Chapter 10
Non-compliant Fruit as New Functional Food Ingredients

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10.1 Introduction

In recent years, healthy eating habits were recognized as fundamental due to the beneficial properties in human health associated with the high level of bioactive compounds (BCs). In this context, consumption of fruits assumes great relevance, since they are rich in these BCs with antioxidant, anti-diabetic and anti-inflammatory activities (Gómez-García et al. 2020). Currently, the main access of consumer to the fruit is restricted to the supermarkets, where the fruit is presented with good aesthetic requirements and under standard size. So far, fruit with a non-standard size or with small irregularities on the surface are usually restricted on the acceptance, assuming a classification of non-compliant fruit that ends frequently as fruit losses in the producer. However, due to their richness in bioactive compounds, non-compliant fruit should not be discarded, but instead considered as value-added value coproduct. Therefore, an effort to find value-added for these fruits has been made contributing at the same time to comply with relevant guidelines of the European Commission and National government that promote food losses and waste reduction or reuse. Efficient waste management is among the most important challenges yet to be addressed in the twenty-first century, and both meet up in the agri-food sector. The production of new functional ingredients from these fruits consists of a valuable and sustainable approach for taking advantage of these food losses. Thus, this book chapter aims to present the most promising alternatives for the valorization of non-compliant fruit, currently underexploited, as well as the challenges that may arise when considering the valorization of this waste in the form of value-added bioactive products.

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10.2 Food Losses and Waste

The Food and Agriculture Organization of the United Nations (FAO) estimates that, annually, about one-third to half of all food globally produced for human consumption is either lost or wasted, leading to considerable economic (representing a cost of around 990 billion dollars), social and environmental costs (FAO 2011; Trigo et al. 2019). Of these, in 2012, more than 88 million tons per year were generated within the European Union (Jiménez-Moreno et al. 2019). Therefore, this problem translates into economic losses for farmers and other stakeholders in the food supply chain and into higher prices for consumers. Additionally, hinder the transition to environmentally sustainable food systems and, since they are associated with considerable use of land, water, energy and agricultural inputs, they also contribute to the emission of millions of tons of greenhouse gases (Adam 2015; van Giesen and de Hooge 2019). Food losses occurring mainly in the first stages of the food supply chain (agricultural production and postharvest) refers to the decrease in edible food mass throughout part of the supply chain that specifically leads to edible food for human consumption (FAO 2011). However, food loss occurring at the end of the food supply chain (retail and final consumption) are usually food waste since it were discarded or because it was not consumed by humans, which relates to retailers and consumers practices and behaviors (FAO 2011; Parfitt et al. 2010; Thyberg and Tonjes 2016). In industrialized regions, food is to a significant extent wasted at the consumption stage meaning that it is discarded even if it is still suitable for human consumption (FAO 2011). Studies commissioned by Gustafsson et al. (2013), estimated that yearly global about 50% of the fruit and vegetable production were food losses and waste. In Europe, losses in agricultural production dominate (20%) (Fig. 10.1), mostly due to the grading caused by demanding quality standards (e.g. aesthetic requirements) set by the Europe, retailers and consumers concerning products shape, size and color (FAO 2011; Jiménez-Moreno et al. 2019). Nevertheless, food losses at the end of the food supply chain are also substantial (19%) in the industrialized regions, since society is very consumerist wasting a lot (Baptista et al. 2012; FAO 2011). The causes of food waste vary throughout the agro-food chain and differ from region to region. As mentioned above, part of the generated food waste comes from the demand of society standards. Thus, some of the agricultural products, although tasty and with good quality, are wasted since do not meet certain parameters.

10.2.1 Non-compliant Fruit

These losses generated during production result in a waste ranging from 10 to 30% for farmers, mainly due to its aesthetic requirements and are called non-compliant fruit. Elimination of these residues is complex and, in many cases, requires heavy investment. Therefore, these food losses are usually conducted for animal feed, or

