2014).

von Schacky (2014) affirms that clinical tests have not shown beneficial effects of consuming omega 3 and 6 with respect to extreme events, such as total mortality, sudden death of cardiac origin, or other major adverse cardiac events, but epidemiological studies have shown a consistent association between higher blood levels of omega 3 and 6 and a lower risk of extreme cardiac events. In order to test such inconsistency, the author suggests that future clinical trials are conducted using the omega 3 index test, which measures omega 3 present in red blood cell membranes.

The main action of fibers and phytosterols is to reduce cholesterol absorption during digestion, thus diminishing its blood concentration, which contributes to reduce CVD risk, since higher concentrations of plasma cholesterol is a significant risk factor in this case. In addition to products containing these ingredients in their formulation, a diet rich in fruits and vegetable is also important, mainly whole grains, legumes, and nuts. Phytosterol supplements can also be used for cases where diet is not sufficient and can contribute to diminish coronary events (Nutritional Insight, 2014k). There are several studies showing the beneficial effect of fiber intake for CVH (Chen et al., 2013; Threapleton et al., 2013; Heart-attack..., 2014).

For phytosterols, *Anvisa* approved the claim that they assist in reducing cholesterol absorption, and the portion of ready-to-eat product should give at least 0.8 g of free phytosterols. Lower amounts could be used since efficacy is proven for such food. For beta-glucan, *Anvisa* approved the claim that it may help in reducing cholesterol, and this is applicable to oat flakes, oat bran, and oat flour only. For other products or food it is conditioned to scientific evidence of efficacy. Other fibers with approved claims are *Psyllium*, which assists in reducing fat absorption, and chitosan, which assists in fat and cholesterol absorption.

The addition of phytosterols to industrialized food as an ingredient to reduce cholesterol has already been approved by several regulatory agencies around the world, including Health Canada, U.S. Food and Drug Administration (FDA), European Food and Safety Authority (EFSA), Food Standards Australia New Zealand (FSANZ),16 and National Health Surveillance Agency (ANVISA) in Brazil. (Cabral & Klein, 2017).

In her paper, Milo (2013) describes the beneficial effect of polyphenols for CVH, emphasizing grape, olive, green tea, and apple as sources. The author highlights the positive opinion issued by Starling (2016) EFSA European Food Safety Authority] to the health benefit claim requested by Callebaut for cocoa drinks. The company showed the daily intake of 200 mg of cocoa flavonoids has positively influenced blood circulation.

Other studies demonstrate that cocoa has also a positive effect on blood pressure and resistance to insulin. The activation of nitric oxide (NO) and antioxidant and anti-inflammatory effects have been mentioned as potential mechanisms to achieve such benefits (Corti et al., 2009). The authors make an important remark that many positive effects on CVH reported in their work may not be applicable to chocolate.

Gammone et al. (2015) confirmed that carotenoids, mainly fucoxanthin, astaxanthin, lycopene and lutein, have antioxidant and anti-inflammatory biological properties that may help to reduce risk factors for cardiovascular diseases. Consequent improvements in blood pressure levels, reduction of inflammation and correction of dyslipidemias may result in CVH improvement. The authors underline those further studies are necessary to define a preventive and therapeutical strategy that reduces the risk of developing CVD, with promising application and no side effects.

There is a great controversy involving potential health benefits of resveratrol. Some studies show there is evidence that resveratrol directly activates a protein that promotes health and longevity in animal models (Cameron, 2013), but other studies show there is no benefit. One example is the study showing a diet rich in resveratrol does not enable a longer life or lower susceptibility to develop cardiovascular disease or cancer (Semba, 2014). In spite of negative results, the work leader author affirms that studies have demonstrated the intake of red wine, fruits, and dark chocolate reduces inflammation in some people and seems to protect the heart. The author considers the benefits may come from other polyphenols or substances present in these foods.

Antioxidant lycopene, lutein, and zeaxanthin are claimed to protect the cells against free radicals, as approved by Anvisa. High-dose supplement intake of βcarotene is warned against by the EFSA (European Food Safety Authority) for individuals at risk for lung cancer, i.e. (previous) smokers (Bohn et al., 2021).

In a review of literature on lycopene and its potential role as a dietary antioxidant, the European Food Safety Authority concluded that evidence was insufficient for lycopene having antioxidant effects in humans, particularly in skin, heart function, or vision protection from ultraviolet light (European Food Safety Authority, 2011). Although lycopene from tomatoes has been tested in humans for cardiovascular diseases and prostate cancer, no effect on any disease was found (Story et al., 2010).] The US Food and Drug Administration (FDA), in rejecting manufacturers' requests in 2005 to allow "qualified labeling" for lycopene and the reduction of various cancer risks, provided a conclusion that remains in effect as of 2017.

Although EFSA is not convinced yet of the positive effects of magnesium on CVH, more and more meta-analyses have been published supporting this thesis (Zhao et al., 2019). Another example is the meta-analysis of Harvard School of Public Health supporting the benefit that increased blood magnesium levels bring to CVH, thus reducing by 22% the risk of ischemic heart diseases. Researchers state that data related to dietary magnesium and its results endorse an increased consumption of food rich in magnesium instead of supplements and remind that between 70 and 80% of USA population does not consume the daily recommended dose of magnesium. Magnesium was the third most used ingredient in the world in products for CVH in 2012 (Food Navigator, 2013).

