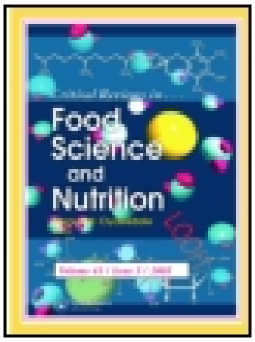

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REVIEW

Manufacturing personalized food for people uniqueness. An overview from traditional to emerging technologies

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ABSTRACT

Personalized nutrition means that we are unique in the way to absorb and to metabolize nutrients as a consequence of our genetic profile and the microbiome that we host in the gut. With the terminology of Personalized Food Manufacturing we want not only to stress the idea of the capability to manufacture food meeting our unique nutritional needs but – based on the idea that eating is a global experience – also to broad this to meet additional personal requirements and expectations, i.e. taste, texture, color, aspect, etc. To address this aim, traditional and advances technologies will have to be employed in new ways and new technological solutions will have to be implemented. All these considerations motivated our paper by which we want to explore and to discuss the technological options having the potential to produce personalized food. After pointing out the main diet styles, firstly we have analyzed the modern approaches of agricultural and animal nutrition in use to manufacture food for narrow group of consumers. Secondly, we have explored emerging technologies at disposal employable to manufacture customized food that meet our uniqueness. Finally the most important market products belonging in the sector of personalized food production have been considered.

KEYWORDS

Nutritional requirements; sensorial properties; personal expectation; technologies; market applications; food design

Introduction

In the last decades the demand for healthy food has been increased significantly. Foods are not proposed only to satisfy hunger or to deliver required nutrients for persons, but also to avoid nutrition-related illnesses and to recover physical and mental well-being (Hannelore, Pamela, and Monique 2016; WHO 2003; Pereira et al. 2009). Although several campaigns of recommendation addressing what is healthy and unhealthy to eat have been broadly utilized by several governments, they have not been capable to change some eating habits, reducing the pandemic increase of metabolic diseases. All these failures highlighted the incongruity of the approach of one-fit-for-all diet (Zeevi et al. 2015). Science has discovered that we are unique in the way to absorb and metabolize the same food due to our DNA diversities and the unique microbiota in the gut. When talking about food, health and people uniqueness, three types of terminologies must be precisely defined: functional food (FF), personalized nutrition (PN), and personalized food (PF). FF defines food which deliver specific nutrients for human body which might overall provide health benefits (Alzamora et al. 2005; Wildman 2007; Granato et al. 2010; Severini and Derossi 2016). Personalized nutrition is a more recent terminology fueled by the aforementioned discoveries that people respond differently to the same foods (German et al. 2011; Reid, Baron, and Zee 2014; Vimaleswaran, Le Roy, and Claus 2015; Severini and Derossi 2016; Abrahams et al. 2017). Shortly, personalized nutrition aims to surgically define the diet that is right for each of us based on the tight relation between food and our unique phenotypic, genotypic profile as well as the microbiome in the gut. However, we have to be aware that often there is a big discrepancy between the advices for a correct diet and what the consumers daily eat. This is mainly because consumer's acceptance of food is based on many others properties such as taste, overall visual aspect, color, texture, flavor, shape, dimensions (e.g. serving size), etc. The choice of consumers is driven not only from what is better for the health but also, and very often, from their sensorial preferences. In addition, what exponentially increase the complexity of this problem is that both nutritional needs and preferences are time-related. On this, Reid, Baron, and Zee (2014) reported that what we eat and the timing of meals play an important role on the weight regulation.

The most recent and exciting terminology – Personalized Food – indicates a broader term which gathers many aspects of the personalization such as: nutritional and functional requirements, sex, age, choice, preferences (including color, taste, flavors, structure, shape, properties and price), timing, food allergies, lifestyle, habits, behaviors, phenotypic, religion, ethics, ethnic, food-phobia, etc. (Maratos and Staples 2015; Hannelore, Pamela, and Monique 2016; Severini and Derossi 2016).

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Under this scenario the demand for innovative manufacturing methods and new source of nutrients to be used in designing and creation of personalized food is suddenly increasing. Moreover, society is demanding technologies not only for higher nutritional value but also sustainable, resilient, responsible, diverse and competitive. The new methods have to provide solutions for tremendous number of cases such as children, adolescents, youth reluctance to eat specific ingredients, neophobia, older people, elderly ability to chew particular food, lactating or pregnant women, vegetarians or vegans people (or any other type of diet), religions, lifestyle, athletes, life events, appetite for certain food (including taste, flavor, structure, composition, etc.), etc.

In this new scenario the developments in this field have took place only in the last few years, and several companies are paying attention on this market sector by creating a customized diet plan and/or personalized ready-to-eat meal but still for a limited number of people. To bring the approach of personalized food from cooking level for few people to the mass customization is not trivial. The extremely lack of comprehensive information on the mass customization of food motivated this paper. Especially, we want to present an overview on the technological options that we have at disposal to produce personalized food for our uniqueness. The paper is organized as follow: after a brief review of the most important diet styles which create smaller consumer's group with specific needs, we firstly will analyze the traditional methods that may be used for the development of nutritionally enriched food to meet the requirements of narrows group of consumers. Secondly, we will present some innovative source of nutrients that could be utilized for home use or food industries to prepare personalized food on the basis of nutritional advices. The third section is focused on the emerging technologies that pioneering researchers are studying to obtain customized food for individuals or narrower groups or people with specific nutritional needs. Lastly, we present the most important market products belonging in the sector of personalized food.

Diversity of diet styles

Although the predominant factors for the diversity of diet styles mainly derive from traditions, heritage, religion, etc., the globalization has greatly contributed to the cross-contaminations of many foods and eating habits around the world. Diet style constantly keeps changing depending on the development of the societies and a deeper understanding of what is better for the health. Moreover, in recent years some popular diets are taking shape in the way 'low environmental impact and contribute to food and nutrition security'.

Certainly, the most popular, studied and healthy dietary pattern is the 'Mediterranean diet' (MD), which is traditionally followed by people living around the Mediterranean Sea. Generally, MD is characterized by the predominant intake of fruits and vegetable, whole grain, legumes, seeds, olive oil as main culinary fat, a moderate intake of animal products, except of red and processed meat, which should be minimized. It is widely recognized that the adherence to MD reduce the incidence or risk of several chronic diseases. The PREDIMED study was a primary prevention trial which suggests a beneficial long-term effect of the MD on cardiovascular diseases (CVD) in adults at high CVD risk (Martínez-González et al. 2015). A recent meta-analysis including 9 studies and more than 122,000 participants highlighted a strong association between MD and lower risk of diabetes (Schwingshackl et al. 2015). Moreover, scientific evidences indicate that the adherence to MD reduces incidence and mortality for cancer (Boccardi et al. 2018). The MD has been recognized by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as "*intangible cultural heritage of France and Italy, Greece, Spain and Morocco, respectively*" recognizing also its incontrovertible benefits on people health and on the local biodiversity as well. Definitely, the MD has been recognized as a model of sustainable and healthy diet, but unfortunately the number of people that follow MD is reducing, mainly teenagers (Burlingame and Dernini 2012).

The Japanese Diet (JD) also deserves to be cited because of its tremendous healthy effects. As a matter of facts, Japanese enjoy one of the longest lives in the world. JD has low calories and fats, particularly saturated fats, due to the predominance of vegetables, fermented foods, seafood, rice and other whole grains. Moreover, Japanese people consume high amount of green tea leaves, not only for infusions but also as ingredient of more complex cooked meals. All the components in such foods explain the great health benefits such as suppressing obesity, reducing stress and fat accumulation, and also acting in a beneficial way on gut microbiota (Asano et al. 2019; Tsuduki et al. 2008). Apart these positive effects, JD is characterized from a high sodium/potassium ratio (Tomata et al. 2019) suggesting a demerit of the JD for an excess of sodium content.

Contrarily to these 'protective diets', other dietary patterns may increase the risk of several chronic diseases and, for this reason, they are known as "risky" patterns. For example, in western countries people consume a huge amount of 'ultra-processed' meat, containing too much sodium, trans fats and artificial sweeteners. For people who brace it, the daily intake of saturated and trans- fatty acids may exceed the accepted daily intake increasing the amount of low-density lipoprotein (LDL) blood cholesterol, while reducing the high-density lipoprotein (HDL) (Dohrmann et al. 2018). Not only, but in such countries it can be observed a huge consume of high-energy foods, related to an over-intake of refined carbohydrates and to a low intake of vegetables. This model, known as 'Western diet', increases the incidence of obesity, cancer, CVD, memory impairment, etc. (Venegas-Pino et al. 2018; O'Neill et al. 2016).

Another 'risky' diet pattern is the traditional 'Argentinean diet' (AG). It consists of high consumption of animal proteins and fats, mainly from red meats, which is also frequently grilled while AG is poor in fish, fruits and vegetables consumption. This diet habits exceeds the recommended limits of FAO for saturated fats while creating an intakes of dietary fiber, vitamins and minerals of half of the daily recommended intakes (Dohrmann et al. 2018).