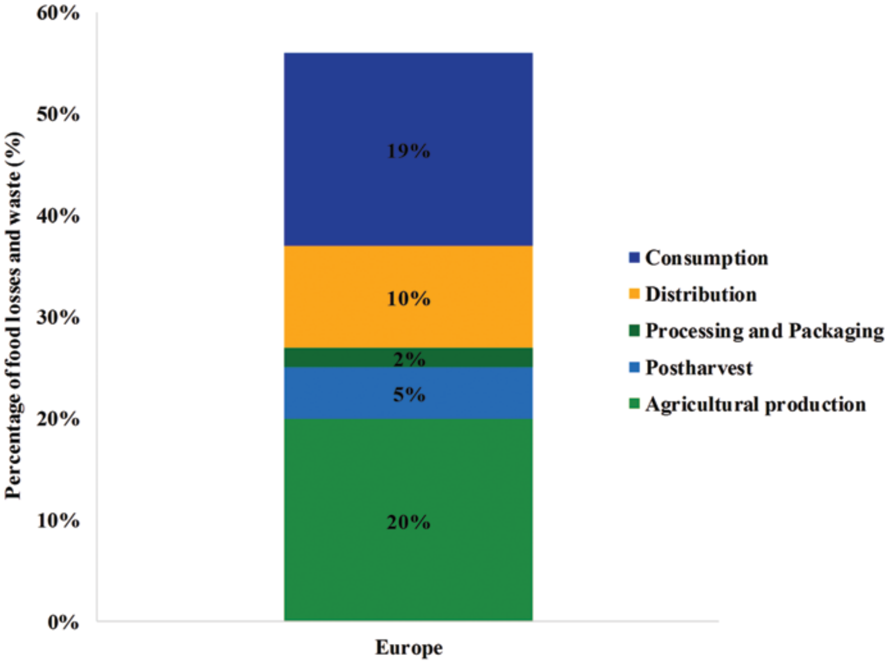

Fig. 10.1 Percentage of food losses and waste of fruits and vegetables generated in each stage of food supply chain in Europe. Adapted from FAO (2011)

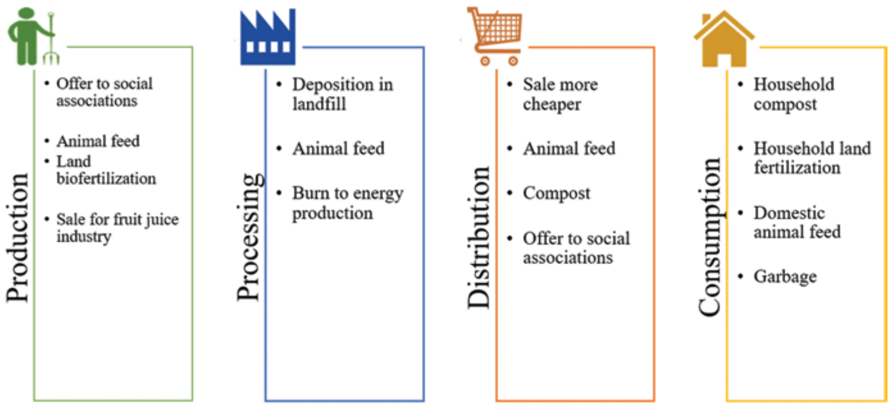

Fig. 10.2 General destination of fruit losses during the food supply chain. Adapted from (Baptista et al. 2012)

to supply social institutions or to supply the production of concentrated juice or to be incorporated into the ground for natural soil fertilization (Fig. 10.2). Losses in processing, distribution and consumption are mainly peels, seeds, pomace and trimmings, and are usually applied, for example, to be burnt towards energy production, sale at cheaper price because the shelf-life is in the end a garbage, respectively.

All the fruit that does not conform to the aesthetic requirements (color, size and shape) and is wasted in production and that is still perfectly edible and safe to eat are non-compliant fruit, previously described. Such fruit represents more than 50 million tons of waste every year in the EU, especially because it does not fit with the aesthetic parameters (Porter et al. 2018). Different factors contribute to the fruit losses as non-compliant food, such as; (1) natural modification on shape or color during production (plant diseases or climate changes), (2) damage during harvest and transportation and (3) low-quality conditions during post-harvest storage. All these considerations directly affect fresh fruit which becomes in economic losses to the producers when they start with the fruit selection process, selecting only those that satisfy the aesthetic requirements (Adam 2015; Göbel et al. 2015; FAO 2011). Supermarkets at the farm gate due to rigorous quality standards concerning weight, color, size, shape and appearance reject some fruit. Therefore, a large amount of fruit never leaves the farms.