Also, there is a great controversy about soy intake having benefits to CVH. EFSA issued a scientific opinion stating that a cause-and-effect relationship between soy protein consumption and a reduction in LDL-cholesterol level was not established (Starling, 2016), contradicting the results of several works published until then. However, there is some works stating the soy protein reduces the risk of CVD, as the one made by Rebholz et al. (2013). Blanco Mejia et al. (2019) conducted a meta-analysis of 46 controlled clinical trials and concluded the soy protein significantly diminished LDL cholesterol by approximately 3-4% in adults. Anvisa approved the following claim about soy protein: "Daily intake of at least 25 g of soy protein can assist in reducing cholesterol". The U.S. Food and Drug Administration has allowed soy products to carry claims about heart benefits since 1999. But in 2017 the FDA proposed revoking this authorization, citing mixed results in more recent studies of the heart benefits of soy (Rapaport, 2019). In the 2017 statement, Susan Mayne, director of the FDA's Center for Food Safety and Applied Nutrition, commented that the analysis of this evidence led the FDA to conclude that the relationship between soy protein and heart disease does not meet the strict standards of a FDA - Authorized Health Claim (Rapaport, 2019).

Zurbau et al. (2020) evaluated the relationship between consumption of several fruits and vegetables and the effects in cardiovascular system, using a systematic review and meta-analysis of prospective cohort studies. The authors verified that fruits and vegetables are related to cardiovascular benefits, with greater benefits for some cases; no adverse association was observed for any case.

Digestive system health

The scientific literature includes countless works showing the importance of eating fruits and vegetables and soluble and insoluble fibers for digestive system health. Zacarchenco et al. (2014) approach this theme in detail, mainly the role of probiotics and prebiotic fibers. These and the low-glycemic index carbohydrates are also highlighted by Sentko (2014) to improve people's health.

Anvisa also approved for dietary fibers the claim that they assist in functioning of the intestines, provided that they can be used and the portion of ready-to-eat product gives at least 2.5 g of fibers, without considering the contributions of ingredients used in preparation: resistant dextrin, which assists in bowel functioning, fructooligosaccharides – FOS and inulin (prebiotics), which contribute to intestinal flora balance, partially hydrolyzed guar gum, and lactulose and polydextrose, which help in functioning of the intestines. In May 2016, the United States (U.S.) Food and Drug Administration (FDA) published, in Regulation 21 CFR 101.9 (c)(6)(i), a new definition for dietary fiber indicating that dietary fibers are "non-digestible soluble and insoluble carbohydrates (with 3 or more monomeric units), and lignin that are intrinsic and intact in plants; isolated or synthetic non-digestible carbohydrates (with 3 or more monomeric units) determined by FDA to have physiological effects that are beneficial to human health".(Venditti, 2019)

Immune system

Non-enzymatic antioxidants are essentially ingested through several food sources, especially fruits and vegetables, and are represented by oligoelements (Zn, Fe, Se) and vitamins (ascorbic acid – vitamin C, α-tocopherol – vitamin E, and carotenoids – vitamin A). Their presence in organism seems to play a relevant role in the development of immune system-related diseases. Therefore, diminishing the consumption of fruits and vegetables also reduces some of the main sources of non-enzymatic antioxidants, which has already been associated with an increase of allergic diseases in the past few years. A mechanism proposed for this fact is the reduction of "antioxidant defenses" in the lungs would increase the susceptibility to oxidative stress, resulting in inflammatory process and asthma (Sarni et al., 2010).

Antioxidants such as ascorbic acid, soy phytoestrogens, carotenoids (α-carotene, β-carotene, lutein, zeaxanthin) can reduce the risk of several types of cancer, since they are reactive oxygen species blockers (Gouveia et al., 2011).

Cognitive performance

Lemos (2014) reports the cognitive performance is a growing concern for consumers of different ages, with emphasis on the ingredients used to increase the attention and energy, relax the mind, improve the mood, and strengthen the brain. Table 3 shows some of ingredients alone and/or present in fruits and vegetables.

A study involving 14 thousand participants aged 16 or over, being 56% female and 44% male, demonstrated the intake of fruits and vegetables can be good both to mental and physical health. The achieved results suggest the higher the fruit and vegetable intake, the higher the chance of improving mental well-being of the subject (Nutrition Insight, 2014c).

Eye health

Silva (2014) emphasizes the ingredients used to formulate products destined for improving eye health, with antioxidants lutein and zeaxanthin being highly mentioned in scientific literature. Table 3 shows other ingredient used.

Skin health

Butzge et al. (2016) developed a powdered food compound that uses natural fruit pulp as a source of antioxidant bioactive compounds rather than artificial aroma and taste. The compound was added to hydrolyzed collagen, obtaining a food supplement that can be directly consumed or be applied as intermediate product in food and beverage production. The proposal of this new supplement is to assist in providing firmness to the skin, fighting skin flaccidity, wrinkles, and fine lines.