Apart of these diets that are rooted in the past, in recent years there is an expanding number of people who decided to adhere to vegetarian or vegan diets. Rizzo et al. (2016) reported that more than the 10% of people in western countries are vegetarian followers. There are many reasons that push people to follow the vegetarian diet as life style, ethical motivation, beliefs, religions, environmental, and cultural issues, and health-related aspects. Many studies have reported that vegetarian followers have lower prevalence of overweight, obesity, a lower risk of CHD, diabetes, diverticular disease and eye cataract in comparison to non-vegetarian (Appleby and Key 2016). However, if vegetarians avoid consuming meat, fish, poultry but they may consume products such as eggs, dairy products, honey (Harrison 2017). While vegan people exclude not only all animal products (meat, fish, poultry, eggs, dairy products and honey) from their diet, but also they avoid all food products manufactured by using, directly or indirectly, animal products (Harrison 2017). Moreover, across the vegetarians and vegans there are several diversities in their eating habits creating many subgroups. Under the large umbrella of vegetarian people, we can find the following groups: Lacto-ovo vegetarians who do not consume animal's meats at all (including fish or shellfish) but they consume milk, all dairy products and eggs, so referred to them with the prefix Lacto- and Ovo- (Watanabe et al. 2014; Geissler and Powers 2017). It is worthy to mention here that there is a religious group which consumes mainly dairy products but exclude eggs, honey and root vegetables which they referred to them as Jain vegetarians (Watanabe et al. 2014; McDermott et al 2018). Pescatarians are a vegetarian group who may consume fish and seafood instead of the other type of meat (Harrison 2017). Much more fractioned is the class of vegan people. Raw vegans behave very strictly pushing their attention on the way by which food must be prepared and consumed. Specifically, they believe that food must be cooked at temperatures below than 62.7 °C in order to preserve the nutritional compounds of foods, which might be lost by exposing them to higher temperatures (Amoroso et al. 2018). Fruitarianism follows the raw style of eating which mostly depends on fruits, nuts, and seeds (Watanabe et al. 2014; Geissler and Powers 2017). Macrobiotic diet is focusing mainly on grains, cereals, beans, vegetables, and some other whole foods, while exclude completely any type of animal products (Watanabe et al. 2014). The group of Buddhist vegetarian follow a vegan diets by excluding all animal products and specific vegetables such as *Allium* family vegetables (onion, garlic, leeks, and shallots) depending on an ethical background (Watanabe et al. 2014).

Likewise, and as mentioned above many people follow a specific diet for religious reasons such as Halal consumers (Muslims avoid pork meats, blood, and Alcohol), Kosher consumers (Jews consume a specific meat or food e.g. birds with wings, fish with scales), Buddhist consumers (Buddhists avoid eating meat or fish), Hindu consumers (Hindu avoid mainly pork and beef meat), Sikh consumers (Sikh religious people are following a very stick vegetarian diet, even additives must have a vegetarian origin) (Kwon and Tamang 2015).

Each diet style has some disadvantages mainly referred to the deficiency or the excess of some nutrients and, on this basis, the capability to produce food with customized functionalities and sensorial properties also in respect of religious, cultural heritage, ethical choice, etc., completely would reverse the traditional point of view of food manufacturing. As example, in western countries where it is observed an overconsumption of saturated fatty acids, the use of designed emulsion with cellulose would enable to create a physical barrier to fat digestion but keeping an appreciated palatability of food (Espert et al. 2017).

Even more, because of the high sodium content in the Japanese diet, the planning and formulation of seasonings with low salt content might significantly help the decreasing of sodium intake of Japanese. More generally, since the World Health Organization has recommended a daily sodium intake of 5 g per day, the manufacturers have been invited to lower the sodium content in processed food. Ghawi, Rowland, and Methven (2014) reduced salt content in tomato soup by adding a blend of herbs and spices resulting in the enhancing of salty taste perception but avoiding the accumulation of salt. Another interesting approach in reducing sodium content is to manipulate the structure of products in order to optimize the delivery of the sodium ions which cause the maximum stimulation of the taste receptors (Busch, Yong, and Goh 2013).

These few samples – but many others will be discussed later sections – reveal the potentiality of personalized foods manufacturing which might be used to fill the nutritional gaps left by any kind of dietary patterns at which people adhere for any kind of reasons.

Modern agriculture and animal nutrition in designing foods satisfying the nutritional needs of specific groups of consumers

One of the most important goals for modern agriculture is to contribute to the end hunger, to achieve food security and improved nutrition and to promote sustainable agriculture, as reported in the 2030 Agenda for Sustaninable Development of United Nations. The key point of the UN Agenda is the link between our capacity to improve the amount of nutrients of vegetables and to reduce food consumption. This would have a huge positive impact on the sustainability of the agriculture.

Although we can mention agricultural as the first method to make food composition more rich in nutrient, only later in time, the agriculture was consciously used in a technological mode to obtain advantages for specific nutritional consumer's requirements, by introducing nutrients or functional compounds in fruit and horticultural products (Wildman 2007; Betoret et al. 2011). When our knowledge has increased especially in the field of molecular biology and genetics, many products were modified in order to improve their properties or to enrich them with healthy compounds

(Al-Babili and Beyer 2005; Sun 2008). Fortification of agricultural products may be attained by adding nutrients to fertilizers, an option that has a great success only for immobilized compounds in soil such as zinc and selenium but it is not suitable for iron or other essential organic nutrients created by plants metabolisms (Gómez-Galera et al. 2012). The alternative is the genetic engineering (GE) which introduces genes in plant by which is possible to increase the level of organic and/or mineral nutrients. Cassava roots expressing the bacterial CrtB gene accumulated 21 μg/g of carotenoids, a 34-fold increase in comparison to the wild type. The so-called Golden Rice 2 produced up to 37 μg/d.m. of carotenoids as result of the introduction of daffodil gene (Paine et al. 2005). Moreover, the enrichment of vitamin A exceeded the application on rice being used for other kind of food such as orange-fleshed sweet potatoes to tackle vitamin A deficiency in many developing countries (Van Jaarsveld et al. 2005; Nzamwita, Duodu, and Minnaar 2017). Maize expressing the rice *dhar* gene accumulated six time the average amount of ascorbate (Naqvi et al. 2010) while the over-expression of L-gulono-y-lactone oxidase (GLOase) increased the amount of vitamin C in lettuce of sevenfold, up to 580 nmol/g of fresh weight (Jain and Nessler 2000). Many other enrichments of vitamin E, essential amino acids, essential fatty acids and minerals have been reviewed by Pérez-Massot et al. (2013). Nevertheless, the mass production of transgenic plants potentially able to satisfy our global needs of nutrients is still far from the practical usage because it waits new progresses in transgene expression, risk assessment and also for better public acceptance.

So, apart GE, the employment of microbial community of bacteria and fungi colonizing the rizhosphere is gaining interest as method to improve nutritional content of food. Several bacteria belonging to the genera *Rhizobium, Pesudomonas, Pantoae, Serratia*, ecc. (Vejan et al. 2016; Goicoechea and Antolin 2017) may be used for plant growth-promoting rhizobacteria (PGPR). The use of PGPR would be able to improve the sweetness, moisture content and several macro- and micronutrients in fruits and vegetables, as reported by Ruzzi and Aroca (2015) and Bona, Lingua, and Todeschini (2016). For instance, for broccoli the use of *Brevibacillus reuszeri* allowed to improve both the yield, the plant weight and the macronutrient and micronutrient uptake (Yildirim et al. 2011). Nautiyal et al. (2008) proved that the use of *Bacillus Lentimorbus* resulted in the increase of antioxidant capacity of edible parts of spinach, carrots and lettuce. Many other improvements of the nutrient content by bacterial usage may be found by Ruzzi and Aroca (2015). About the beneficial use of fungi in agriculture it was proved that *Trichoderma spp*. increases the level of carotenoids and minerals in tomato fruits (Molla et al. 2012) while Colla et al. (2015) reported the increase in chlorophyl contents in lettuce. Likewise, mycorrhizal fungi (AMF) is gaining interest in modern agricultural showing their capability to increase the overall content of carotenoids, phenols, tocopherol and minerals in lettuce and berries (Baslam et al. 2013; Castellanos-Morales et al. 2010; Torres et al. 2016).