Two quality standards for fresh products can be identified in European-regulations: (1) general marketing standards, consisting of minimum quality requirements regarding the freshness, safety and shelf-life of a product and guarantee the consumers' safety and wellbeing and (2) specific marketing standards, applied to only 11 fruits and vegetables and consist mostly of aesthetic requirements (product's color, size and shape). Furthermore, retailers have been maintaining the old and their quality requirements as a guideline and have been reluctant to sell non-compliant fruit, since they assume that consumers are not willing to buy it and because selling this fruit might affect the image of the high quality store (De Hooge et al. 2018; Loebnitz et al. 2015). Then, changing the regulation is not enough to decrease fruit losses. Recent studies from Helmert et al. (2017), De Hooge et al. (2017) and Loebnitz and Grunert (2015), showed that several consumers prefer to buy compliant fruit instead of non-compliant when the priced is equivalent, as expected. This behaviour could be explained by the fact that consumers use the appearance to measure the intrinsic quality of fruit (Göbel et al. 2015; Helmert et al. 2017; Aschemann-Witzel et al. 2015). However, when some retailers have taken the initiative to sell non-compliant fruit at cheaper prices it appears to be effective in increasing sales of this kind of fruit (Aschemann-Witzel et al. 2016; Kulikovskaja and Aschemann-Witzel 2017). Nevertheless, is not a long-term solution to reduce fruit losses. Firstly, because price reduction leads consumers to think that non-compliant fruit have less quality; and secondly, selling non-compliant fruit at low price next to more expensive than normal fruit in the long-term lead to reduction of profits for both retailers and producers (Aschemann-Witzel et al. 2017; De Hooge et al. 2018; Völckner and Hofmann 2007; Adam 2015).

For all these unfavourable reasons different approaches are needed regarding non-compliant food application, which contribute with the world sustainability, exploiting its nutritional and phytochemical richness developing novel functional food supplies. In this context, a great scientific interest has risen in order to employ the high amount of non-compliant fruit. Consequently, an effort to increase the value-added for this kind of food has been made as well as with the purpose to decrease the food losses generation. However, the production of functional ingredients and/or products is a good alternative to increase the income that comes from these fruits, such as extraction of specific BCs for the production of antioxidant extracts or functional fiber flours. The optimal valorization strategy depends on the nature and properties of the substances that are still present and can be obtained from each fruit (Jiménez-Moreno et al. 2019). Currently, there are a lot of studies on fruit waste, mainly employing peels, pomace and seeds, and such studies showed their abundance of BCs and exposed these raw materials as rich sources of beneficial BCs with health benefits for the consumers and as a cheap and renewable source (Trigo et al. 2019; Jiménez-Moreno et al. 2019). However, there are scarce data available, regarding the employment or valorization of non-compliant food as sources of nutritional molecules and BCs. In Fig. 10.3 are represented the traditional process of fruit industrial production as well as its possible future management. Traditionally, fresh fruit categorized as compliant fruit is distributed by the producers (farmers) to different customers (mostly markets and fruit processing industries) to get the normal (high) economy revenue. On the other hand, the non-compliant food is highly accumulated and categorized as food grade and non-food grade, the food grade is commonly used for juice producers, while the non-food grade is used for animal feeding with lower economic revenue. Currently,

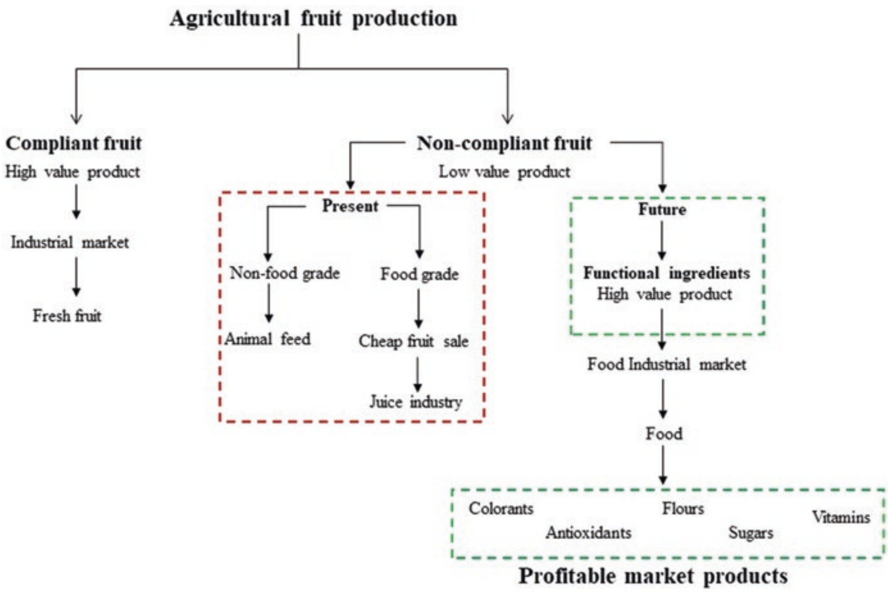

Fig. 10.3 Chart flow of compliant and non-compliant fruit in agricultural fruit production

