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Fruit and vegetable by-products as functional ingredients: what are the limitations for large-scale industrial processing as powder?

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ABSTRACT

Fruit and vegetable by-products have been studied worldwide and have shown to be an important source of functional components such as bioactive compounds and fibers, among others. However, the industrial processing of such by-products has not been observed as occurring in a large scale for human consumption. Therefore, the aim of this work was to analyze and evaluate a hypothesis for the main barriers to the industrial processing of edible parts of food by-products turned into powder. Data from the literature suggest that culture, force of habit, and food neophobia are key issues to a positive attitude in the consumers' buying decisions. Also, characteristics of food by-products such as moisture, temperature, low volumetric density, susceptibility to spoil, costs, and the lack of tested and proved protocols, for the industrial processing of this kind of material, seem to be barriers for the food industries financial support to this part of food processing chain. The lack of information on the markets in the scientific and technical literature, additionally to the industrial technological difficulties, may play an important role in the decision-making of industries for the wide processing and sale of by-products. Therefore, applied studies with a holistic view on the utilization of food by-products, together with a high follow-up communication, can result in better knowledge and, consequently, in the reaching out to consumers and market for these food by-products.

Index terms: food by-products, powder, solid vegetable food residue, sustainability, valorization.

Subprodutos de frutas e vegetais como ingredientes funcionais: quais são as limitações para o processamento industrial em grande escala como pó?

RESUMO

Os subprodutos de frutas e vegetais têm sido estudados em todo o mundo e têm-se mostrado uma importante fonte de componentes funcionais, tais como compostos

Ideias centrais

- Food by-products are nutritionally rich, but little produced on industrial scale.
- Low volumetric density, susceptibility to spoil and costs are technological barriers.
- In-depth exploration of specific flowcharts and equipments is important.
- Lack of information about markets is a critical barrier.
- Deeper data towards consumers' acceptance and behavior about the topic is important.

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bioativos e fibras, entre outros. No entanto, o processamento industrial de tais subprodutos não têm sido observado em larga escala para consumo humano. Assim, o objetivo deste trabalho foi analisar hipóteses quanto às principais barreiras ao processamento industrial de partes comestíveis de subprodutos alimentares tornados pó. Dados da literatura sugerem que a cultura, a força do hábito e a neofobia alimentar são questões-chave para uma atitude positiva das decisões de compra dos consumidores. Além disso, as características dos subprodutos alimentares tais como umidade, temperatura, baixa densidade volumétrica, suscetibilidade à deterioração, custos e a falta de protocolos testados e comprovados, para o processamento industrial desse tipo de material, parecem ser barreiras para o apoio financeiro das indústrias alimentícias nesta parte da cadeia de processamento de alimentos. A falta de informações sobre mercados na literatura científica e técnica, somada às dificuldades tecnológicas industriais, pode desempenhar um papel importante na tomada de decisão das indústrias para o amplo processamento e comercialização de subprodutos. Portanto, estudos aplicados com uma visão holística sobre a utilização de subprodutos alimentares, em conjunto com maior acompanhamento de comunicação, podem resultar em melhor conhecimento e, conseqüentemente, atingir consumidores e mercados para esses subprodutos alimentares.

Termos para indexação: subprodutos de alimentos, resíduos sólidos vegetais, gestão de resíduos, sustentabilidade, valorização.

INTRODUCTION

Food systems in the new era need to consider four important factors that could direct intervention actions in the food supply chain, as follows: to increase the availability of functional foods with bioactive components, as the consumer demand for healthier foods may increase; to strengthen hygienic-sanitary safety of food to prevent the spread of viruses among producers, retailers and consumers; to contribute with people's food security, providing quality food in sufficient quantity to supply the population; and to produce food in a sustainable way to curb relevant crises in the future (Galanakis, 2020). This is in the context of "The Sustainable Development Goals" – declared in 2015 by the United Nations (FAO, 2020) – which require the optimized use of all raw materials produced by food systems in all stages of the food chain, from reducing post-harvest losses through processing, with the valorization of bioactive compounds from food by-products, until commercialization (Galanakis, 2020).