Food of animal origin (FoA) still represents a significant part of the energy and nutrients intake in human diet. A recent review reported an amount of 45 million tons of meat, 135 million tons of milk and 7 million tons of eggs produced in Europe in 2013 (Pinotti et al. 2012). On this basis the contribution of the animal nutrition for food quality and to promote not only the reduction of hunger but also the wellbeing and the protection against chronic diseases, is a strategy of utmost importance. The employment of nutritional additives, their doses, and the formulation of different additives and the mode of assumption being important variables are under the attention of several research groups. For instance, the supplementation of cows' feed with plant oils, oilseeds, or marine lipids is a good way to increase the amount of polyunsaturated fatty acid PUFAs (Markey et al. 2017). The high availability of choline for dairy ruminants has been correlated to a greater milk production as well as a significant change in lipid metabolism during lactation thereby influencing the nutritional content of milk (Pinotti et al. 2010; Pinotti 2012). With regard to mineral elements, the shortfall of selenium (Se) could be reduced by using it as a dietary supplement, selenium furnished either as organic (e.g. selenoyeast) or inorganic (sodium selenite) source; however, the first source seems to have the greater efficiency transfer from animal to milk (Juniper et al. 2006). Similarly, Moran (2010) proposed the same approach to improve the amount of selenium in fish products. With regard to lipids, fatty acids profiles of milk and dairy products are the easiest compounds to control by planning the animal feeding. The basic strategy is to reduce the portion of saturated fatty acid (FA) favoring the amount of unsatured FA by introducing linseed and rapeseed oil in the daily diet of animal. Finally, it has been widely reported that diet supplementation of vitamin E, carotenoids and Se are efficiently transferred to the eggs. For instance, it is possible to provide with a single egg the daily needs of vitamin E (15 mg), the 50% RDI of Se (30–35 μm) and appreciable amount of lutein and zeaxanthin (Surai 2011).

Formulation and blending may be considered the easiest and cheaper strategy to design and manufacture more nutritious food for narrow group of consumers. The blend of different ingredients can be utilized to modulate the amount of nutrients meeting the specific requirements of consumers such as high sensitivity to some diseases such as, osteoporosis, atherosclerosis and coronary heart disease, etc. (Wildman 2007). Alternatively, the partial or total substitutions of some compounds, which are effective for the prevention of diseases such as allergies or intolerances, may belongs under the class of food formulation and blending. Back in the history, Swaziland was the first country deciding to fortify salt with iodine since 1920s, then this approach was adopted by the USA, and then spread all over the world (Betoret et al. 2011). Later, cereal products started to be used as vehicle to deliver many vitamins such as thiamin, riboflavin and niacin, making these fortified cereals capable to satisfy the nutritional needs of specific groups of consumers (Kyritsi, Tzia, and Karathanos 2011). In USA and Canada, the fortification of cereal products allowed to reduce the risks of anemia, (Naderi and House 2018) while in Australia thiamin fortification in bread-making flours is mandatory because enables to reduce the prevalence of the Wernicke-Korsakoff syndrome (Tiong, Chandra-Hioe, and Arcot 2015); also iron fortification of wheat-based products may reduce the occurrence of iron deficiency especially in women of childbearing age (Rebellato et al. 2017).

An interesting example of personalized blended food formula is reported by Farouk et al. (2018) who designed novel bread, spaghetti, yoghurt, ice cream and chocolate for elder people having mastication problems. The authors enriched the traditional food formulation by a fine powder of red meat obtained by a freeze-drying step of *Longissimus dorsi*. The authors made possible an increase of protein content in spaghetti from 5.7% to 13.6% by using the 28% of red meat in pasta formulation. The fortification of milk and dairy products with vitamin D have been worldwide used because milk has also a good capability to deliver calcium (Dąbrowska-Leonik et al. 2018). However, the fortification of milk and dairy products it is not limited to vitamin D but also with probiotic, prebiotics, polyunsaturated fatty acids, vitamins, etc. (Betoret et al. 2011; Puccio et al. 2007; González-Molina, Moreno, and García-Viguera 2009). With regard to probiotics and prebiotics in food formulation – predominantly *Lactobacillus* and *Bifidobacterium* – there is an extensive bibliography at disposal (Roberfroid 2000; Schrezenmeir and Vrese 2001). The use of *Lactobacillus reuteri* in enriched chewing gum and lozenges was found useful to reduce Streptococci population in the saliva alleviating dental plaque or gingivitis (Çaglar et al. 2007) while the use of *Lactobacillus casei* Shirota (LcS) was indicated for its ability of reducing the gastrointestinal symptoms of chronic constipation (Koebnick et al. 2003).

However, under the wide number of examples of probiotic used in manufacturing healthy food products (Do Espírito Santo et al. 2012; Blaiotta et al. 2018; Navab-Moghadam et al. 2017) it is reasonable to sustain that personalized strains of probiotic could be easily used at home or in food-shops preparing products as smoothies, kefir, beverages, etc., getting several tailored benefits for our personal needs. In 2018 the company Future Market, proposes the so-called *Custom Culture* consisting in personalized yogurts based on the use of AnalyzeMe data to get a map of personal microbiome and to design a personal equilibrium between probiotics and prebiotics usable for customized yogurts (Custom Culture 2018). A very interesting approach – unfortunately not used yet for food manufacturing – is the personalized therapy called 'TripleA method' (Kort 2014). Essentially this method is based on the sampling of host-specific probiotic bacteria from some part of our body (i.e. the intestinal tracts or vaginal environment), to propagate/cultivate them and to manufacture tailored population of probiotic that can be stored in different conditions allowing multiple dosage over time. The most important benefit of this approach is that the bacteria are perfectly adapted to the host and it is expected they to colonize human gut and delivery tailored healthy effects. This would be an excellent example of truly personalized food products if we push on the idea of using the bacteria from our intestinal environment for the production of tailored probiotic food. However, to our knowledge any detailed experiment on this potential approach is not available.

Moreover, an interesting application is the so-called Albert Smoothies Station capable to formulate personalized smoothies by blending several types of fruit and vegetables. People may order a personalized smoothie by mixing two to four ingredients. The system also returns exact nutritional content of the smoothies giving the possibility to accept or to make some modification.

Modify food composition poses his bases on the idea of eliminating – partially or totally – some constituents from fresh food. Definitely, the most important examples are the production free-lactose milk and dairy products as well as the gluten-free foods which has gained great attention in the last 15 years due to the increase not only of celiac but also many inflammatory conditions of the gastrointestinal tract (Rosell et al. 2014; Lionetti et al. 2015; Gobbetti et al. 2018). Although the complete removal of wheat from food products is the main route to dodge the aforementioned problems it is still a big challenge because the loss of sensorial properties of traditional food may be significant for these products (Mezaize et al. 2009). On this aspect we want to mention an innovative technology that has been recently proposed to keep unvaried the main physical and sensorial properties but reducing his related-healthy problems. Recently, the company New Gluten World (NGW) has registered a Italian patent (No. 0001414717) valid in 105 other countries around the world (NGW 2015). NGW claimed that their patent is describing a new process of detoxification of gluten proteins. The new method does not remove gluten portion from the flour by using the traditional methods (chemical and enzymatic methods), but only eliminates the toxic component by using chemical- physical process. Rodriguez Furlán and Campderrós (2017) have substituted sugar and fat contents of dairy desserts. Schmiele et al. (2015) successfully used dietary fiber of cellulose to substitute fat content of pork processed meat obtaining a reduction of fat content in meat products of 50%. Other examples of reducing fat content in food by using many substitute such as oat dextrin (Shen, Luo, and Dong 2011), soy milk in addition with xanthan and guar gums (Nikzade, Tehrani, and Saadatmand-Tarzjan 2012), green banana puree (De Souza et al. 2018), sunflower oil as 'organogels' (Moriano and Alamprese 2017), dried chia seed mucilage (Fernandes and Salas-Mellado 2017), to namely only few, are available in scientific literature.

Use of innovative sources of nutrients to aid food personalization

As discussed before, within the idea of food personalization belongs not only the nutritional needs but also the sensorial expectations. This open for an important question: do we have all is needed – the raw food or ingredients – to get a truly personalization able to satisfy all people? People diversity is incommensurable therefore the correct answer should be that we cannot satisfy anyone or, at least, this is very hard to do. However, this question demands of exploring innovative sources of nutrients potentially usable for the specific requirements of narrow group of consumers or for any individual. For instance, the unstoppable increase of the number of people who have adhered to the vegetarian and vegan diet gives us the opportunities to discuss, as first step, on the possibility to use innovative plant-based proteins such as micro- or macroalgae (Stone et al. 2018).

Plant based sources

We want to start with plant-based sources of proteins because the use of meat protein is currently in crisis for healthy, environmental and ethical concerns. There are a plenty of plant-based sources that are considered as good substitute of meat protein. Within this group there are soy, rice, wheat, sorghum, millets, oat, hemp seed, flaxseed, pea, lupin, moringa, lentil, African legumes, peanut, quinoa, amaranth, chia, canola seed, rapeseed (Nadathur, Wanasundara, and Scanlin 2017). For many of them is possible to find a wide literature, while for others the attention has growing only recently. Among these we want to review the potential of using moringa and lupins in designed food formulation.