non-compliant fruit future management could pass through the development of novel supplies, such as functional ingredients, which also can be reincorporated within the industrial chains increasing the industrial profits. Functional ingredients (for example, extracts) obtained from non-compliant fruit are rich in BCs and they can be used in a wide range of products developing of functional foods. Even when the fruit is non-compliant the nutritional quality and microbiological safety are still good and that is why this fruit can be consumed and the health benefits obtained. Fruit production generate a high number of non-compliant fruit, which is perishable due to the high-water content and huge amounts of organic load, as well as their chemical composition, particularly rich in dietary fiber and phytochemicals, provides a costless source of BCs that may favor an efficient and sustainable industrial development. A circular economy model can be implemented for instance in the apple production by recycling its non-compliant production, thereby creating added value with fewer resources. As already mentioned above several strategies for the valorization of these food losses have been proposed, including its direct use for animal feed, but a more sustainable approach should be designed and applied to the apple producers, increasing their economic revenue, as well adding value to the non-compliant fruit products (Fig. 10.3).

10.3 Valorization of Non-compliant Fruit

The non-compliant fresh fruit fractionation is the common approach that generates high-added-value products with applications in several areas. The main objective of the fractionation process is to generate two different fractions: liquid fraction and solid fraction. Thus, compounds with high molecular weight like dietary fiber remain in solid fraction and the smaller and soluble molecules, such as phenolic compounds and simple sugars stay in the liquid fraction. Before starting the fractionation will be interesting to apply a bleaching process as pre-treatment, that could be applied to the fruit, which would allow the reduction of color in the final ingredients due to the inhibition of polyphenol oxidase (Rabetafika et al. 2014). After that, the fractionation process applied could be a simple roll press belt or a press juice centrifuge (cold pressure). In both cases, new functional ingredients/products are produced. These processes are a new low-cost way—process to obtain sustainable and high value-add products within fruit producers' facilities. However, a more complex process could be applied to fractionation by couple extraction processes for specific extraction of phenolic compounds, which are embedded within the cellular matrix of plants, so it is necessary to apply extra extraction methodologies to improve and maximize the recovery yields. However, in this case, it is necessary a pre-treatment, such as wet milling to facilitate and improve the yield of the extraction.

The technologies of extraction can be classified as conventional or non-conventional. Nevertheless, these conventional extraction techniques present various drawbacks, including (1) thermal decomposition of thermolabile molecules such as phenolic compounds, decreasing the bioactivity of the final extract; (2) high energy consumption; (3) consumption of large amounts of water and/or organic solvents; (4) longer extraction time; (5) low yields (Galanakis 2012). To overcome these limitations, non-conventional extractive methodologies (green methodologies) have been developed to improve these unfavorable facts and they have led to the development of more innovative approaches, with higher yields, low processing times and minimal consumption of extract solvents, water and energy. Green methodologies include ultrasound-assisted extraction, microwave-assisted extraction, pulsed electric fields, supercritical fluid extraction, enzymes assisted extraction and microbial processes (Ferrentino et al. 2018). However, each extraction technique has advantages and drawbacks, so the selection of the most appropriate in each case depends on several factors, mainly availability, acquisition and operational costs, lack of regulatory and well-defined industrial applications.