Food waste is defined as part of waste that is originally intended for human consumption. It presents a different definition for food by-products, since it is related to food, as it is initially intended for human consumption, removed from the food supply chain to be recovered or disposed, while waste is the part of food from a production process destined to be used afterward for a different product from the primary food chain aim (HLPE, 2014; Spigno et al., 2017). However, the International Organization of Vine and Wine (OVI) (Novello, 2018) classified the secondary products from wine processing as: i) wastes: with negative environmental impact and not suitable for recycling or post-industrial processing; ii) residues: without negative environmental impact, but not suitable for recycling or post-industrial processing; iii) sub-coproducts: with or without negative environmental impact and suitable for recycling or post-industrial processing; iv) by-products: with well-defined economic and industrial value.

Upcycling economy has been shown to be more than a trend in the food supply chain. It is a necessity due to the current backdrop of global demand for food, natural resource depletion and climate change. Nowadays, 1.3 billion tonnes of food are wasted per year worldwide, from harvest processing up to consumer consumption (Pleissner et al., 2016; Roth et al., 2019). Mirabela et al. (2014) estimated that 42% of food waste is produced by households, while 39% losses occur in the food manufacturing industry, 14% in the food service sector, and remaining 5% in retail and distribution in developed countries. Food leftovers are part of food wasted after retail and household consumption, which are usually disposed due to uncertainty regarding its safety. However, edible solid food by-products from industrial processing may be reutilized to produce value-added products, after proper treatment. The large amounts of unexplored food by-products from industrial level indicate that there should be inefficiencies with potential for improvement (Roth et al., 2019).

In this context, edible vegetable, fruit, and grain by-products are used for animal feeding or composting, although they have been largely studied in the past decades as source of important components for human diet. Grape skins and seeds, carrot peel, spent grains of brewery, and apple pomace among others have been studied as natural source of polyphenols, carotenoids, fibers, compounds

with antimicrobial, antioxidant, anti-hypertensive, anti-cancer capacity, and pigments, and show a clear potential to be processed by food industries and used for human diet (Coelho & Wosiacki, 2010; Sant'anna et al., 2014; Zhu et al., 2015; Dalla Costa et al., 2016; Nagy et al., 2017). Also, recently, potato skin have gained the interest of researchers and the food and pharmaceutical industries, due to their potential for recovery of bioactive compounds and antioxidants which can be used as antimicrobial agents, or as functional ingredients in foods, which could increase the overall added value and minimize the environmental impact of this crop (Sampaio et al., 2020). Although several studies have shown these sources of important functional ingredients, Galanakis (2016) estimated that in 2014 there would be about 50 companies worldwide doing the recovery of valuable compounds from food residue, which shows that the potential for by-products to create new markets has been underestimated (Galanakis, 2020).

Most of the current applications focus on the extraction of components (phenolics, dyes, oils) from these materials, although the wholly utilization of the vegetable edible parts for sustainability and nutrition are more appropriate in a circular economy perspective, aiming at not generating new materials to be treated from the processing of these materials. In this context, fruit and vegetable skins, peels, seeds, leaves have been usually studied as dried ingredients, and added as powder in food applications. This is a common approach in the field of food by-products in the food science and technology area.

Herein, an important question rises for food scientists and engineers: why there is not innumerable food industries processing these feedstocks for human consumption, since they are largely disposed, seem to be cheap, have functional properties, and represent a better way for a sustainable residue management? The answer for this question is challenging.

Therefore, the aim of this paper was to fully analyze and evaluate a hypothesis for the main barriers to the industrial processing of edible parts of food by-products, in the form of flour or powder for human consumption. To facilitate the reading and comprehension through the text, the expression food by-product is used related to the edible vegetable parts from industrial food processing. The present work focuses on the utilization of full edible food by-products from fruits, cereals and vegetables turned into powder, such as commonly proposed in scientific articles in food science. Special focus is given to the consumer perception, technological barriers, and market issues.