Moringa (*Moringa oleifera Lam.*) is a tree natively grows in north-western of India which has been recently recognized as a good source of many nutrients (Maizuwo et al. 2017). Almost all parts of the trees are useful for human use but the most important commercial part of *Moringa* are leaves which can be eaten as fresh, dried or cooked. *Moringa*'s leaves contain protein up to 30% constituted of a good balanced essential amino acids making them a source of high quality protein (Gopalakrishnan, Doriya, and Kumar 2016). Additionally, *Moringa* may provide 7 times more vitamin C than oranges, 10 times more vitamin A than carrots, 17 times more calcium than milk, 9 times more protein than yoghurt, 15 times more potassium than bananas and 25 times more iron than spinach (Sreelatha, Jeyachitra, and Padma 2011). Based on this data, the daily usage of *Moringa* in the diet could alleviate people who suffer of iron deficiency (Nambiar 2017) or could help in controlling the blood glucose levels and plasma cholesterol and triglycerides due to the good amount of isothiocyanates and chlorogenic acid, respectively (Cho et al. 2010). Based on its good nutritional value and the easy use of its powder, *Moringa* may be a valuable ingredient for the production of the personalized food. Oyeyinka and Oyeyinka (2016) and Ogunsina, Radha, and Indrani (2011) reported that *Moringa* powder can be widely used in various food such as to fortify amala (stiff dough), ogi (maizegruel), bread, biscuits, cookies, yoghurt, cheese and in making soups. Moreover, being commercialized mostly as powder, *Moringa* would be very easy to use at home or for industrial applications. We are currently studying the possibility of using *Moringa* as a nutritional source to enrich vegetables and fruits for vegetarian or vegan diners (Husain 2018).

Sweet lupin seeds recently have gained interest as proteins source due to their nutritional content increasing the number of options to create new food formulation. Protein content of lupins is of 35–40% of the dry weight among which albumins and globulins are predominant. Fat content is about 8–12% consisting of a good amount of α-linoleic acid, tocopherols with values of 6-13 mg/100 g, phenolic acid (43 mg/kg dry seed) and fiber content up to 39% make lupins interesting source of nutrients. Moreover, prebiotic activities of yellow lupin polysaccharides were tested by Thambiraj et al. (2018) who suggested their use as nutraceutical and functional agents for designing innovative food formulation. Wolkers-Rooijackers, Endika, and Smid (2018) reported that vegan peoples could gain many benefits by increasing the amount of vitamin B12 in novel 'lupin tempe'. Considering practical usage in food formulation, Kornelia et al. (2018) employed germinated lupin and soybean flour to improve the nutritional properties – protein content and amino acid profiles – of novel muffins. Also, example of novel formulation with lupins addition may be found for yogurt (Hickisch et al. 2016), wheat bread (Villarino et al. 2015) and pork patties (Danowska-Oziewicz and Kurp 2017).

Sea-based source

Keeping our discussion mainly focused – but not exclusively – on alternative sources of proteins, marine products, specifically algae, are of great interest because their nutrient content is relevant and also they are renewable and sustainable (Cofrades, Serdaroğlu, and Jiménez-Colmenero 2013). Microalgae are quickly gaining interest in food industry for their ability to deliver protein to vegan and vegetarian (Lancaster et al. 2005). For instance, *Spirulina* accumulates 60–70 wt% of proteins and it belongs in the group of Generally Recognized as Safe (GRAS) products therefore they can be used in any type of food formulation. Moreover, microalgae contain a plenty of vitamins such as A, B, C, E, and minerals especially calcium and iron by which could be possible to obtain several advantages for personalized food production (Guedes and Malcata 2012; Santos et al. 2016). Among a huge diversity of microalgae such as *Chlorella* and *Spirulina*, *Dunaliella*, *Haematococcus*, *Schizochytrium*, *Scenedesmus*, *Aphanizomenon*, *Odontella*, and *Porphyridium* (Aqualgae 2015; Mobin and Alam 2017) the first two are the most popular and they recently have started to be commercialized over the world as dried powder.

The application of microalgae in food formulation especially for innovative breads have been experimented in the studies of Figueira et al. (2011) and De Marco et al. (2014). On the other hand, Castillejo et al. (2018) focused their tests on the planning of customized food reporting that different types of microalgae could be used to enrich smoothies with high level of nutritional compounds especially vitamin B12 useful for vegan consumers. Moreover, Santos et al. (2016) developed chocolate flavor shake-type powdered food for elderly formulated with *Spirulina* with the aim to get customized nutritional benefits. In our laboratory we are testing the use of *Spirulina* to enrich fruit and vegetables by using vacuum impregnation techniques with the aim to get food products for vegetarians (Husain 2018).

Although the consumption of seaweeds (macroalgae) in East China, Korea, Japan, Asia, Azorean Islands has a century, their wide use in Western Countries is limited to sushi and other kind of Asian food. Among four main groups of seaweeds, the most commercialized are Kombu (*Saccharina japonica*), Wakame (*Undaria pinnafidita*) and Nori (*Porphyra sp.*) (MacArtain et al. 2007). Even though the economic value of macroalgae is great (Rioux, Beaulieu, and Turgeon 2017), dieticians, researchers and industries just recently opened their interest for a practical usage of macroalgae in food processes. Seaweeds are rich in polysaccharides with a concentration up to 76% on dry weight as well as in protein with values of 9.71–24.8% on dry weight for brown seaweeds, 26% for green seaweeds, and 47% for red seaweeds (Paiva et al. 2014). Moreover, the proteins exhibit an amino acids profile very close to that of legumes or eggs (Fleurence 2004) and high digestibility while their amount is near to the FAO/WHO requirements for dietary proteins. Similarly they are rich in polyphenols and polyunsaturated fatty acids (PUFAs) (Shanab, Hafez, and Fouad 2018) as well as they show a great antioxidant activity (Maqsood, Benjakul, and Shahidi 2013). With this variety of nutrients the use of seaweeds in food formulation would be a useful methodology to obtain food products with unique attributes for home use or at the market (Rioux, Beaulieu, and Turgeon 2017). However, even if several papers analyzed the effect of seaweeds in novel food formulation, very limited experiments tested the manufacturing of food with nutritional and sensorial properties for narrow group of consumers or for individual. This is a pity since the great potentials of seaweeds not only in terms of nutritional contents but also for their physical properties as gelling or flavoring agents. For instance, Umami taste was discovered from *dashi*, a Japanese soup made with Kombu and other ingredients. So, the high amount of glutamate in marine macroalgae could be used to obtain specific taste. Pasta enriched with a small amount of seaweed was capable to reduce cooking loss (Prabhasankar, Ganesan, and Bhaskar 2009). Furthermore, in 2014 a cookbook based on recipes obtained by using seaweeds was published proving the extremely variety of applications in food preparation (Tinellis 2014). The market already counts macroalgae-enriched products like seaweeds crisp, biscuits, instant mashed potatoes, pasta, salads, to namely only few. Nonetheless in western countries there are some reluctances in eating food products derived from macroalgae and to use them in the kitchen (Rioux, Beaulieu, and Turgeon 2017).

Insects

Entomophagy is common for more than 2 billion people over the world. There are more than 2000 insects species that can be consumed by humans particularly in tropical and sub-tropical countries (Van Der Spiegel, Noordam, and Van Der Fels-Klerx 2013). Moreover, recent advances in chemical analysis showed that insects are a good source of high quality proteins (Dossey, Morales-Ramos, and Rojas 2016). Also, they have a low environmental impact and a very high feed conversion rate (Testa et al. 2017). Mainly there is a fraction protein content ranged between 13 and 77% – depending of different insect types – that make insects valuable sources of nutrients for human consumption (Jonas-Levi and Martinez 2017). But, also they contain good amount of lipids (20% of phospholipids), vitamins (riboflavin, biotin) and minerals (iron, zinc, potassium, etc.) (De Castro et al. 2018).

Based on these properties, the Food Agriculture Organization of the United Nations (FAO) added in its global agenda the employment of insect in food productions (FAO/WUR 2013). However, the employment of insect in Western countries is not easy because people are rather reluctant for many reasons (Chan 2019). What could be very useful is the introduction of small amount of insects in different forms such as dried powder, pastes, etc. So, by precisely modulating food formulation would be possible to obtain specific nutritional features reducing the reluctance of the consumers. This was the main aim of Azzollini et al. (2018) who utilized insects powder to produce enriched product by using extruding cooking and 3D printing. Southerland, Walters, and Huson (2011) used insect powders mixed with soft cheese in 3D printing to produce printed products with desired shape, structure, taste and nutritional value. Van Bommel and Spicer (2011) extracted basic carbohydrates, protein and others useful nutrients from both insects and algae. This mixture was employed in 3D printing tests in order to simulate the nutritional composition of steak and chicken.

Emerging technologies usable for mass customization of food

Gradually, the purpose to meet the personal needs of each consumer is capturing the interest of many companies. Mass customization affords products with uniqueness and appropriate costs. Under this light, the mass customization offers benefits for the economies of scale and economies of scopes. In food sector, mass customization is a multi-fold problems consisting not only in the obtaining of unique nutritional content and unique sensorial properties but also the guarantee of safety for an appropriate shelf life keeping stable food for a convenient lenght of time. To our knowledge there are not researches in progress exploring innovative technologies thought for this purpose but some food techniques – or borrowed from other fields of productions – are appearing in food sector as good candidates for the manufacturing of food for our uniqueness. Below we present those that – at the moment – we retain to be the best options for a practical developing of the mass customization of food.