With the application of this approach, it is possible to obtain different high added value functional ingredients, which will present a different composition and therefore can be applied to different products from different areas. The current state of non-compliant fruit fractionation is outlined in Fig. 10.4. Potential applications of dietary fiber extract due to low-caloric value and functional properties such as water holding capacity, viscosity, gelation and sensory properties may be a good food additive or ingredient, for example, used as wheat flour substitution in bread and other bakery products like cakes and biscuits (Trigo et al. 2019). These replacement increases the fiber content of end-products and brings functional nutritive values. The valorization of the polyphenols existing in non-compliant fruit as new functional food additive increases the antioxidant capacity of the end-products could be used as a natural antioxidant to stabilize lipidic products oxidation once the use of synthetic antioxidants. Furthermore, the polyphenols are linked to numerous health

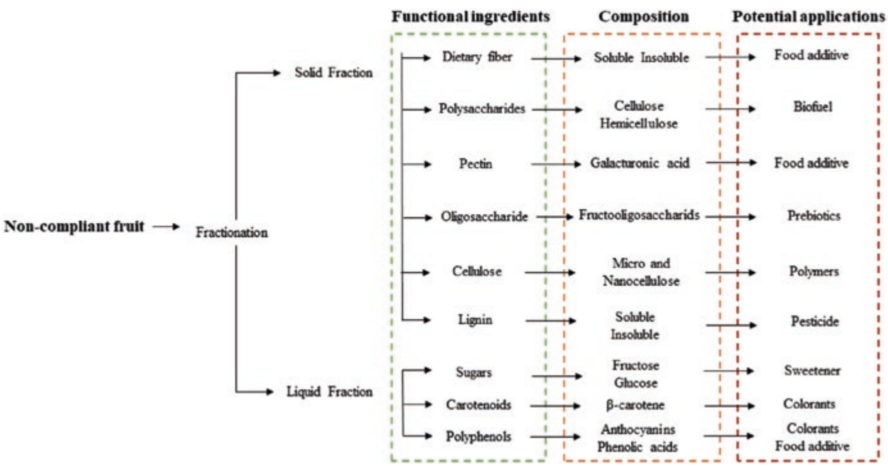

Fig. 10.4 Fractionation of non-compliant fruit into functional ingredients and identification of potential applications

benefits such as antihypertensive, anti-diabetic and anti-cancer activities so, the addition to the food products could provide new functional properties and new perspectives for their commercial use (Campos et al. 2020). Depending of the fruit matrix, the profile, and the composition of the two fractions are different. The dietary fiber, pectin and polyphenols receive the top interest and have been explored for new functional ingredients from food losses, mainly by-products (peels, pomace and seeds) while, other functional fractions (hemicelluloses, cellulose and lignin) are hindered by the complexity of processes (Rabetafika et al. 2014).

10.3.1 Antioxidant Extracts

There are two main groups of BCs: essential and non-essential. The essential BCs include mostly vitamins and minerals and are essential in the prevention of diseases and maintaining specific biochemical processes in the body. While, non-essential BCs consist of secondary metabolites such as phytochemicals, which allow the maintenance of optimal cellular health, leading to an improvement in human longevity (Trigo et al. 2019). These secondary metabolites are extra nutritional constituents that naturally occur in minor quantities in the plant kingdom. Nevertheless, these phytochemicals have received increasing interest in the last years, since they can be found in great amounts in fruit, vegetables, plant-derived beverages, leaves, seeds and peels. Most common phytochemicals include alkaloids, terpenes and phenolic compounds (Martínez-Ávila et al. 2012).

Phenolic compounds are one of the biggest and widely distributed groups of phytochemicals. They are classified in different groups, which include flavonoids, phenolic acids and tannins among others. Therefore, phenolic compounds have common characteristics, namely, the presence of at least one aromatic ring hydroxyl-substituted, commonly bound to other molecules, frequently to sugars (glycosyl residue) and proteins. Flavonoids constitute the largest group of plant phenolics accounting for over half of the thousand naturally occurring phenolic compounds (Martins et al. 2011). Flavonoids are further divided into several categories depending in substitution patterns to ring C in the structure, such as flavones, flavonols, flavanones and flavonols and anthocyanidins. Anthocyanins are glycosylated anthocyanidins, which are water-soluble glycosides and possess several hydroxyl groups, being highly correlated with the antioxidant activity (Gonçalves et al. 2018). On the other hand, the phenolic acids are simple molecules divided into two groups that include hydroxybenzoic and hydroxycinnamic acids. The most frequent hydroxybenzoic acids include gallic, *p*-hydroxybenzoic, protocatechuic, vanillic and syringic acid, while hydroxycinnamic acids, caffeic, ferulic, *p*-coumaric and sinapic acids. Tannins are phenolic compounds of molecular weight from intermediate to high (500–3000 Da) and can be classified into two major groups: hydrolyzable tannins and non-hydrolyzable or condensed tannins. The condensed tannins are polymers of catechin, not readily hydrolyzed by acid treatment, and constitute the main phenolic fraction responsible for the characteristics of astringency of the vegetables.