METHODOLOGY

The present work was carried out as a bibliographical review of current scientific documents on food by-products worldwide. Information on processing, consumer behavior and perception, legal concepts and requirements from articles, books, international organization archives and legislation were analyzed, in order to evaluate the potential utilization and barriers of food by-product processing. To that end, the following databases were searched: Scientific Electronic Library (SciELO), Scopus, Web of Science, and Google Scholar, with the following keywords: food residues/waste, food residue polyphenols/antioxidants/fibers, food residue/waste storage, food residue/waste processing; drying food residues/by-products; upcycling economy food waste; food waste/residues/by-products eco-innovation food residue/waste consumer perception, food residue/waste consumer behavior; food waste/by-product sensorial analysis; waste processing challenges; legal concepts food residue.

In order to present updated data on the issues, the criteria used for inclusion and exclusion of the scientific documents were to favor articles from 2010 on that studied edible fruits, cereals, and vegetable by-products from industrial processing, for consumer behavior and perception, since few works were found in the current literature, and residue/by-product from retail and household consumption were considered. The search took place between November 2019 and April 2020. The criteria to include the reference within the analysis was to evaluate the food by-product as an edible ingredient. Also, documents that dealt with food residues, food waste, and food by-products as a potential eco-innovation were added to discuss the results. The keywords and number of citations

selected (n) are the following: food residues/waste (n=40); food residue polyphenols/antioxidants/fibers (n=35); food residue/waste storage (n=3); food residue/waste processing (n=10); drying food residues/by-products (n=5); upcycling economy food waste (n=6); food waste/residues/by-products eco-innovation (n=7); food residue/waste consumer perception (n=11); food residue/waste consumer behavior (n=2); food waste/by-product sensorial analysis (n=12); waste processing challenges (n=4); legal concepts food residue (n=3). The broad database search was performed to provide enough material for a comprehensive discussion on the subject.

RESULTS AND DISCUSSION

Food by-products processed as dried material for incorporation into different formulations is a trend, since they enhance the nutraceutical characteristics of foods when added as powder or flour. Additionally, it is possible to find patent deposits using them in the form of flour, such as: “Wheat flour containing grape marc flour and wheat flour production process containing grape marc flour” (BR 102015030876-0), an invention which belongs to the technological sector of the inventors’ food industry (Revista da Propriedade Industrial, 2016); and “Vegetable seasoning with preservative properties, salt substitute and procedure to obtain it” (ES 2 524 870 B2), with bagasse of grape (UBU, 2020). However, flour types of food by-products are not easily found to this purpose, and there is a lack of information on the reasons for the absence of these materials.

Grounded on our database searching, we propose that the limitations on large-scale industrial processing should be considered in three ways, as follows (Figure 1): i) consumer behavior and perception; ii) technological barriers; and iii) uncertainties in the consumer market.

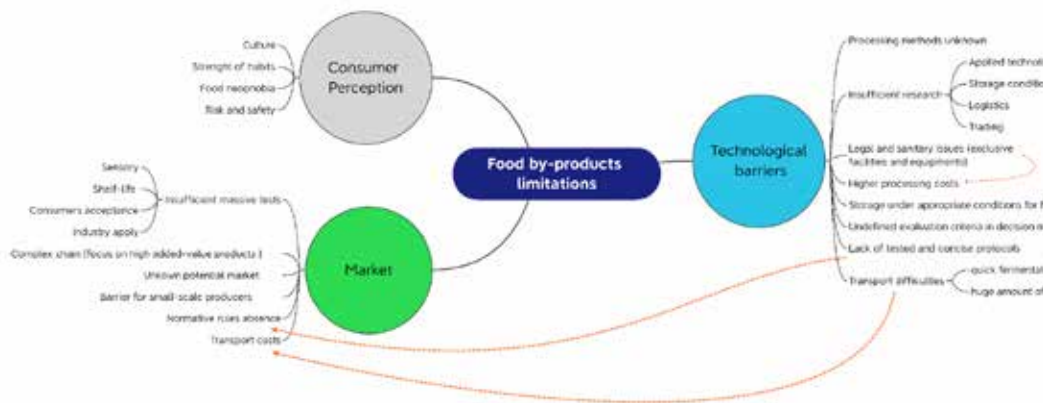


Figure 1. Main limitations for powdered food by-products for human consumption.