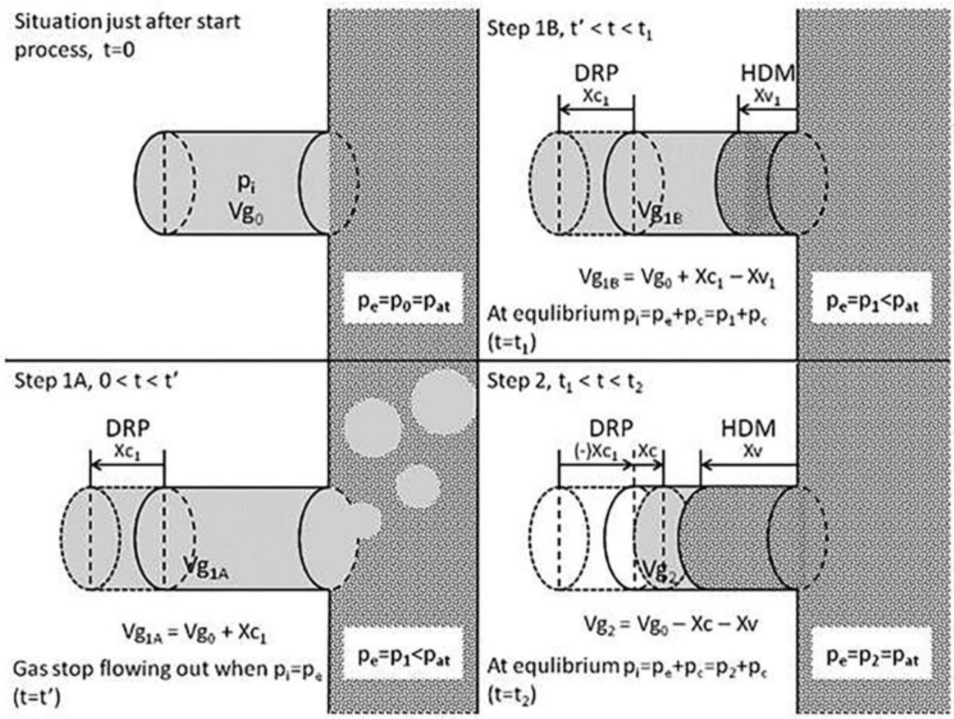

Figure 1. Hydrodynamic mechanism (HDM) and deformation-relaxation phenomena (DRP) contribute to the filling of ideal capillary with liquid during vacuum impregnation (from Radziejewska-Kubzdela, Biegańska-Marecik, and Kidoń 2014).

Vacuum impregnation treatments

Vacuum impregnation (VI) is a nondestructive method based on the fact that the majority of food products (i.e. vegetable, fruits, meats, cheese etc.) are rich of pores containing native liquids or gases. So, the main purpose of VI process is to replace the content of these pores with an external solution prepared by any desired chemical composition. Food structure and properties including porosity fraction, size and shape of capillaries, connectivity, mechanical properties of the solid phase are the determinants factors playing an important role for the filling of pores during VI treatments (Fito et al. 1996; Radziejewska-Kubzdela, Biegańska-Marecik, and Kidoń 2014; Galindo and Yusof 2015).

During VI process, vacuum is applied to fresh food (such as vegetables, fruits, cheese, meat, fish, etc.), which must be immersed in a solution of desired composition. Firstly, a vacuum pressure is applied promoting gases and native liquid to escape from the pores. Then, the atmospheric pressure is restored and the external solution penetrates into food structure under the action of a negative pressure gradient (Fito et al. 1996; Hironaka et al. 2011; Radziejewska-Kubzdela, Biegańska-Marecik, and Kidoń 2014; Galindo and Yusof 2015). The phenomena involved during VI treatments have been deeply explained by Radziejewska-Kubzdela, Biegańska-Marecik, and Kidoń (2014) (Figure 1).

Overall, vacuum impregnation (VI) may be used for many different purposes such as preserving food products, prolonging shelf life, enhancing freezing tolerance, etc. But, what we want to deeply analyze is the capability to improve – in a controlled way – the nutritional value or the amount of bioactive compounds (Betoret et al. 2003; Galanakis 2016). As examples, flavonoids which have a high antioxidant activity and free-radical scavenging capacity have been used to enrich many vegetables or fruits, with the aim to obtain food more effective in the prevention of some diseases as inflammation, coronary heart disease, atherosclerosis, diabetes, etc. (Yao et al. 2004).

Castagnini et al. (2015) impregnated 100 g of fresh apples with 22 mL of blueberry juice capable to significantly improve anthocyanin content of the final products. Furthermore, the authors reported that by dehydrating apples disks at 40 °C it was possible to maintain 50% of the initial anthocyanin content of the impregnated apples.

Likewise, vacuum impregnation has been used for mineral fortification to introduce calcium and iron into eggplants and orange rings. The authors found the best nutritional enrichment when applying vacuum pressure ranged between 5–50 kPa for a vacuum time of 10–60 min (Fito et al. 2001). Sanzana, Gras, and Vidal-Brotons (2011) impregnated broccoli, cauliflower, endive and carrot with a solution prepared by dissolving in water Aloe Vera powder (Sanzana, Gras, and Vidal-Brotons 2011), that is recognized useful to tackle some diseases such as dermatoses, reducing blood glucose sugar, lowering lipid level in patients with hyperlipidemia. Similarly Derossi et al. (2018a) impregnated apple slices with an aqueous solution of Aloe Vera gel. The results proved that is possible to improve the polymannans content from 1 to 8 mg/100 g for fresh and impregnated apples, respectively.

On the basis of these few examples the capability to enrich food matrix with nutrients or bioactive compounds by VI treatments has been extensively proved, but, with the

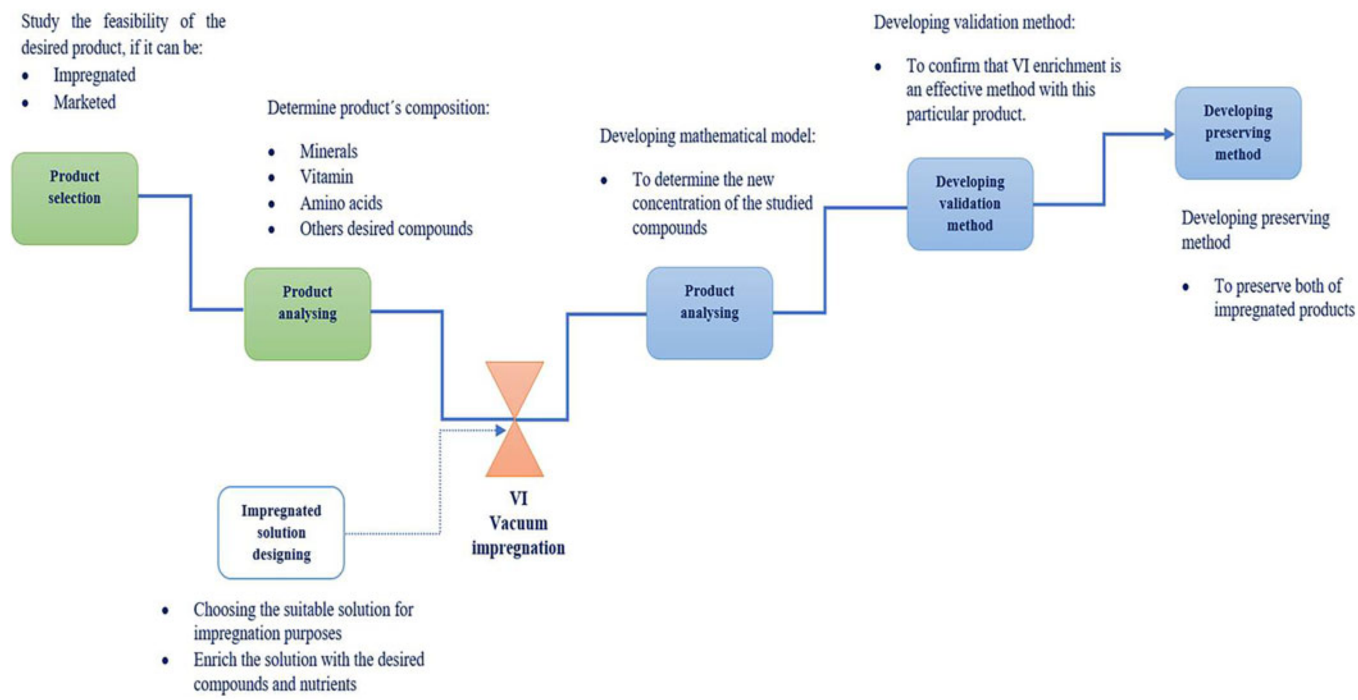

Figure 2. Schematic representation of strategy which might be followed to use vacuum impregnation as a useful tool to produce personalized food.

aim to obtain personalized food, that means a very precise modulation of the amount and the type of macro- and micronutrients, vacuum impregnation can be oriented in some simple steps.