Although the term condensed tannins are still widely used, the chemically more descriptive term “proanthocyanidins”has gained more acceptance.

The non-compliant fresh fruit fractionation generates a liquid fraction, rich mainly in phenolic compounds well known for their antioxidant activity. Due to their bioactivity, this fraction could be used as a food additive, such as preservative. The preservatives group is divided into three classes, antimicrobials, antioxidants and anti-browning agents (Carocho et al. 2018). The antioxidant is used to extend the shelf life of foodstuffs from the oxidative process that could result in degradation of food, such as lipidic peroxidation, changed the flavor, color, nutritional and texture value, as well as, creation of toxic compounds. For, itself, antioxidant extracts are one of the most important conservation technologies used by the food industry, with their main function being the prevention of oxidative processes (Faustino et al. 2019). Natural antioxidants have been widely studied on the food additives field as an alternative to the synthetic antioxidants since the latest raised issues over the safety application into foodstuffs (Franco et al. 2019). The synthetic antioxidants have been increasingly substituted by natural antioxidants mainly phenolic compounds since in Europe, the use of some of these compounds had been prohibited, and the discovery for new and natural ones has been promoted, subsequently, much of the research on natural antioxidants also focused on phenolic compounds (Campos et al. 2020). Fruit, vegetables, and their by-products are among the most relevant potential sources of natural antioxidants that could be exploited for antioxidant extracts production. Due to the high content of phenolic compounds present in non-compliant fruit, these food losses may be considered as a possible source of new antioxidant extract. Furthermore, is a cheap source of new natural antioxidants and, some of the antioxidant compounds naturally found in some by-products are already approved for use as antioxidant additives and possess an E number, namely ascorbic acid (E300), lutein (E161b), tocopherol (E306), and carotenoids (E160a–E161g) (Carocho et al. 2018).

10.3.2 Dietary Fiber Extracts

Dietary fiber (DF) intake has shown several health benefits, including the regulation of intestinal transit, risk reduction of obesity, diabetes and cardiovascular diseases, as well risk reduction of hyperlipidemia, hypercholesterolemia and hyperglycemia, since modulates food ingestion by influencing digestion, absorption and metabolism of nutrients (Macagnan et al. 2015). DF refers to a group of substances in plant foods that cannot be completely broken down by human digestive enzymes; the common structural base are carbohydrates and their derivatives. The DF are divided into two groups, soluble and insoluble dietary fiber. The soluble DF includes non-starch polysaccharides, such as pectin’s, β-glucans, gums, mucilage’s, oligosaccharides or inulin and insoluble dietary fiber includes mainly cellulose and hemicellulose (Burton-Freeman 2000; Quirós-Sauceda et al. 2014). Soluble DF has several beneficial physiological functions: (1) increase the viscosity of food, changing the rate of nutrient release and absorption in the gastrointestinal tract; (2) lowers blood cholesterol concentration since it binds to bile salts in the small intestine leading to excess fecal excretion of bile salts. In contrast, insoluble DF has less physiological effects in the upper gastrointestinal tract. Nonetheless, plays an important role in intestinal regulation by mechanical peristalsis (Trigo et al. 2019). The DF also enclose attached an appreciable number of phenolic compounds, proteins or other substances with positive health effects, which usually co-exists in all plant cell structures (DeVries 2004). Some extraction techniques do not allow the complete extraction of these BCs of a given matrix. In fact, there is a high amount of phenolic compounds that may be disregarded as they remain within the extraction residue (Silva et al. 2018). These compounds are referred to as non-extractable phenolics (NEP). Given their association with these cellular structures, after ingestion, they are not released from the food matrix by any of the steps of the digestive process. Instead, they pass relatively intact throughout the digestive tract, not being absorbed in the small intestine, until they reach the colon where they can be fermented by the gut microbiota (Silva et al. 2018; Trigo et al. 2019). So, NEP compounds and DF are intimately associated; in fact, the phenolic compounds are frequently associated with DF and, should be considered as a specific DF: the antioxidant dietary fiber, which has specific health-promoting properties. Recently, fruit by-products (peels and pomaces) have been discovered as a novel source of DF and are the main source of pectin, gums and mucilage (Campos et al. 2020). Then, non-compliant fruit could be also a novel source of DF, which can be incorporated into market food products. Fruit DF have more quality than cereals DF (majority DF source in food products) due to their higher total and soluble fiber content, water and oil holding capacity and colonic fermentability, as well as their lower phytic acid content and caloric values. For instance, production of DF concentrate powders from non-compliant fruit could be a great commercial opportunity to create new functional ingredients from a renewable and economical source moreover, an environmental problem could be solved.