Lefevre & Perrett (2015) were the first ones to show strong evidence of the importance of skin coloration in attractiveness judgments. Furthermore, the authors clearly expose the importance of carotenoids in coloration as a suggestion to health and attractiveness.

An article of Nutrition Insight (Nutrition Insight, 2014d) showed the Symrise company has launched SymVital AR, which is a 100% pure and natural ginger root extract. SymVital AR has been proven to significantly improve the texture and smoothness of the skin, smoothing out wrinkles and softening skin irregularities within three weeks. It also helped to reduce the signs of sun damage in less than two weeks.

Another Nutrition Insight (Nutritional Insight, 2014e) article has introduced Spanish ingredient supplier Monteloeder, which states that the market for skin lightening products will continue growing quickly, but many consumers of this category will avoid the topically applied products favoring the dietary supplements that offer "lighter skin from the inside out".

Monteloeder markets Melagenol, a natural oral nutricosmetic formulation that offers excellent skin lightening and whitening properties. Produced from plant extracts, it is proven safe and effective as both a beauty aid and in the treatment of skin pigmentation disorders.

3. Personalized nutrition

3.1 Fruit and vegetable consumption targeting specific groups

Table 4 shows the importance of fruits and vegetables, as well as their derivatives and ingredients, in products with functionalities for specific populations.

3.2 Nutritional products for each life stage

Children and teenagers

One of the biggest challenges to this segment is to increase fruit and vegetable consumption, when eating both at home and outside. Many products have been launched in the market with this purpose. Some examples are healthy beverages, smoothies, and snacks, so-called due to their nutritional content.

Elderly

The Nutrition Insight document (Nutrition Insight, 2014b) demonstrates that, to slow down the emergence of Alzheimer's disease, the neuronal health should be kept as much as possible, and it concludes the optimal supply of micronutrients plays a fundamental metabolic role in supporting the normal functioning of the brain. The new research follows a study published on Neurology magazine that shows a strong correlation between low levels of vitamin D and the risk of developing dementia, further showing the critical importance of micronutrients to protect the brain from aging.

The article highlights that a variety of vitamins and polyunsaturated fatty acids (PUFAs) were identified as having essential function in metabolism of vital components of a healthy brain and contributing to countless processes, including synthesis of cell membranes, neurotransmitters, amino acids, amines, and steroids that give support to signal transduction and neuronal health. Brain energy production strongly depends on several vitamins and minerals, such as vitamins C and A, which are essential cofactors in metabolic processes responsible for releasing energy from carbohydrates.

Currently there are approximately 35 million patients affected by Alzheimer's disease-related dementia worldwide, and the number is expected to quadruplicate until 2050. It has been recently estimated that low nutrient, high energy food accounts for over 25% of total energy consumption in people older than 50 years in the United States, and 50 to 70% of the residents in German nursing homes have been found to have an unhealthy level of energy intake. The paper has reviewed a variety of social-, economic- and health-related factors that are negatively impacting the supply of micronutrients to elderly people.

According to that document, "Degenerative neurological conditions are expected to cost global economies trillions in patient healthcare costs over the next 35 years. We encourage healthcare professionals, governments, and other key stakeholders to take note of the strong science in support of an alternative nutritional approach to protecting against the onset of Alzheimer's disease pathology".

According to Nutrition Insight (Nutritional Insight, 2014f), depression and dental problems seem to be of great relevance,

Table 4. Use of fruits and vegetables, as well as their derivatives and ingredients, in products for specific populations.

PRODUCTS / INGREDIENTS	CHILDREN AND TEENAGERS	WOMEN	MEN	ELDERLY	PERFORMANCE
Fruits and vegetables in their several forms, parts, and extracts	Mainly those rich in fibers, lutein, and omega 3 and 6	Linseed, chia seeds, soy, cranberry, blueberry, ginseng, and others rich in iron, folic acid, and omega 3 and 6	Turmeric and others rich in protein, lycopene, and omega 3	Rich in micronutrients, antioxidants, proteins, and omega 3 and 6	*Guarana*, coffee, teas, *Gingko biloba*, ginseng, yerba mate, *Hypericum perforatum*, *Gracinia cambogia*, and coconut water.
Proteins	No restrictions	Mainly soy protein	No restrictions	No restrictions	Several
Soluble fibers	Mainly prebiotic fibers	No restrictions		No restrictions	
Insoluble fibers	No restrictions	No restrictions		No restrictions	
Antioxidants	Mainly lutein		Curcumin, lycopene, vitamin E, and coenzyme Q10	Mainly vitamins C and E	Vitamins C and E, and quercetin
Micronutrients	No restrictions	B-complex vitamins, vitamins D and K, folic acid, iron, calcium, iodine, and zinc	Vitamin E, selenium, and folic acid	Vitamins A, C, D, E and K, iron, calcium, and magnesium	Several
Other ingredients / nutrients	Omega 3 and 6	Isoflavones, omega 3 and 6	Omega 3	Omega 3 and 6	Sucrose, glucose, ribose, caffeine, L-carnitine, creatine, medium-chain fatty acids, glycerol, and inositol

Adapted from Soler (2014).

as well as the difficulty of buying groceries. Since elderly people seek emergency care over 20 million times per year in the United States, physicians have the opportunity to intervene in a particularly useful way that is not too much expensive.