Consumer perception on food by-products

The growing concern of consumers on environmental issues – such as climate change, environmental pollution, and the use of natural resources – have encouraged the growth of sustainable food markets (Van Doorn & Verhoef, 2011; Daou et al., 2020). Recently, the perception of consumers for the consumption of these products has been little explored (Cattaneo et al., 2019), and the evaluation of different techniques for the food by-products processing largely was analyzed (Roth et al., 2019; Ferri et al., 2020). The studies in the past decade have focused on the following issues: total food loss quantification through the supply chain, its causes, and mitigation strategies; cooperative marketing; cooperation among farmers to avoid food losses; safe handling of food products; markets for sub-standard products; education of consumer to eat foods integrally; research on the consumer preferences, and the value of food by-products in retailers (Cicatiello et al., 2016). Despite the growing concern of the consumer’s perception of food by-products and the increase of research on its

valorization, there are few works focused on the consumer's perception of industrial edible food by-products from fruits, cereal, and vegetable available for human diet. Currently, industrial food by-products are usually handled with no or low profit and taken to incineration, and used as composting or animal feeding (Lavelli et al., 2017; Cattaneo et al., 2019), although they show potential to be used as functional ingredients in food industries.

The most popular technique for measure the consumer's acceptance of food products manufactured from food by-products is the sensorial analysis. We summarized some of the current studies from the literature on the addition of food by-products into several formulations, and their impact on sensorial acceptance (Table 1). Most articles evaluate the influence of food by-products on bakery products acceptance, although they may be added into other food formulations too.

Table 1. Consumer sensorial acceptance of food added of powdered food by-products.

Food residue	Product	Replacement	Result	Reference
Açaí fiber	Cookies	10%	No effect on crispness and acceptance index.	Lima et al. (2015)
Acerola powder	Cookies	10% and 20%	Reduced appearance, aroma, flavor, texture, and global acceptance.	Aquino et al. (2010)
Apple pomace	Banana vitamin, cake		Globally, over 90% people liked the products, or liked them very much.	Coelho & Wosiacki (2010)
Grape marc	Fettuccini pasta	2.5%, 5%, and 7%	Reduced appearance, color, texture, flavor, aftertaste, and overall acceptance; among the samples with grape marc powder, no difference was observed	Sant'Anna et al. (2014)
Pitaya peel powder	Cookies	5%, 10%, and 15%	No effect on color, aroma, texture, and overall acceptance; enhance of flavor acceptance	Ho & Latif, (2016)
Tomato skin and seed powder	Bread	6% and 10%	No effect on crust color, taste, flavor, texture, and overall acceptance	Nour et al. (2015)
Mango peel powder	Biscuits	5%, 10%, and 15%	No effect up to 10% of replacement; replacement of 15% reduced color, flavor, taste, texture, and overall acceptance	Aslam et al. (2014)
Carrot peel	Pasta	10% and 20%	No effect on appearance, color, texture, taste, flavor, aftertaste, and overall acceptability	Dalla Costa et al. (2016)
Broccoli stalk and leave	Bread	2%	No effect on overall acceptance	Lafarga et al., 2019
Brewer's spent grain	Frankfurters	1%, 3%, and 5%	Replacement of 1% did not affect appearance, texture, flavor, and overall acceptance; 3% and 5% affected negatively appearance, texture, color, flavor and overall acceptance	Özvural et al. (2009)
Brewer's spent grain	Smoked sausage	1.5%, 3%, and 6%	No effect on appearance, texture, taste, aroma, and overall acceptance	Nagy et al. (2017)
Passion fruit peel	Yoghurt	1%	No effect on flavor, texture, consistency, and global impression	Perina et al. (2015)
Grape marc flour	Bread	5%	No effect on odor and texture; impact on appearance and overall liking	Carlini et al. (2021)