Basically, fortification of food using some specific compounds is the corner stone in this track. First, an evaluation for the feasibility of some products should be done to ensure the capability of impregnating them by specific solutions. Second, it must be followed up by determining the concentration of the desired compounds (such as minerals, vitamins, biological compounds, probiotics, amino acids etc.) in the interested fresh food (such as vegetables and fruits). Third, there is the need to develop a mathematical model to determine the concentration of desired compounds in the prepared solution which will be impregnated into the products. Finally, developing a validation method to confirm that enrichment of food products by some compounds is an effective method in this field (Figure 2).

Under the approach of VI modeling, Castagnini et al. (2015) reported that vacuum impregnation may be intended as an important tool for designing nutritional balanced, healthy and/or functional innovative products. Betoret et al. (2012) used vacuum impregnation to introduce homogenized mandarin juice with low-pulp content in apple snacks. The results showed that 40 g of the impregnated snacks were capable to furnish the same amount of hesperidin obtained from 250 mL of mandarin juice. These apple snacks were served to the obese childrens in order to mitigate inflammatory conditions and increase the antioxidant capacity. Schulze et al. (2012) used vacuum impregnation to enrich apples with quercetin glycosides (flavonoid) discovering that the average daily flavonoid intake (22 mg/d) could be obtained by consuming 36.4 g of these VI apples.

Gras, Vidal-Brotóns, and Vásquez-Forttes (2011) fortified iceberg lettuce with calcium using vacuum impregnation. The experiments were capable to increase the Ca^{2+} content up to 160 mg Ca^{2+} per 250 g of lettuce; this amount is comparable to general dairy products. This usage of VI could made iceberg lettuce a good source for calcium especially for people that, for any reason, do not eat milk and dairy products (Gras, Vidal-Brotóns, and Vásquez-Forttes 2011).

De Lima et al. (2016) stated that by using VI it was possible to enrich of Ca^{2+}, pineapple samples up to a concentration of 91% higher than the samples treated at atmospheric pressure. These pineapples samples may be considered as enriched products according to both North American and Brazilian legislation; moreover a serving size of 50 g of dried VI pineapples would be able to provide 100% of the Dietary Reference Intakes (DRI) of calcium (IOM 2011). Xie and Zhao (2003) impregnated fresh cut apples with solution of zinc and calcium. The results proved that 15 – 20% of the Daily Reference Intake (DRI) of calcium and above 40% of DRI of zinc could be provided by consuming 200 g of these fresh impregnated apple slices.

Apple samples vacuum impregnated with green tea extract resulted in an increase of total phenolic content (TPC) 5 times of fresh apples (300 mg GAE/100 g f.w.) and a catechin concentration between 100 and 130 mg GAE/100g f.w., as reported from Tappi et al. (2017). Moreno et al. (2017) applied vacuum impregnation (VI) in combination with ohmic heating (OH) to get a significant increase of L-arginine into apple cubes.

Apart minerals also vitamins have been used to fortify vegetables and fruits by using vacuum impregnation. Park, Kodihalli, and Zhao (2006) proved that the content of vitamin E in impregnated apple slices was 100-fold to the fresh samples. Another study was performed by Lin et al. (2006) who introduced solution of 20% diluted honey and vitamin E of 0.4% to 0.8% (with 3 different sources of α-tocopherol) into pears´ tissue. The experiments indicated that 65% to 80% of the vitamin E in the impregnated pears was preserved for 2 weeks during storage at 2 °C. Similarly, when working with strawberries, the impregnated amount of vitamin E did not show a significant reduction during storage after 2 weeks at 2 °C and after 6 months at −23 °C (Han et al. 2004).

Hironaka et al. (2011) investigated the possibility of impregnating whole potatoes with ascorbic acid (AA) and its remaining content after cooking and storage. The results proved as would be possible to increase of 10-times AA contents in whole fresh potatoes. Therefore, consuming 100 g of these impregnated potatoes (25 min steam cooked) can provide the adults of 90–100% of the RDI of AA. Similarly, by working with potatoes, Erihemu et al. (2014) proved that it is possible to improve of 6.4 times the iron content of potatoes by using an impregnation iron solution of 0.4/100 g providing 67–90% RDI and 31–41% of RDI respectively for adult man and woman.

With regard to other kind of healthy effects, also probiotic microorganisms may be introduced in the pores of food structure by VI techniques (Radziejewska-Kubzdela, Biegańska-Marecik, and Kidoń 2014). According to the study carried out by Betoret et al. (2003), impregnated apple slices which were air dried and maintained at 4 °C for 2 months, still showed a good number of viable bacteria equal to 10^6 cfu/g of *L. casei*, that is the same number of bacterial concentration which exists in the commercial dairy products (Betoret et al. 2003). Later in time Betoret et al. (2012) impregnated apples obtaining 10^7 CFU/g dry matter of bacteria *L. sallivarius ssp*. The innovative apple snacks were served to five groups of dyspeptic children showing a positive effect in the suppression of *H. pyroli*. Flores-Andrade et al. (2017) used vacuum osmotic dehydration (VOD) to introduce *L. rhamnosus* in apple slices. Their results proved the ability in accumulating a microbial above $1.64*10^7$ CFU/g d.b., corresponding to the concentration found in commercial probiotic food products.

However, VI may could be used for manufacturing personalized food in an alternative point of view: by reducing the amount of some anti-nutrients or toxic compounds in food. This is the interesting approach adopted by Yusof, Rasmusson, and Galindo (2016) who modulate nitrate accumulation in spinach leaves. The authors have introduced sucrose into the intercellular space of spinach leaves. This promoted the metabolism of the stored nitrate in cell structure reducing the accumulation in the edible leaves. The authors argued that by a deep understanding of metabolic pathway, VI could be used as a useful tool to reduce anti-nutrients content or, alternatively, to increase nutrients or bioactive substances. Finally, under the broad term of personalization of food we want to consider the capability to use vacuum impregnation to improve sensory properties of food products in order to increase consumer's acceptance. Diamante et al. (2014) impregnated apples by black currant extract resulting in color modification, improvement of water loss during dehydration of apples samples and the increase of antioxidants compounds and vitamin C (Diamante et al. 2014). Rößle et al. (2011) used vacuum impregnation to introduce in apple tissues honey combined with some browning inhibitors. The reported data proved some modifications in both physical and chemical properties of apple slices which made the final product more marketable for specific consumers (Rößle et al. 2011). De Lima et al. (2016) by performing VI treatments on apples using a calcium solution interestingly reported that apples were porous-and-crunchy due to the change in glassy transition temperature. This definitely proves that by VI treatment some sensorial properties could be modified opening possibilities in the designing and creating customized features capable to improve the acceptance of consumers.

With regard to others food categories such as meat, fish and cheese, for our knowledge very few experiments have been performed in detail and none of these experiments were conducted to improve the nutritional content but essentially to introduce desired flavors/tastes or to control salt diffusion. Chiralt et al. (2001) have used vacuum impregnation for salting of meat products (ham and tasajo), fish (salmon and cod) and cheese (Manchego type cheese). Their experiments have indicated that salt distribution was much better in comparison to the traditional process at atmospheric pressure, and that the samples enhanced in flavors and textures. Likewise, Hofmeister, Souza, and Laurindo (2005) applied VI to Minas cheese for salting reasons and found that VI was very effective in obtaining more salt in cheese layers improving its quality and acceptability. Finally, the use of vacuum impregnation in food processing might have a promising future in manufacturing personalized food when using innovative source of nutrients such as *Spirulina* which is very rich in protein (60–70% dry basis) and vitamin enabling to obtain customized food for vegetarian or vegan people. These potential applications are under evaluation within our research group with the aim to use VI to obtain personalized food products for vegetarian people (Husain 2018).

3D printing as promising method for shaping food based on our desires

3D Printing is an innovative technology belonging in the wider Additive Manufacturing (AM) technologies defining a class of manufacturing methods capable to create complex 3D structure by depositing layer-by-layer some type of materials, predominantly plastic materials. Recently in time, 3D printing opened new perspectives in the manufacturing of goods never thought before, due to the fact that each people can produce things based on a 3D model designed with personalized properties and functionalities. The New York Times (2014) indicated the 3D printing as the world-changing technology. Although 3D printing is mainly used for rapid prototyping and for the production of spare parts, recently is gaining interest in food sector.

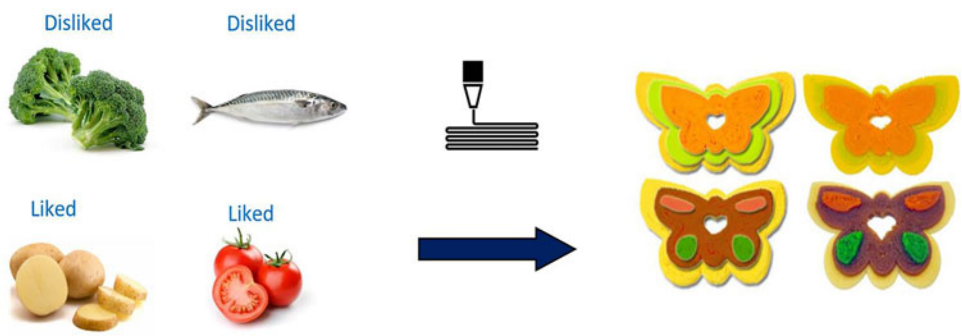

Figure 3. Schematic representation of the use of 3D Printing process to create innovative food by increasing the overall appeal by working on shape, color, dimension and taste. A representative example considering child preferences (Sun et al. 2015a).