Most of elderly patients experience malnutrition or is at risk of malnutrition. Elderly people with symptoms of depression have the worst malnutrition setting. There are several problems that contribute to malnutrition, such as difficulty in eating and difficulty in buying food.

Performance

A study published in *The Journal of Physiology* (Soler, 2014) shows that a mixture of soy protein, casein and whey taken after exercising prolongs the supply of certain amino acids to muscles in one hour in comparison with the use of whey only. The study shows that the use of mixtures of milk and soy can be an efficient strategy to physically active individuals who seek products to improve their muscle health.

There are other scientific works disproving many beneficial effects popularly attributed to a lot of products/ingredients of sporting food. One example is the review made by Schoenfeld et al. (2013), in which they concluded the moment the proteins are taken (during or close to physical activity) is not critical to muscle adaptation. However, the analysis indicates that consuming the appropriate protein combined with resistance given by physical activity is a key factor to maximize the muscle protein increase.

A study published in *The Journal of Physiology* (Medicalxpress, 2014) reveals that vitamin C and E supplements may mitigate the process of developing muscle resistance through their antioxidant action, which prevents muscle cells adaptation to exercise.

Nutritional products for each gender

Women

There are several studies recommending pregnant women to increase the intake of long-chain polyunsaturated fatty acids, iodine, zinc, iron, B-complex vitamins, mainly folate, and proteins. During the second and third trimesters of pregnancy, the calorie intake is recommended to be increased by 15%-20%. However, overweight and obesity should be avoided, since they may cause many problems both to the mother and the baby. Fruits and vegetables are important to provide the necessary nutrients in this period, as well as to keep the optimal weight.

Urinary tract infections occurrence is relatively common during pregnancy. One of the alternatives used to avoid this problem is eating cranberry, a fruit rich in antioxidants. There are many cranberry products in the market developed for this purpose. One example is Pacran, launched in 2014 (Nutritional Insight, 2014g).

With population aging, the number of women experiencing menopause and problems such as arthritis and osteoporosis has increased a lot. Blueberry has been frequently used to formulate products with natural appeal to bone health, since it has significant amounts of calcium and vitamins D and K. Soy isoflavones, linseed, and ginseng are used to alleviate the post-menopausal effects, while the dog rose or rosehip fruit extracts are used to reduce inflammations and the pain and stiffness commonly associated with arthrosis.

Men

In comparison with women, men use to have a more reactive behavior with respect to health, looking after it only when they experience health problems. However, this setting has been changing with more access to information, mainly in younger population. For men, cardiovascular diseases, hypertension, and obesity require more attention. People seek for products claiming to control or attenuate such problems.

Younger men are concerned about their physical performance and appearance in general. Energy drinks and products for muscle development are some examples of products desired by this population. At middle age, men seek for products that reduce stress and assist in healthy aging, avoiding common diseases at this age, such as diabetes, obesity, and prostate problems.

3.3 Restrictive diet products

Ethnic / certified diets (vegetarians and vegans, Kosher and Halal)

With the purpose of clarifying vegetarian and vegan populations with respect to risk factors for chronic diseases, risk of all-cause mortality, incidence and mortality for cardiovascular and cerebrovascular diseases, total and specific types of cancer (colorectal, breast, prostate, and lung), Dinu et al. (2017) conducted a study through a meta-analysis. Such comprehensive meta-analysis reports a significant protective effect of vegetarian diet versus incidence and/or mortality due to ischemic heart diseases (-25%) and the incidence of total cancer (-8%). Vegan diet had a significant reduced risk (-15%) of total cancer incidence.

Kosher products have been constantly increasing and many non-religious consumers consider Kosher as a healthy diet option (Lever & Fischer, 2018). In the USA, over 60% of Kosher food consumption is associated with non-religious values related to health and food quality. While Kosher is a Hebrew term meaning “appropriate” or “adequate”, Halal is an Arabian word literally meaning “allowed” or “legal”. The Kosher consumer diet includes eating vegetables, fruits, grains, and cereals. Those products that should be eaten raw, such as vegetables, fruits, and leafy vegetables, more attention should be paid in their preparation. All types of vegetables are Halal. Fresh or dried fruits, vegetables, and seeds are Halal, provided that not contaminated by pesticides. A great number of rules and practices enable appropriate eating quality to these products.

4 Considerations

Just because many of currently available processed food are not healthy when eaten to excess, this does not mean processed foods are unhealthy or undesirable. It is possible to create healthier processed foods by carefully using science and technology. Nutritionists have encouraged public in general to eat more fruits and vegetables, nuts, and whole grains for decades, but this has contributed little to improve the overall health status of general population or to overcome the imbalance between consumed energy and spent energy. For instance, although a reduction in mortality due to coronary diseases has been observed in the last decades, increases have been occurring in overweight and diabetes. Many people have no time, resources, or mood to prepare food with fresh ingredients on each meal. Instead, many people prefer the convenience of buying processed food, which are cheaper and quickly prepared. Therefore, we should encourage the food industry to create healthier processed food rather than criticize all processed food. In addition, food processing, including traditional methods such as freezing, may cause a reduction in food waste, thus improving food supply sustainability. Many fresh foods are thrown away because they are not used before deteriorating. This problem can be solved by converting fresh food into processed food, which usually have a longer shelf-life and can be used as we wish, e.g., frozen, dried, or canned. In the future, we must design more plant-based foods, since they have good macronutrient and micronutrient balance and are digested slowly. This effort will lead to a healthier and sustainable food supply (McClements, 2020).