The summarized results (Table 1) show that the addition of fruit by-products into cookies, cake, and banana vitamin, up to 20%, had important sensorial acceptability (Coelho & Wosiacki, 2010), or it did not affect the sensorial acceptance, in comparison with control samples (Aslam et al., 2014; Lima et al., 2015; Dalla Costa et al., 2016; Ho & Latif, 2016; Lafarga et al., 2019).

However, Aquino et al. (2010) observed that the addition of 10% or 20% of acerola skin and seed significantly reduced the sensorial liking, from liked moderately to slightly liked appearance, aroma, flavor, texture, and global acceptance of cookies.

Similarly, Sant'Anna et al. (2014), when added grape marc powder into fettuccini pasta formulation, observed that it negatively affected the acceptance of the product's appearance, color, texture flavor, aftertaste, and overall acceptance. These authors observed that, among the samples added of the grape residue, no statistical significance was observed for all evaluated sensorial properties for scores between "liked moderately" and "really liked".

Nour et al. (2015) observed that all breads added of tomato by-products were acceptable, although panelists preferred white bread without this addition, which registered the highest score for general acceptability. These authors observed that, as the amount of dry tomato by-product increased to 10%, bread was less acceptable, probably due to the notable differences for color, flavor, and odor of these breads, as a result of the original properties of the dry tomato.

Carlini et al. (2021) observed that the incorporation of 5% of grape marc powder into a cake formulation had no effect on the odor and texture acceptance, but impacted negatively on the appearance and overall liking. These authors also observed the importance of adding organic acids in combination with grape marc powder, in order to stabilize anthocyanins during pH changes and heat treatment, during the baking process, otherwise, green cakes may be produced (Carlini et al., 2021).

Additionally, food by-products were also tested in sausage and yogurt formulations with important results. Özvural et al. (2009) observed that the addition of 1% of dried brewer's spent grains did not affect the appearance, texture, flavor, and overall acceptance, but when authors tested 3% and 5% concentration, the appearance, texture, color, flavor, and overall acceptance were affected negatively, although the sensorial scores remained in a good acceptance range.

Nagy et al. (2017) observed that in smoked sausage, the addition of dried brewer's spent grains had no effect on the appearance, texture, taste, aroma, and overall acceptance. Similarly, Perina et al. (2015) observed no effect on flavor, texture, consistency, and global impression when added passion fruit peel into yogurt formulation.

Thus, the results show that the addition of industrial by-products into food formulations is an interesting approach, to enhance the product functional properties, with slight modification on the sensorial acceptance. The analysis of the articles show that protocols should consider smaller additions of the dried residue into product formulation, to maintain the improvement of the functional properties of the product, while avoiding higher concentrations that might negatively affect the sensorial acceptance. Product powder may be more expansive than the regular ingredient being replaced and, therefore, it can affect the final product's cost. It is important to point out that all articles presented (Table 1) used untrained panels, composed of university students and staff, who might have been aware in some level of the study's objective. In these circumstances, the panel could have been favorable to this kind of innovation and might have given, unconsciously, higher scores. Ordinary consumers' perception of these food by-products is not a regular issue being studied nowadays. Current studies have focused on household and market retail food residue. The barriers to change on ordinary consumers' behavior regarding food by-product are linked to culture, strength of habits, and food neophobia.

Culture is particularly important in the consumer's behavior for the use of food waste (Stuart, 2009 cited by Stancu et al., 2016). Initial perceptions of waste were (and still are) related to dirt, disease, and death. According to these notions, the waste is seen as something threatening, and it is generally sent to a remote place far from our living spaces and away from our thoughts (Velloso, 2008). Probably, these perceptions are underlying the difficulties to convert safe food by-products into human feed. Aschemann-Witzel et al. (2020) observed that consumers have few positive associations with stores selling foods with imperfections, to counter food by-products in the context of an emerging retail market. Moreover, concerns over food safety are a major reason why households decide to bin food or leftovers (Aschemann-Witzel et al., 2015).

