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Review article: Current research trends in fruit and vegetables wastes and by-products management-Scope and opportunities in the Estonian context

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Abstract. Globally on an annual scale, considerable amounts of fruit and vegetables wastes (FVW) are generated in the agri-food industrial sector. Costs insured for safe disposal of FVW remains uneconomical and they can pose a serious environmental hazard if left untreated. However, FVW have high potential for reuse, recycle and recovery, which is an indication that there are productive, sustainable and affordable ways of reducing and tackling them at the industrial levels. Recent years have seen progressive innovative research on FVW management strategies, which has been developed with an idea of reducing wastes and fully exploiting its potential. Further, FVW represents a potential source of valuable compounds and bioactive ingredients. Today, there are many proposed innovative approaches for handling the FVW. These include reintroducing sub-standard fruit and vegetables (small sized or misshaped fruit and vegetable) in the market, reusing FVW for soil amendments, composting, or as an animal feed, and much more. In addition, the extracted bioactive compounds from FVW and by-products can find wide applications as a natural additive in food, cosmetics and/or in pharmaceutical applications. Currently, novel cost effective strategies have been developed for effective valorisation of agri-food wastes and by-products. The field of FVW management is still limited, thus leaving a wide gap for new ideas, novelty and applications of more efficient green techniques for complete utilization of agri-food wastes and by-products. Some of the interesting aspects on wastes and by-products management are discussed in relevance to Europe and in Estonia.

Key words: food wastes and loss, circular economy, waste management, bioactive compounds, livestock feed.

INTRODUCTION

Globally agri-food sector generates enormous volumes of food wastes and by-products. The majority of these wastes are disposed as landfillscreating serious negative impact on the environment (FAO, 2011; Wadhwa & Bakshi, 2013; Stenmarck et al., 2016; Sagar et al., 2018). Unsustainable disposal of wastes can also represent high economical cost for many of the food processing industries (Stenmarck et al., 2016). According to FAO (2019), food losses and waste can occur in the food supply chain, starting from harvest up to retail and consumption levels. Food wastes can also be categorised as to unprocessed and processed ones. On a global scale, an average of 30–40% of annual food production is wasted (Laufenberg et al., 2003; Parfitt et al., 2010;

FAO, 2016; Gu et al., 2019; Huang et al., 2019). This adds up to about 1.3 billion tons of waste created every year in the world (FAO, 2011). In the EU alone an annual food waste ranging up to 88 million tonnes are generated, resulting in a cost of around 143 billion euros (EU Fusions 2020). There has been an increased focus on food loss and waste, which is included as a part of 'Sustainable Development Goals' (SDG) of the UN (FAO, 2019). SDG contribute to Zero Hunger goal, aimed to achieve food security and sustainable agriculture systems. Itis witnessed that food wastes generation to be much higher in industrialized countries than in developed ones. In the industrialized world, consumers at the very end of the food supply chain tend to waste much of the food. In developing countries, food loss is much higher, owed to presence of poor processing infrastructure and preservation technologies. However, very little amount of edible portion of food is wasted by consumers (FAO, 2011). For a better understanding, it is a necessity to explain differences between a food waste and the food loss. Food loss represents food mass that is lost during the various stages of production, postharvest and processing along the agri-food supply chain. Lack of appropriate processing infrastructures, handling, transportation and storage facilities as well as the extrinsic climatic conditions can also contribute for the loss (Papargyropoulou et al., 2014; Sagar et al., 2018). On the other side, food wastes occur during final consumption stage, more precisely when a decision to discard the food happens, and this is commonly attributed to the behaviour of retailer and/or consumers.

Back in 2014 and 2015, food waste analysis was undertaken from researcher in Estonia (by SEI Tallinn). The purpose of this analysis was to estimate the amount of food wastes in the country and this was undertaken from the support of Ministry of the Environment of Estonia. There were two separate studies, one which estimated the amount of wastes in Estonian households and catering institutions, such as restaurants, bars and pubs, cafés, canteens, buffets, schools, kindergartens and a hospital (Moora et al., 2015), while the second one included retail and wholesale sector and food industries (Moora et al., 2018). Based on the results, it was estimated that food wastes are created mostly at households (up to 71,000 tons per year) followed by catering services (up to 13,000 tons per year), and then retailers and food processing industries (Moora et al., 2015; Siani et al., 2016).

Fruits and vegetable wastes (FVW)

The production of fruit and vegetables has recently increased significantly due to growing population and changing of eating habits, with more number of people shifting to vegetarian based diets (Schieber et al., 2001; Vilariño et al., 2017, Sagar et al., 2018). The increased production coupled with poor handling of fruits and vegetables and behaviour of retailers and consumers towards wastage have led to huge quantities of loss and waste of vital agri-food commodities (Sagar et al., 2018). FAO (2011) has estimated that fruit and vegetable wastes contribute to nearly 60% of all the food waste. With regard to FVW in Estonia, in an analysis conducted by SEI Tallinn, but this study did not precisely concluded on how much of the wastes came from fruits and/or vegetables (Moora et al., 2018). FVW represents a serious problem for environment as most of them are being disposed of as landfills or directly disposed off to water bodies such as rivers (Wadhwa & Bakshi, 2013). This causes serious environmental pollution, as they are easily perishable due to their high moisture content, which leads to microbiological contamination (Banerjee et al., 2017; Plazzota et al., 2017, Pham Van et al., 2018; Coman et al., 2019; Bas-Bellver et al., 2020).