When speaking about the 3D food printing several technologies may be mentioned and all of these have been widely reviewed (Sun et al. 2015b; Lipton et al. 2015; Godoi, Prakash, and Bhandari 2016). But, the most used method for 3D printing of food is the material deposition by extrusion of a like-filament of food formulation by creating the desired structure. There are several critical variables affecting the fidelity of printing some of which belongs to the properties of food formula and they can be summarized as 'food printability'. On the other hand, there are several processing variables which regard the printer movements and their effects on the quality of the final products (Severini and Derossi 2016; Kim, Bae, and Park 2017; Liu et al. 2017; Lupton 2017; Derossi et al 2018b). However, we want to exclusively analyze 3D Food Printing in the way of potential benefits for a personalized food. Firstly, 3D printing has hundreds of degrees of freedom, because being capable to potentially produce any type of shape, dimension and internal structure. Secondly, it is possible to prepare nutritionally personalized food formula exhibiting good printability. Thirdly, complex food formulation may be designed not only in terms of nutrients and/or bioactive compounds but also in terms of color, taste and flavors, obtaining customized sensorial properties. Finally, 3D printing is a sustainable food processing because it is possible to print only what we want to eat; that means that waste production would be significantly reduced.

On these bases, 3FP may be considered as the first option to make feasible the concept of food mass-customization. The main pillar of this technology is that the consumer data could drive the production of foods. Practically, by enabling food ingredients and their ratio to be prepared automatically on the basis of consumer's information (nutritional need and sensorial desires) it would be possible to greatly improve the diet of any people. Moreover, the consumer's acceptance of some kind of food, containing important bioactive compounds but that usually are not appreciated for their sensorial properties (i.e. broccoli or fish for children), could be improved by adjusting taste, flavor or color as well as the visual aspect of the final food product (Figure 3). Taking into account the published data, several shapes and structures have been designed and printed to improve the appeal of food. Yang et al. (2018) printed objects like an anchor, gecko, snowflake, ring and a tetrahedron by using a lemon juice as edible ink. Liu et al. (2018), who performed some 3D printing experiment with a mashed potato, printed 3D structure like apples, hear-shape, bear head, Chinese character, xi (Figure 4). Mantihal et al. (2017) printed three models by depositing melted chocolate. Hamilton, Alici, and In Het Panhuis (2018) tested the ability to print two available breakfast spread, Vegemite and Marmite, created several structures very attractive for child such as Vegemite Smile, Vegemite stick and Vegemite fish. Finally, the authors concluded that 3DFP may be used to fabricate food into an attractive form for special occasion such as children birthday parties (Figure 5). Other uncommon food structures have been tested in the last 5 years such as cubes by using pectin solution (Vancauwenberghe et al. 2017), 10-triangular faces pyramid by using a blend of fruit and vegetables (Severini et al. 2018), the symbol of Apple Inc. (Wang et al. 2018) by using surimi gel, some creative structures by using sodium caseinate dispersion (Schutyser et al. 2018).

However, the level of customization by using 3D printing is not only exclusively for visual aspect, taste and flavor, but another important promising benefit is the possibility to modify food structure and composition in order to customize it for specific requirements of some consumers. Kouzani et al. (2017) proposed the use of 3D printing technique to produce a custom design and production of visually appealing foods, which will be consumed by people with special mealtime needs. The authors produced objects based on a mixture of tuna puree (high with protein) to be served for people suffering of dysphagia. Le Tohic et al. (2018) for the first time created a 3D printed cheese analyzing the effect of several variables on the main textural and melting properties. They observed significant differences in structural properties of cheeses by 3D printing, concluding that by a careful modulation of critical variables will make possible to modulate sensory attributes for new potential tailoring structures.

Derossi et al. (2018b) reviewed the main nutritional requirement for children with ages from 3 to 10 years, and then they printed snacks consisting in banana (73.5%), white canned beans (15%), dried nonfat milk (6.0%) and dried mushrooms (2.0%). The authors were able to satisfy the 5–10% of the recommended daily intakes (RDA) in energy, vitamin D, calcium and iron. (Lille et al. 2018) printed food pastes made of protein, starch and fiber-rich materials as a

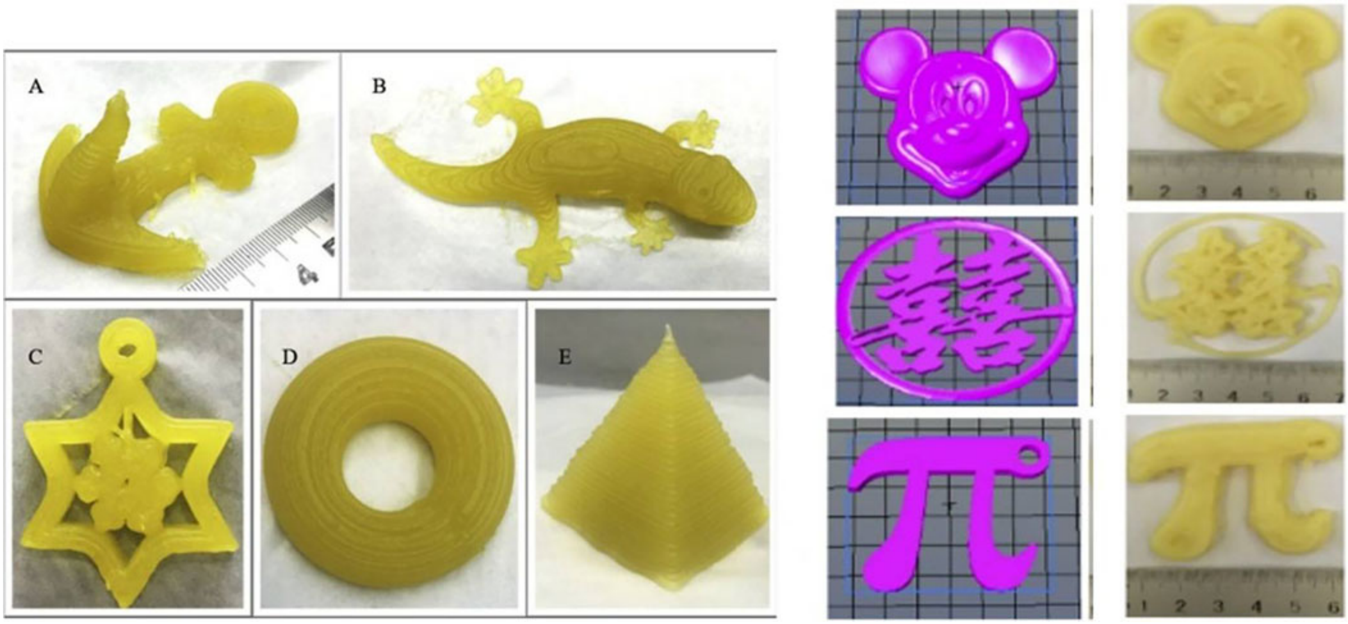

Figure 4. Examples of personalized food structures obtained by 3D Food Printing from (Yang et al. 2018; Liu et al. 2018).