Cattaneo et al. (2019) observed positive attitudes towards breads, tomato, and apple puree and yoghurt added with grape skin extract; they also observed that informing consumers on the benefits

and concerns of food by-products can result in a more positive attitude towards the use of these products.

Baldissera et al. (2022) observed that the consumers' awareness of the presence of grape pomace powder in food formulation positively impacted the acceptance of the product; these authors also observed that attitude, environmental concern, knowledge, and personal beliefs are key drivers of grape pomace powder consumption, although health concerns did not play a significant role in the consumer's intention of purchasing.

Within the consumers context, the force of habit is another challenge to consumption of industrial processed food by-products. The consumers' positive attitude toward sustainability does not mean behavioral change. Taste, price, convenience, and familiarity are still most important factors in daily food choice (Hoek et al., 2017).

Stancu et al. (2016) observed that the intention to not waste food presented a rather small contribution in explaining food waste behavior, in comparison to food-related routines and perceived behavioral control. By the consumer's view, food waste may be classified as pollution and dirty, or "non-trash" (pure food, useful, and appropriated food), and it is related to culture, income, safety, and risk (Schneider & Almeida, 2016).

Another interesting issue related to the consumer's behavior is neophobia (the rejection towards new or unfamiliar foods). There are three main reasons for rejection of food by humans: i) aversion to sensory characteristics; ii) danger, a fear of negative consequences of eating a food; or iii) disgust, arising from the idea of nature or origin of food (Rozin & Fallom, 1980; Vidigal et al., 2015).

Vidigal et al. (2015) observed that neophobia regarding food technology is related to the consumers' age, education level, and income. It suggests that older, less educated, and those with lower incomes are significantly more neophobic.

Cattaneo et al. (2019) observed that food technology neophobia was slightly but significantly influenced by education level, and that information is a key strategy to increase the consumers' confidence and to reduce the fears regarding these products.

Similar results were observed by Pagliarini et al. (2022), who observed that consumers less neophobic show higher acceptance rates to plant-based foods enriched with winemaking by-products, and that market segmentation is critical to properly insert grape marc based-products successfully. Also, the follow-up communication on by-products as ingredients and residue-based products among consumers can result in better knowledge and, consequently, to in the reaching out to consumers and resonate with sustainable thoughts (Cattaneo et al., 2019; Aschemann-Witzel et al., 2020).

Technological limitations to food by-product processing

Skins, peels, seeds and spent grains after industrial processing show high levels of moisture and usually reach room temperature quickly. These conditions turn the residue highly susceptible to spoilage, foodborne micro-organisms, and undesirable physicochemical changes. The reduction of water activity, refrigeration, and heat treatment are techniques to primarily stabilize the food by-products right after the industrial processing line.

The huge amount produced, the high moisture level, the rich polysaccharide and protein concentrations, and suitable temperature for microbial growth make food by-product difficult to transport over a long-distance industry, since fermentation may happen quickly in the material, whereas, at the point of production, food by-product may be safe for legal limits. Brewer's spent grains that were subjected to high temperatures before being discarded showed to be microbiologically adequate within legal limits (Robertson et al., 2010a). However, untreated samples are highly susceptible to fungi and microaerophilic bacteria proliferation, which requires that the material be stabilized and stored under appropriate conditions post-production, if it is to be utilized at a later stage (Mussato et al., 2006; Robertson et al., 2010a, 2010b).