5 Technological impact and alternatives to product development

A series of important scientific initiatives and technological advances is being made in a wide range of subdisciplines of agricultural and food sciences, and it is changing the way we produce and consume food. Such advances are being driven by academics, and industrial and governmental scientists who try to deal with the main food-related challenges faced by modern society. However, they also have to get involved with other concerned parties, such as consumers, policy makers, and agriculturists, so that those advances can be widely adopted. Such challenges include feeding an increasing global population without causing damages to the planet, fighting the increase of chronic diet-related diseases in developed and developing countries, and fighting malnutrition, which still remains in certain regions of developing countries (Poore & Nemecek, 2018; Willett et al., 2019).

An overview about the most common technologies for food processing was shown by Wang & Bohn (2012). According to the authors and depending on the desired product, several steps should be followed from raw material, changing physical and chemical appearance of the product, and assuring safety, quality, and expiration date of the food until its final use.

The process applied to many solid and liquid foods is thermal treatment, which can be used for preparing the product and developing the desired tastes, aroma, and colors (e.g. by Maillard reaction), changing food structure (e.g., texture changes due to ingredient or drying process) or preserving or sterilizing the food, inducing inactivation by heat treatment of microorganisms, toxins, and enzymes (e.g., heat sterilization of canned products; vegetables blanching to inactivate enzymes).

Thermal processes can lead to loss of bioactivity of natural ingredients present in food that are essential to human diet. Fruits and vegetables, which are an important source of phytochemicals, have to be protected during processing, packaging, and storage, assuring bioavailability in human diet. The constant search in the food industry is for the development of new processes that can preserve bioactive ingredients in natural food as much as possible. Examples of these new methods are listed in Table 5, and the purpose of preserving and protecting food nutrients and native bioactive ingredients can be easily understood, mainly in non-thermal processing area.

In this approach, the advantages of a thermal processing, e.g. microorganism inactivation or texture modification, are achieved by non-thermal methods, such as high-pressure processing. Nott et al. (2000) and Zhong et al. (2004) demonstrated that, through ohmic heating and microwave technology, a food product could be manufactured at the same safety level achieved by conventional thermal treatment methods, but with better organoleptic properties. Reduction of quality degradation due to food processing by high-pressure processing and pulsed electric field, both characterized as non-thermal methods, was studied by Matser et al. (2004). These approaches certainly have advantages regarding nutrition and human health, as well as food quality improvement. Nevertheless, other benefits of food thermal processes should also be considered, such as assuring the effective microorganism inactivation, when non-thermal methods have limitations, including their ability of processing large volumes and the processing costs.

Possibly more than any other factor, color significantly affects product acceptability. In general, it affects judgment, being used as a strong quality indicator; therefore, developing products with an attractive appearance is relevant to food industry. However, recently artificial dyes have been questioned by certain population segments and this trend, combined with continuous adverse publicity, has increased the interest in natural dyes.

The addition of natural dyes to color processed food can be desirable since it does not have toxic effects and for its possible therapeutical effects. With the purpose of making natural dyes more competitive, it has been observed in the last decades that research focus ranges from finding new pigments to studying the stability and applicability of these pigments in industrial food. The use of natural dye requires the chemical knowledge of its molecules to adapt them to the conditions of use in processes, packages, and distribution (Horst, 2009).

Thus, the food industry needs technologies to protect natural dyes from environment due to their instability in the presence of light, air, humidity, and high temperatures.

Consumers are increasingly seeking for a healthy diet and agree that food has an impact on increased life expectancy and health of population (Landström et al., 2007). Among the products existing in the market, consumers look for aspects such as naturality and well-being, and are more and more interested in natural products against "synthetic" products, preferring to get functional benefits from a food instead of a drug. Good taste is also an important requirement for a functional food. Recent research has indicated the need of food having antidepressant and anti-fatigue appeal and calming properties. There is an acceptance among consumers to trying foods that change

Table 5. The most common thermal and non-thermal processes.