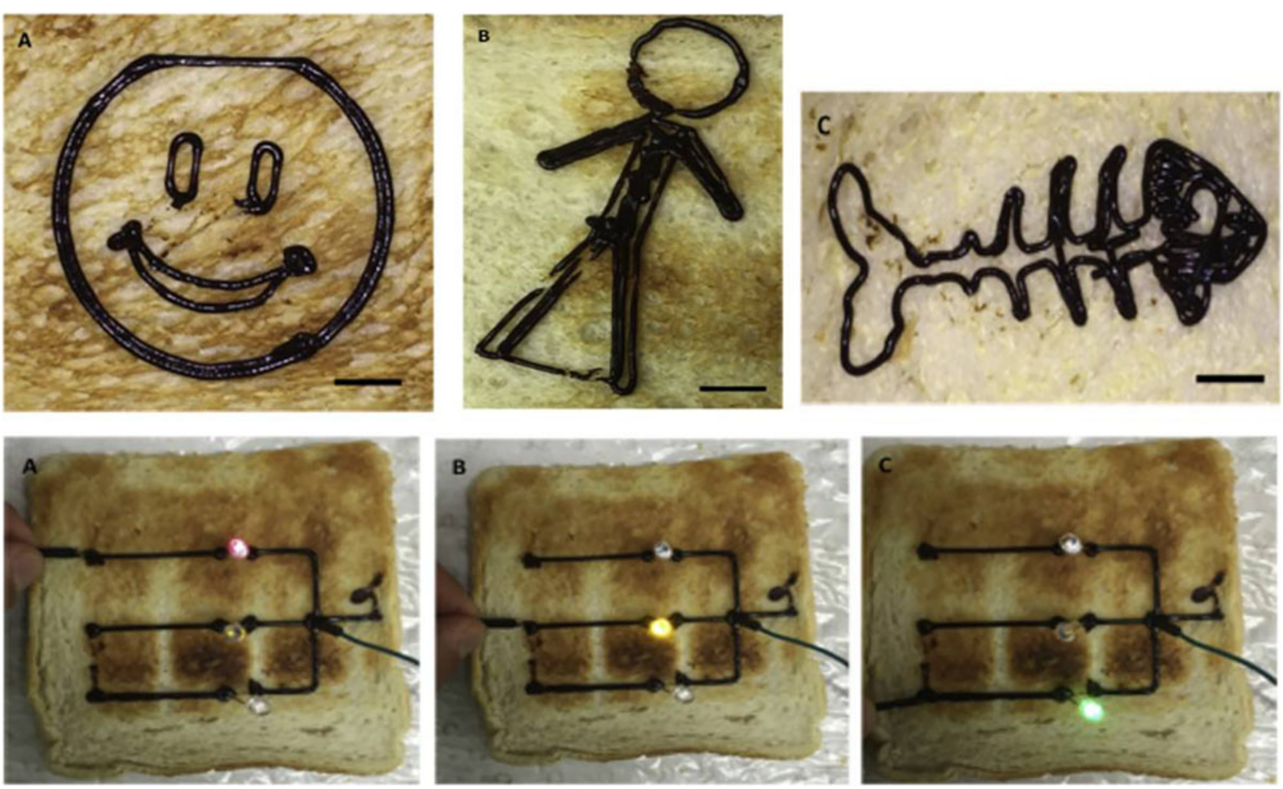

Figure 5. 3D printed personalized food. Examples of structures printed on bread slice from (Hamilton, Alici, and In Het Panhuis 2018).

first step of the development of healthy and customized snack products. Azzollini (2017) combined 3D printing technology with the use of insect powder as innovative source of protein. They produced snacks enriched with ground larvae of Yellow mealworms showing an increase of essential amino acid from 32.5 (0% insect) to 38.2 and 41.3 g/100 g protein, respectively for snacks enriched at 10 and 20% of insect.

Vancauwenberghe et al. (2017), working with pectin-based bio-ink, had the main purpose of introducing cells isolated from leaves as ingredients in 3D printed foods. This is the first experiment performed to produce 3D printed cellular or particulate foods and open new perspectives in the manufacturing of cellular edible materials, having similarities with real plant tissue. Recently, the Barilla S.p.A. has launched some innovative and unique shape of pasta by using 3D printing technology. In a report published from the company they stated that this technology will allow the shape that like you, but also changing taste, texture, color and nutritional values in a very pioneering customized eating experience (Barilla 2016).

What personalized food the marketplace offers?

Theoretically the market of personalized food products is the greatest as possible because it is based on the idea that each individual needs specific meals many times for day. This is an immensurable potential market and as expected several companies have started to propose some products able to provide some general personalized properties. In this section we want to briefly summarize What does the market offer and what type of solution, if reported, the company has used to prepare, produce and deliver food with this level of individualization.

However, the terminology 'Personalized' is used in a very broad sense in the majority of the cases for which the companies offer the possibility to choose on the individual sensory preferences, also considering personal budget at disposal and desired goals such as weight to loss, the rate of losing weight, etc. But, very few companies really are proposing personalized food based on the individual responses of the body to specific health biomarkers and genetic information. Other essential gap existing in the market of personalized food is between the capability to furnish only advices on what food are right for the customers leaving them the buying of ingredients, food preparation and choice of cooking conditions, while in other cases the consumers are helped to cook by using app which contains hundreds of recipes to accurately follow. Finally, very few companies after designing personalized food are capable to create and to deliver the meals at home.

One of the most popular company is Habit (2018), based in San Francisco bay area, which proposes to generate personalized information on how individual body responds to the nutrients by looking more than 60 indicators grouping in sensitivity biomarker, blood sugar biomarker, cholesterol biomarkers, etc. Each individual must collect samples at home and he must send the sample to a laboratory that analyzes and obtain basic personal data. Also, at each customer is asked to collect blood samples before and after 60 and 120 min of drinking a Habit Challenge Shake and send they to the company's lab.

Metabolic meals (2018) gives the opportunity to every person to select his meals with the portion that better fit his body on the basis of a wide variety of meals defined and prepared by a team of chefs and nutritionists. ONO is a young company (ONO 2018) that collects and elaborates several personal data such as personal DNA, the state of immune system and gut health and overall information of the life-style and then, after data elaboration, the company prepares tailored meals directly delivered at home.

Similarly, Eatthismuch (Eat This Much 2018) which gives personalized advices on the correct meals to prepare and eat. On the basis of desired goal of each people (weight loss, weight loss rate per day, etc.) and considering personal preferences, the consumers weekly receive an email in which the complete list of food to buy and cooking advices are given. Blue Apron (2018) enables to choose desired food within a wide list of chef-designed meals and to receive at home the fresh ingredients and the advices necessary to cook these meals. Diettogo (2018) is a company offering four customized menus on the basis of taste and lifestyle. Weight loss menu, balance menu, balance diabetes menu and vegetarian menu are possible may be chosen after that consumers receive the meals at home.

In the field of food for athletes Fresh Fitness Food (2018) helps to reach specific fitness goals like building mass muscle, reducing body fat or more easily to feel better and more energized. Interestingly this company reports on its web site the use of innovative cooking methods – not clearly reported – to obtain a perfect balance between taste and tailored nutritional content. More simply Fitness Ration (2018) prepares and delivers four specific menus called High-protein active, Low-cal artisan, Cutting edge Keto and Addons.

Nutrifit (2018) is a company that prepares diet plan for some specific consumer groups intended to reach some aims classified as weight management, health management, sport specific nutrition, family meals and body after baby. Moreover, for each of these groups it is possible to customize the personal meals choosing the diet style like Mediterranean diet/Omnivore, Zone-Friendly/High protein, Gluten free and Vegan Meal plan. Daytwo (Day Two 2018), a company that patented the research of Prof. Segal and Prof. Elinav published on cell (Zeevi et al. 2015), has proposed a smart and personalized nutrition by advancing consumers on the basis of individual body metrics and gut microbiome. Especially, each individual has called to use a stool sample kit, by using a simple blood test and by filling a questionnaire. After individual usage, the samples are submitted to the analysis of DNA sequence acquiring individual information on the profile of microorganisms that we uniquely host, and all these information are used to predict what food are right for us.

DNAfit (2018), similarly to Habit, is a company that after analyzing a series of genetic information gives us advices for fitness and diet, for sport or for wellbeing. In the same way is the work of Fitness Genes (2018) that after receiving personal saliva samples and after DNA analysis provides personalized advice on diet plan workout.

Conclusions

In a scenario in which it is expected that world population will growth up to 9.7 billion of people in 2050, the capability to tailor the nutrients intake to people uniqueness – in a personalized mode – is one of the most important challenges of the next years. When it will be feasible, this strategy will significantly improve the consumer's health, to reduce the chronic diseases also to use nutrients in a more sustainable way. This belongs in the wide terminology of Personalized Food Manufacturing (PFM) meaning the capability to produce food that satisfies people uniqueness according to the discovery that, based on our genetic profile and microbiome in the gut, each people is unique in the way to metabolize food. However, for a reliable application of personalized food manufacturing will be necessary to satisfy many other specific needs/desires of each consumer such as sensorial preferences, lifestyle, socio-economic conditions, diet styles, religions, ethical concerns, gender, age, personal health problems, etc. To address these challenges there is the tremendous need of new technological solutions in many different fields such as agriculture, breeding, medicine, biology, food processing, food formulation, food design, etc. Modern agriculture and breeding may play an important role for the nutritional enrichment of fruit and vegetables, meat and fish with specific nutrients contributing, for instance, in satisfying the requirements of narrows consumer's group – i.e. vegetarians and vegans – or to increase the options at disposal for designing food products with novel nutritional profile. Also, the employment of innovative plant- or animal source of nutrients such as microalgae, seaweed and insects will play an essential role because they suddenly could increase the portfolio at disposal for designing innovative food formula with tailored properties. Nevertheless, for some of these the public acceptance is still hindered by cultural habits on food while for others a more extensive usage is waiting more scientific information. Another essential step for the PFM will be the discovering and implementation of new technologies able of making possible any type of food design both in terms of nutritional value and sensorial properties. Among this, 3D Food Printing seems to be a good candidate for food customization because it allows of creating any shape and dimension by depositing, layer-by-layer, food material on the base of a 3D CAD model. Due to the great interest on PFM, several companies are already paying attention on this market sector, some of which are able to prepare personalized meals for restricted number of people based on analysis of the genes. Nevertheless, none technologies have been tested or used for a medium-large size group of consumers. Universities, public entities and private companies are called to search technological solutions to deliver personalized food for a large number of people in the market, at restaurant, bars, and school and university canteens.

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