The addition of formic and benzoic acids in brewery's spent grains showed to be effective to avoid microbial proliferation, meanwhile lactic and acetic acid solutions were not (Mussato et al., 2006). However, the increased demand for food without the addition of chemical preservatives is a future limitation for this treatment. Refrigeration, freezing, or thermal treatment are alternatives for primary processing, although there are few works in the literature on these subjects with food by-products. Brewery's spent grain stored at 4 °C up to 16 days showed low growth of bacteria and no changes on phenolic content; however, changes on sugar concentration were observed, possibly due to microbial or enzymatic activity. Nonetheless, the freezing of brewer's residue showed no changes on the material characteristics (Robertson et al., 2010a). It is important to point out that, due to the low volumetric density of fresh food by-product, several large volume containers would be necessary to store them, especially those extremely seasonal materials such as those from grape processing. Moreover, the material's temperature must be reduced to 7 °C in few hours, and the disposal of large amounts in refrigerator containers must not be effective, to avoid microbial and physicochemical changes. Robertson et al. (2010a, 2010b) observed that the heat treatment of brewery's spent grains by autoclaving was an important operation for the microbial stabilization during storage, but resulted in a solubilization of polysaccharides and associated phenolics, resulting in notable compositional changes.

Other important technological concern on food by-products added into new formulations is the stability of bioactive compounds responsible for color characteristics. Carlini et al. (2021) observed that changes on pH during a cake baking with grape marc powder – an anthocyanin-rich residue – resulted in a green product, which may be not an appropriate product; the authors added ascorbic and citric acids to avoid this phenomenon.

Drying methods are the most popular for the reduction of water activity and for the stabilization of food residue. However, some alternative techniques were studied for these aims. Lyophilization and hot air-drying are the most popular methods studied in the field of food science and technology. Freeze-drying is a technique by which food is frozen, and water is removed by sublimation under low pressure, which leads to the low degradation of bioactive compounds, color, and sensorial changes. Existing industrial drying techniques consume from 20% to 25% of the total energy in the food processing supply chain (Erbay & Hepbasli, 2017; Masud et al., 2020). Therefore, energy consumption is one of the critical factors for selecting suitable drying methods, as it is related to the cost of the whole process.

Saifullah et al. (2019) observed that, among the techniques evaluated, the lyophilization of lemon myrtle leaves required more energy (165.33 kWh), followed by hot air (1.013 kWh), vacuum (0.48 kWh), and microwave drying (0.097 kWh); however, samples treated by freeze-drying showed the highest retention of bioactive compounds; these authors concluded that microwave drying can be applied, for industrial purposes, to the drying of lemon myrtle leaves because it allows of a satisfactorily preservation of bioactive compounds, consuming less time and energy. Thus, hot air-drying treatment remains the most widely used industrial method, due to its high performance and low cost equipment. Additionally, it may not impact significantly on the phenolic contents, that is, when temperature up to 70 °C is applied (Larrauri et al., 1997; Torres et al., 2010; Vashisth et al., 2011; Vega-Gálvez et al., 2012; Inada et al., 2020). Considering that lyophilization is a high energy consumption and high cost method, the choice between hot air-drying and freeze-drying techniques depends on the purpose of the final product, that is, if the intention is to use the ingredient as a natural food coloring, freeze-drying is the best choice (Inada et al., 2020).

The lack of tested and concise industrial protocols and equipments for food by-products processing are additional barriers to its adoption. Despite hot air-drying seems to be the most appropriate method for food residue processing, to store the high-moisture residue and to process a large amount of it are big challenges for food industries, during the production of highly seasonal products, such as grape juice.

Beyond operating costs, the implementation of a food residue processing unit should address legal and sanitary issues. For instance, in Brazil, it is forbidden to have beverage and residue processed at the same plant, and the construction of adjacent and exclusive residue processing facilities is mandatory. The costs of such facilities raise the product cost and influence the industry decision.