THERMAL PROCESSES	PROCESS OBJECTIVE	OPERATION PRINCIPLE	TYPICAL EXAMPLES OF USE	EXAMPLES OF EQUIPMENT
Heating	Support to other processes for changing the texture; chemical properties; pasteurization; sterilization; denaturation; taste development	Food is exposed to thermal energy in different uses and by several methods (steam, boiling, indirect roasting, heating, microwave, etc.)	Throughout the food production process	Heating tanks, autoclaves, reaction vessels, continuous sterilization (UHT), and drying equipment
Cooling	Temperature control of products	Heat removal by active or passive cooling	Throughout the food production process	Equipment similar to heating applications
Evaporation	Liquid phase reduction / increased solid content	Heating (under pressure to evaporate the solvent, such as water, etc.)	Beverage industry / powder and ingredients industry	Evaporation tower
Crystallization	Separation of solids from liquids	The temperature changes inducing solid crystallization at high concentrations	Sugar industry / ingredients industry	Crystallization reactor
Osmosis	Separation of liquid-solid mixtures	Pressure difference through separation membrane	Fruit and vegetable juices / proteins and lactose production	Ultrafiltration unit / reverse osmosis
Non-thermal processes	Benefit	Use	Limitation	
High pressure (HPP) and (UHP)	No formation of undesirable compounds; better preservation of nutritional value, taste, appearance, texture; possible production of safe food (microbiological safety) at the highest quality (nutritional and sensorial)	Products highly prone to deterioration and damages through processing (e.g., dairy products, meats, seafood, fruits, and vegetables)	High costs of processing (investments and maintenance)	
Freeze drying	Good preservation of product characteristics and applicable to a wide range of products	Used in products with fragile texture when natural ingredients (e.g. tastes) need to be protected. For instance, fruits as high added-value ingredients	Absence of formation of certain heat-induced compounds; limited microbiological safety; high costs of processing	
Electric pulses	Mild processing in spite of cell disintegration (if desired); no formation of undesirable compounds (thermal treatment products)	Applicable to a wide range of solid and liquid products	The lack of heat limits microbiological safety (spores); Reduced enzyme inactivation; refrigerated storage required	
Membranes / ultrafiltration	No formation of undesirable compounds (thermal treatment products)	As additional treatment in milk pasteurization (as little treatment by temperature as possible)	For liquid products only; high energy cost	

Adapted from Wang and Bohn (2012).

the mood. In addition, safety and efficacy are essential to the continuity of use of such foods (Sun-Waterhouse, 2011).

Developing a functional food is a process that goes from the conception to the development of an acceptable marketable prototype. Developing functional foods involve a structured approach, requiring the understanding of target population, the specific health target, the chemical-structural composition, the properties of the bioactive ingredients used, and how these bioactive ingredients as food compounds would be modified in the absorption site of the human body (the bowel). Food design and process development should be made by the market and focusing on the costumer (Bogue et al., 2006). Current trends and new consumer needs indicate a great opportunity to innovation and development. The developed prototypes need to be evaluated so consumer's acceptance as well as their efficacy and safety can be proven, using tests in animals and humans to prove the health claims (Jones & Jew, 2007).

Industrial food consumers have been increasingly concerned about nutritional and sensorial quality, demanding nutritive and tasty products that do not have chemical preservatives.

Based on these factors, a search for non-thermal processes preserving food quality has grown (Franchi et al., 2004; Kouniaki et al., 2004). Among those, the membrane separation process, such as microfiltration and reverse osmosis, should be highlighted (Matta et al., 2004; Sa et al., 2003), as they are conducted at room temperature and do not involve phase transition, thus allowing to maintain product characteristics (Cianci et al., 2005).

The high-pressure processing (HPP) is an emerging technology used for non-thermal pasteurization of food, as well as rapid freezing and thawing of cold-sensitive food. In Europe, products obtained by using this technology are growing. The HPP of fruits and horticultural crops enables to maintain the high quality and increased shelf-life (Hayashi, 1992; Gould, 1996; Butz & Tauscher, 1998). For pasteurization, HPP can preserve nutritive substances of food and their beneficial biological properties. The ultra-high-pressure (UHP) process in general does not induce loss of beneficial substances, such as vitamin C and carotenoids in products based on oranges, apples, peaches, carrots, tomatoes, strawberries, and raspberries (Butz et al., 2003).

Nanoscience is an emerging science area that allows knowing the interactions and behavior of food components on the microscopic scale, which deeply influences food structure, rheology, and functional properties on a macroscopic scale (Sanguansri & Augustin, 2006). The supercritical fluid extrusion process has been used to produce healthy snacks with 40.6% of protein weight (Cho & Rizvi, 2010).

It is worth noting that there are obstacles to the introduction of new food processing technologies. Usually the food industries are not willing to totally replace traditional processing technologies with new ones due to acquisition costs, difficulties in installation, team formation, and space use. Public acceptance of a new technology is another key factor for its success. Consumers tend to prefer minimally or naturally processed foods rather than processed ones and have restrictions with respect to food produced by using state-of-the-art technology. Minimizing the undesirable impact of bioactive compounds is a challenge for functional food area.

Microencapsulation is a process in which there is microparticles formation and an active ingredient (solid, liquid, or gas) is coated by a thin layer of other material (Constant et al., 2002); it enables to isolate and maintain active substances inside of a microstructure, giving protection to the encapsulated ingredient against adverse environmental conditions, such as: light, humidity, oxygen, and interactions with other compounds, stabilizing the product, increasing its shelf-life, and promoting the controlled release of the encapsulated ingredient under pre-established conditions (Horst, 2009).

The material to be encapsulated has many names, such as: nucleus, active ingredient, or internal phase. The material forming the microsphere coating is called core material, carrier, membrane, shell, or coating (Constant et al., 2002). Microcapsules may have diameters ranging from micrometer units to millimeters as well as several shapes, depending on material and methods used to obtain them (Constant et al., 2002; Gibbs et al., 1999; Schrooyen et al., 2001). With respect to the shape, microcapsules are ideally spherical, although the shape is influenced by the original structure of the encapsulated ingredient. The retention of active ingredients inside the microparticles is controlled by factors such as their chemical nature, including chemical functionality, relative volatility, and polarity.