10.4 Development of New Value-Added Products

As previously described, non-compliant fruit presents a relatively high content of dietary fiber, pectin, polyphenols and antioxidant properties when compared to other sources. These features could be fully exploited for the development of different food ingredients such as supplements, additives or ingredients, which could be potentially applicable in bakery, dairy, beverage and animal products and animal feed industries. The quality and safety of such ingredients could be significantly improved by the addition of bioactive fractions, however, is essential to select the best concentration to keep, without any modification, the sensorial properties regarding texture, color and taste, among others. Diabetes and its drawbacks are a serious global concern, which is progressively developed by the oxidative stress, this health problem is inflicted by the imbalance between the overproduction of reactive oxygen spices and the short intake of antioxidants (Ibrahim 2017). Polyphenols and carotenoids are natural antioxidants well-characterized by their capability to minimize the negative impact of the oxidative process caused by the free radicals, thus enhancing the problems associated with the oxidative stress (Lo et al. 2017). In this scenario, functional foods are described as food supplies, which exhibit diverse benefits upon human health, helping in the prevention or reduction of certain illnesses, such as cancers, cardiovascular, inflammatory disorders and diabetes (Gómez-García et al. 2020). Beyond, future perspectives for the valorization of non-compliant food could be applied as functional ingredients, since these plant tissues hold a high concentration of significant nutrients namely dietary fiber and proteins, as well as polyphenols and carotenoids which have been shown a good correlation in the prevention of health diseases. For example, apple fractions present high content of dietary fiber which can be directly used to develop functional flours, due to this natural polymer has been contributed to the modulation of the gut microbiota, such as *Bifidobacterium*, a bacteria associated with colon, stomach, prostate and breast cancer prevention (Veiga et al. 2020). On the other hand, polyphenols exhibit good digestive enzymes inhibition, such as lipase, amylase and glucosidase, minimizing hyperglycemia, which is also strongly linked to diabetes and obesity disorders (Sulaiman and Ooi 2014). By these functional benefits and based on their richness in BM, apple fractions could be employed as functional ingredients, developing new food supplies such as flours, fiber bars, or extruded products, which promote health benefits.

10.4.1 Application of New Value-Added Products in Food Supplies

10.4.1.1 Bakery

Bakery supplies are widely consumed worldwide, which are made principally by white wheat or corn flour, as well as sugar, egg, fat, milk and water. All of these ingredients display an important function in the batter and despite being a good source of energy and nutrients, in many cases, they exhibited low antioxidant activity (Quiles et al. 2018). Hence, different studies have been carried out regarding the incorporation of fruit by-products to enhance fiber and antioxidant content. De Toledo et al. (2017) substituted a portion of wheat flour in cookies with flour prepared by pineapple stem, melon peels and apple pomace, where cookies made with 15% of melon flour represented a good relation to the nutritional characteristics about fiber (4.67–6.46%) and ash (1.74–2.25%) contents, while by pineapple and apple flours were positively influenced concerning consumer's preference. Mir et al. (2017) incorporated apple pomace as flour at increasing levels (0, 3, 6 and 9%) for the formulation of gluten-free crackers prepared with rice flour. At 9% of dosage was observed a significant increase in dietary fiber content from 3.01 to 7.41% and soluble dietary fiber from 0.25 to 3.07%. Also, total phenolic content (TPC) and total flavonoid content (TFC) significantly increased from 0.61 to 0.82 mg GAE/g and 41.96 to 53.88 μg catechin equivalents/g, respectively, with the increase of apple flour levels. Simultaneously the antioxidant capacity increased by exhibiting an increase on DPPH scavenging capacity from 51.7 to 61.53%. Enhancing the fiber content and antioxidant properties of bakery supplies has been an important science trend due to it is well correlated with several health benefits alongside increases in dietary fiber and polyphenols.