Knowledge is necessary to create a new industrial process, to improve the access to the market, to ensure food safety, and to change the consumer's behavior. Furthermore, the lack of data on the new process is an issue for management (Santos et al., 2020). Knowledge gaps are also related to global food losses and waste/residue (Papargyropoulou et al., 2014). Another undefined question is the evaluation criteria in the decision-making process for the most appropriate waste management options, including improved agricultural infrastructure, technological skills and knowledge, more efficient storage, transport and distribution techniques (Papargyropoulou et al., 2014). Additionally, some new technologies that could be used for food by-products processing are still in the initial development stages, in laboratory or pilot scale, and the upscaling to industrial applications would be an important barrier; thus, higher knowledge and characterization of incoming waste feedstocks are the key to applying the correct technology for product manufacture (Matharu et al., 2016).

An important deal of effort is necessary to industrialize such processes and to implement the upcycling economy in food industries, mainly with focus on the organic by-products reutilization. Those efforts include laboratory research, transfer to a pilot plan and large-scale production, protection of intellectual property, and the development of defined applications. Therefore, it is necessary to find alternatives, to guarantee the sustainability of the process, the economic benefits, and the continuous establishment of by-products in the market (Galanakis, 2016).

Market

The consumer's attitude and trends toward sustainable and organic products stand out because those products positively affect the environment, provide consumer well-being, and reduce the risk of diseases related to chemical ingestion (Weisenburger, 1993; Daou et al., 2020).

Since the processing of edible by-products is a complex issue, research groups and industries are focusing on high value-added products from these materials, such as phenolic extract, oil seed extraction, and natural dyeing. In Europe, the compliance with regulations is a major barrier for small-scale producers who focus on the production of novel compounds and mixtures via food by-products reprocessing. According to Ravindran & Jaiswal (2016), the European law [Regulation (EC) No 1907/2006] of the European Parliament and Council requires the manufacturer to obtain a registration for newly chemicals that should not exceed one tonne per annum (Council of the European Union, 2006). However, this utilization does not consider the high nutritional value of the whole organic material.

Food by-product characteristics and its proper processing costs are the main reason why they have been sold as cattle feed (Mussatto, 2014), and few works have addressed the potential market for the integral use of food by-products as powders or flours for nutritional purposes.

Spigno et al. (2017) made a comprehensive review on the worldwide post-utilization of grape processing by-products, and they observed that this huge volume of industrial waste is mainly destined to distillation, and tartaric acid and seed oil production. These authors also carried out a survey of European studies on the use of grape residue and observed that, from 16 projects, just one dealt directly with the whole use of grape pomace, and the majority of them evaluated the potential utilization of polyphenolic and oil extraction. In this context, from a complete circular economy perspective, these proposals still leave an organic solid residue.

Ferri et al. (2020) proposed the optimization of phenolic extraction from grape pomace and the production of bioplastic with the residual organic solid. However, in the literature, there is no information on what are the market perception and attitude for the reuse of food by-products as flours for food applications, which is a barrier to industries regarding the decision to process it.

CONCLUSIONS

The looking at circular economy as complete as possible within the food industry, as well as the use of skins, seeds, wholly spent grains – without generating new materials which should be treated –, and the data raised in the literature support the proposed perspectives for large-scale industrial processing not being used for human consumption.

People's perception, technological barriers, lack of knowledge on trade, logistics and applied technologies are significant limitations to the residue processing of vegetable food in the industry.

Food by-products from beverage and horticulture show up as alternatives for industries as ingredients for high added-value nutritional products. However, efforts should be done to evaluate their marketing potential, as well as the perception and attitudes of consumers and industries toward by-products goods, in order to these products be proffered for human diet. Additionally, a more in-depth exploration of single by-products flowcharts and equipments should warranted for the adoption of food by-products processing by the industry. Food by-products are most commonly used in the areas of cosmetics, biological control, and new materials, and can be the basis for further analyses to shed light on the limitations presented in this work. As limitations, like any work that proposes to be based on data from the literature, this manuscript is a transversal study, thus, a longitudinal analysis (through time) is important to assess the evolution of data to overcome the limitations presented here. Also, it is important to point out that the present article focused on using fruit/vegetable by-products as powder/flour as food applications, which may bring a restrict approach to the issue, since other barriers and limitations show up for other applications such as oil, polyphenols, dyes extraction, composing, and others.

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