In the food industry, microcapsules containing volatile compounds responsible for implementing aroma and taste, dyes, acidulants, enzymes, probiotic microorganisms, and antifungal agents have been increasingly studied and used (Constant et al, 2002; Desai & Park, 2005; Shahidi & Han, 1993). With respect to the encapsulating agent, it should preferably have low viscosity at high concentrations and should be easily handled during process, having low hygroscopicity, turning liquids into solids for use in dry systems, having the ability to disperse or emulsify and stabilize the encapsulated ingredient, not reacting with the material to be encapsulated, having the ability to seal and hold the active material inside the capsule structure, and completely releasing the solvent or other materials used during the encapsulation process. It should also give maximum protection to the encapsulated ingredient against adverse conditions (light, pH, oxygen, and active ingredients), as well as have the appropriate properties to release the encapsulated ingredient, not having an unpleasant taste (in case of oral consumption), and, finally, it should be economical (Constant et al., 2002; Giunchedi et al, 1998).

In microencapsulation studies, encapsulating agents usually used are vegetable gum hydrocolloids, jelly, modified starch, dextrins, lipids, emulsifiers, chitosan, and alginate, among others (Constant et al., 2002; Shahidi & Han, 1993). New procedures to prepare hybrid materials by mixing natural or synthetic polymers have been quite investigated (Giunchedi et al., 1998; Shu & Zhu, 2002).

Theoretically any material needing to be protected, isolated, or slowly released can be encapsulated. Currently there are several methods to prepare or obtain microparticles, which can be classified into:

a) Physical Methods: Spray drying, spray chilling, spray cooling, fluidized bed, co-crystallization, and freeze drying
b) Chemical Methods: Molecular inclusion and interfacial polymerization
c) Physical-Chemical Methods: Coacervation, ionic gelation, organic phase separation, and liposome formation (Gouin, 2004; Constant et al., 2002; Gibbs et al., 1999).

The microencapsulation technique is used to protect the bioactive compounds and it was used in both liposoluble and hydrosoluble systems (Saenz et al., 2009). The spray drying has been the most frequently used technique in food industries (Chiou & Langrish, 2007). It enables to convert a liquid product (e.g. juice or milk) into free-flowing powders with an extended shelf-life and easy handling (Sun-Waterhouse & Wadhwa, 2013). In addition, we could have double benefits if the encapsulating agent used to protect the bioactive compound is also an active ingredient such as fruit fiber.

Some of the most commonly studied bioactive substances include nutrients such as carotenoids and omega-3 fatty acids, and phytochemicals such as curcuminoids, polyphenols and phytosterols. There is a series of challenges associated with the incorporation of many of these substances into food and drinks (Gonçalves et al., 2018). They may have low solubility in water, making their dispersion in a food matrix more difficult to occur. They can be chemically unstable, which means that most of them is lost before the food is eaten. In addition, many of these substances have low bioavailability, which means most are not really absorbed by the human body, where they can have their beneficial effects. Therefore, food scientists are trying to develop different types of delivery systems, in order to increase the dispersibility, stability, and bioavailability of bioactive substances (Huang et al., 2010).

A detailed discussion about microencapsulation and nanotechnology is found in Alvim (2014). The author emphasizes that there are still several challenges related to microparticles obtaining techniques, and these should be overcome, so that such technologies are appropriately developed and made available for use in food for consumers' benefit. Regulatory aspects involving the validation of benefit claims are the main barrier for placement of microencapsulated substances into food. The author also approaches the market of micro- and nanostructures in food and examples of products by using micro- and nanostructures in food.

Alvim (2014) highlights the company *Funcional Mikron*, a Brazilian company, which has been developing microencapsulated ingredients for application in food. Among its products there are microencapsulated ascorbic acid, timed-release caffeine, and omega-3 nanoencapsulated with phytosterol.

The microencapsulation technique enhances ascorbic acid properties and increases its bioavailability with respect to the products available in the market, also being responsible for reducing the interaction of it with other compounds present in food, thus avoiding early discoloration of some types of dye.

The microencapsulation of caffeine anhydrous results in a timed-release product, in which "stimulating" effects as well as other properties can be extended and better utilized.

Omega-3 nanoencapsulated with phytosterol is a product derived from coating of vegetable oil sterols, resulting in isolation of microparticles of such sterols. Such isolation gives properties which are different from those of the original product, such as, for example, the easy dispersion in liquids enabling its use in several products of the food industry.

Microencapsulation by ionic gelation, both by dripping-extrusion and atomization techniques, was used by Moura et al. (2018). The microparticles generated had high retention of anthocyanins from hibiscus extract without causing excessive degradation of bioactive ingredients, showing to be feasible for stabilization of heat-sensitive compounds, although the high humidity content of particles has limited their stability under non-refrigerated conditions. The application of such microparticles showed technical feasibility, being able to give color and healthiness to industrial products (Moura et al., 2019; Moura & Schettini, 2019).

According to McClements (2020), two approaches were developed to improve bioavailability and potential performance of bioactive substances in food.