10.4.1.2 Beverages

Traditionally, fruit juices are the principal way of significant consumption of bioactive compounds and hence can be used as vehicles to deliver functional health benefits. Beyond, consumers' demand has been increasing for food, not for safe food but also for providing health benefits. In this scenario, some researchers have been focused on novel strategies to development natural additives to incorporate in juices such is the case of Adiamo et al. (2018), showed that the addition of orange by-products extracts to carrot juice enhanced its phenolic content (30.25 mg GAE/100 mL) and antioxidant properties (61% DPPH scavenging activity).

All of these pieces of evidence reinforce the capability to use non-compliant fruit as novel functional ingredients, which positively influence nutritional and biological properties aimed to enhance human health. In general, the new functional ingredients obtained from the valorization of non-compliant fruit can be included at significant levels in many food supplies, while maintaining consumer acceptability, the healthiness of the products and potentially reincorporation in the food chains.

10.4.1.3 Dairy

One of the most significant drawbacks of dairy foods is related to the high content of fat, which is highly susceptible to lipid oxidation. Therefore, the addition of bioactive antioxidants from the fruit into the dairy matrices has been shown interesting good results to retard oxidative processes, improve self-life and increase nutritional aspects (Özvural and Vural 2011). Marchiani et al. (2016) reported an increase in the TPC (55%), antioxidant activity (80%) and acidity (25%), compared with the control, in 3 week-stored yogurts enriched with grape flour (60 g/Kg). For instance, when apple fractions (0.5 and 3%) were directly added in ice cream, fat (10.18%) and protein (4.03%) content was higher than the control (9.48 and 3.67%, respectively) and with high acceptable sensory properties (Ayar et al. 2018). Adhikari and Bajracharya (2018) incorporated apple pulp (6%) in probiotic yogurt, and results showed good self-life after 21 days of storage at 4 °C. Dairy products fortified with apple fractions as natural preservatives can improve the nutritional profits of the final products.

10.4.1.4 Animal Feed and Supplies

Animal feeds are frequently composed of agricultural by-products, such as rice bran, corn, soybean meal or fish meal as complex nutrients. Regarding consumers' demand for attractive food products, aquaculture and chicken feed usually contains bioactive compounds such as fiber, proteins polyphenols and carotenoids. In the animal feed industry, carotenoids are employed as a feed additive for fish and laying hens to enhance the color of their flesh and egg yolk. However, this pigment used in these industries is mostly chemical synthesized which means expensive processes and low yields (Roadjanakamolson and Suntornsuk 2010). Some researchers have been looking for different sources rich in bioactive compounds to employ as animal feed additives, such is the case of Abdollahzadeh et al. (2010), they incorporated a mixture of tomato and apple into alfalfa at different levels (0, 15 and 30%) for feeding dairy cows. A dosage of 30% of tomato-apple pomace with a ratio of 50:50 showed higher content on cow's milk as well as improvement on milk yield production from 20.8 to 21.6 kg/day, compared with the control. On the other hand, animal supplies such as meat, fish and poultry have some inconvenient issues related with their high susceptibility to oxidation and microbial contamination since they present significant content of water, lipids and proteins which face with short self-life and short time of storage, as well as a negative modification on the sensory characteristics. Moreover, natural antioxidants derived from fruit and vegetable have been proven to be efficient and profitable compounds to avoid these drawbacks. Biswas et al. (2015) added to chicken and turkey meat different concentrations of drumstick leaf powder, aloe vera gel, apple and banana peel paste in a concentration of 0.5, 2, 2 and 2.5 g/100 g, respectively. After 60 days of storage at 37 °C, all the treatments had higher antioxidant activity on DPPH, ABTS and superoxide anion scavenging, than the control, where apple peel contained the highest amount of TPC and TFC (18.7 and 8.74 g GAE/100 g, respectively). The application of apple pomace for animal feed as additives or ingredients and as natural meat preservatives could represent a sustainable way to valorize food by-products.

10.5 Conclusion

The current chapter shows a clear example of non-compliant fruit products application with high value-add, which shows the potentialities lost until now as a rich source of bioactive compounds, such as polyphenols and dietary fibers. It is possible to extract these bioactive compounds from non-compliant fruit in a successful way and to exploit their great potential in relevant industries through the production of functional ingredients/foods. The use of non-compliant fruit would allow saving large amounts of fruit, while simultaneously reducing the negative impact on the environment, as well as, increasing the diversity of new ingredients in the market and consequently the availability of new food products, leading to increase of the economic value of the raw materials and stimulate the transition of fruit producers to the circular economy.

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