- Functional foods: as mentioned, delivery systems are used to encapsulate, protect, and release bioactive compounds. Delivery systems carried with bioactive substances may then be incorporated into functional foods or beverages.
- Excipient foods: an alternative approach is to design an 'excipient food' that does not have any bioactive agent itself, but that increases the bioavailability of bioactive agents in a food containing them. For instance, an excipient food may be a sauce or a cream that is consumed with fruits or vegetables. When the excipient food is lacking, the bioactive agent bioavailability in fruits or vegetables is relatively low, but when it is present such bioavailability is relatively high. However, excipient foods should be carefully designed to show their beneficial effects. Particularly the type, amount and size of lipid droplets should be controlled, as well as the presence of other additives such as antioxidants, enzyme inhibitors, or permeation enhancers.

Food property characterization and analysis of composition of bioactive agents are not just mandatory evaluations during product research and development, but they are also used for quality control and to verify the effects on health. This is the key to build a market image and reputation of a functional food product. In addition to routine analysis for conventional foods, it is essential to evaluate the bioactive compound composition and quantities before adding such compounds to food, after processing, and during the time required for storage, whether chosen by the manufacturer or demanded by the client. The types of methods of analysis depend on the type of bioactive compounds targeted by the study. The extraction solvent requirement should be taken into consideration when measuring the bioactive compounds (Sun-Waterhouse et al., 2009, 2010a, b, 2013 a, b).

In order to characterize fruit and vegetable properties based on functional foods, High Performance Liquid Chromatography (HPLC) and gas chromatography (GC) are the analytical methods of choice, showing high resolution and excellent precision, especially when accompanied by mass spectrometry (MS). HPLC or LC-MS can be used to analyze polyphenols, carotenoids, and vitamins (Stevenson et al., 2006). GC or GC-MS can be used to analyze flavors, aromas, fatty acids, and fiber monosaccharides (Sun-Waterhouse et al., 2008b, 2009, 2010b). Spectrometry methods are also widely used to evaluate the uric acid content of pectic polysaccharides, the total content of extractable phenolic compounds (Sun-Waterhouse et al., 2008b) and other nutrients such as protein. Fourier transform, infrared spectroscopy, Raman spectroscopy, high performance liquid chromatography, rheology-nuclear magnetic resonance spectroscopy can be used to examine the changes in food components caused by their interactions in a food matrix (Sivam et al., 2013). The methods to measure antioxidant activities include DPPH and ORAC (Sun-Waterhouse et al., 2008a, b).

6 Conclusions

The world faces an increasing burden of diseases related to lifestyle, diet, and population ageing, resulting in a growing demand by consumer for healthy and fortified foods. Due to their nutritional characteristics, fruits and vegetables are essential to the diet, but in many countries their consumption is quite below the desirable amount, requiring the authorities to implement public policies to revert this setting. Sensitive to this issue, the food industry engage itself to make safe, qualified, and convenient products available to the different types of consumers.

Phytochemicals as natural sources to promote health have been extensively studied, and great opportunities to develop fortified foods with these active ingredients have been identified worldwide. These new food products contribute to improve and maintain a nutritional balance, but the use of phytochemicals, nutraceuticals, and functional food requires a deep knowledge and comprehension about complex physical-chemical processes occurring in food, thus assuring efficient strategies for food that may increase bioactive agents' bioavailability (Wang & Bohn, 2012).

Current trends and new needs of consumption remain to stimulate the production of new functional food and innovative technologies of food processing. Ingredients deriving from fruits, vegetables, and bioactive compounds remain the cornerstones of the functional food market due to their benefits for consumers' health and known perceptions of natural food. There are considerable opportunities for expanding and innovating the fruit and vegetable category of products.

Before being made available in the market, functional foods need to have their efficacy, safety, and claims proven through tests in animals and humans, besides being accepted by consumers. A structured approach for the conception and development of functional foods is essential to assure success in the market. Maximizing synergistic interactions between the bioactive ingredients and other food components during food processing and storage is the key for innovations in this functional food area (Sun-Waterhouse, 2011).

Researchers and the food and pharmaceutical industries are not only required to keep the quality and stability of functional foods, but also to improve consumers' knowledge about the efficacy and safety of food supplements and functional foods, which are claimed to promote health. From food technology point of view, the future challenge will be the new food processing methods, food design, and understanding the relationships among the launching of bioactive ingredients, specific nutrition, processing technology, improved efficiency, and sustainable production. Adjusting these activities is an opportunity for functional food engineers to increase health-promoting benefits.

Processed foods can be redesigned to become healthier, by changing their nature and structural organization of their components in order to modulate the way they behave inside our bodies. This includes reducing the level of undesirable food components, such as saturated fat, salt, and sugar, and incorporating health-promoting ingredients, such as vitamins, minerals, bioactive compounds, prebiotics, and probiotics. Moreover, food products are being designed to be chewed and digested slowly, or for their components being released in specific sites of our gastrointestinal tract, what may help to fight obesity and diabetes and reduce appetite. Some new technologies are being developed to create alternatives for foods of animal origin, such as meat, milk, and egg, what should reduce meat consumption and alleviate some of its negative impacts on our environment (Mc Clements, 2020).

Conflict of interest

The authors declare no competing financial interest.

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