WASTE MANAGEMENT STRATEGIES

Recent years have seen progress in the FVW management strategies. There are many sustainable approaches for handling FVW, and some of these include: reusing FVW as an soil amendment or animal feed, extracting of bioactive compounds, and much more (Arvanitoyannis et al., 2008; Prokopov et al., 2014; Plazzotta et al., 2017; Coman et al., 2019; Peng et al., 2019; Salehiyoun et al., 2019). Some of these aspects are discussed in the preceding text.

In Estonia, the utilization of FVW is under consideration in various institutions of higher learning, government as well as the involved R & D sector. The necessity of identifying the existing research gaps on use of FVW in Estonia, and filling these gaps with new and innovative ideas have been identified. The quest for new ideas and improvement of current methods will contribute to creating of sustainable food/feed production systems and the further utilization of FVW in various industries. The vegetal waste and by-product are currently analysed for their composition, bioactive compounds and bioactive properties. Novel technologies of FVW utilization and applications is being explored and improved. Under the prestigious ERA Chair for Food (By-) Products Valorisation Technologies at the Estonian University of Life Sciences, active research activities is being undertaken aimed towards minimizing agri-food wastes and efficiently utilize by-products in order to support zero waste concept and circular economy of the region.

In the preceding text, we have summarized some of the important aspects relevant to trends in waste management. The present article is structured as follows. First part includes methodology used for writing this review article, and second part presents the methods of prevention of food waste (including fruits and vegetable waste) generation and management of food surplus. In the sections three to eight, current research trends of fruit and vegetable waste management are discussed with the special focus on scope and opportunities in Estonia. As there is a serious lack of data and information's available in the database or published research articles on fruit and vegetable waste management in Estonia, the discussions on current use of FVW in Estonia is mostly based on author's opinions and point of view. Further, in the chapter nine, use of fruit and vegetable waste in Estonia is summarized, followed by the conclusion part.

Nevertheless, the main objectives and aim of writing this review is to focus on the current fruit and vegetable waste management strategies on the global scale and to evaluate if these ideas can be extended with regard to Estonia.

Methodology

The methodology for writing this review used a descriptive approach. Accordingly, only those published articles that can find potential scope and practical applicability in Estonian context were shortlisted and selected. For identification of the research articles, a detailed search was undertaken by using popular electronic database such as Scopus (https://www.scopus.com/) and PubMed (https://www.ncbi.nlm.nih.gov/pubmed/). Additional search included websites of EU commission and Google databases. The keywords used were: Food wastes and loss; fruit and vegetables wastes and by-products, Circular economy; Waste management; Bioactive compounds from wastes and by-products; Food and livestock feed, EU status, Statistical data and Estonia. The short listed references were scanned for additional relevant information's. No time limitation were applied for shortlisting of the references.

Marketing of malformed fruits and sub-standard fruits and food rescue programs

In the present global scenario, significant amounts of agri-food wastes provide negative environmental, economical and social impacts. Hence, every country world over are focusing on waste prevention, management and valorization strategies for achieving sustainable development. In the waste hierarchy, it is vital to distinguish waste prevention from waste management as well as food surplus and food wastes. Waste prevention mainly represents those actions taken against generation of wastes, while waste managements are related with the waste that has already been generated in the supply chain. On the other note, food surplus is related to the oversupply of foods (Papargyropoulou et al., 2014).

This chapter discusses certain food waste management (fruits and vegetables) options (both globally and in Estonia) with the special focus on retail sectors. Retail sectors contribute to generation of food wastes by disposing overstocked and oversupplied commodities. These might be damaged or spoilt ones, having a damaged package, nearing the expiry date or those which do not fit the set quality standards (Cicatiello et al., 2019). Approximately one third of fruits and vegetables never make it to the grocery shelves or the supermarkets, as they do not meet the quality standard criteria concerning weight, size, appearance and shape (FAO, 2018). Majority of the supermarket chains are not interested to buy such products, which do not meet the quality specifications as per the consumer's needs (Mena, et al., 2011; Plazzotta et al., 2017). These malformed fruits and vegetables are referred to as sub-standard. Re-introducing these type of products into the market is one of the new initiatives that has begun or is rather being under consideration globally. Even though these products have flaws in the appearance, they do not lack in quality and value (Economist, 2018). Their unusual look (malformed) does not affect the taste, nor compromise the health benefits they impart. Several companies in Europe and United States have begun providing these malformed fruit and vegetables to retail customers with minimal costs (Slate, 2015; Economist, 2018). However, there is no available information on the initiatives of introducing substandard fruits or vegetables in the supermarket chains in Estonia. In addition to this initiative, there are many organizations world-over, which are directly linking farmers/ producers with the community and relevant industries. There are also food rescue programs wherein retailers work in hand with charity organizations to donate food that is close to best before dates (Plazzotta et al., 2017; Hecht et al., 2019). Further, phone applications have been created to reduce/reuse restaurant, bakery, fruit and vegetable market based products, which are either sold at lower costs or are given for free (O'Sullivan, 2016; Hajjdiab et al., 2018). According to Siani (2016), contributions coming from food industries in Estonia are infrequent, as they require additional work and labour, leading to high economical costs. In certain cases, these food donation and contributions can also involve food safety issues, which can result in legal matters. In addition, most of the industries do not have available storage place for food, which needs to be donated, and they cannot afford to provide them.

In the 'Sustainable Development Forum' from Tallinn, Estonia, several waste management strategies were considered. One of the strategies was raising of consumer awareness as it was witnessed that majority of the consumers had trouble distinguishing labels such as 'best before' and 'use by' which resulted in disposing of food which were still good for consumption. Consumer's habits regarding separating of the waste are discussed, as the separation of waste is still not reaching the satisfactory levels in Estonia comparing to other EU countries. The solution to this could be the enhanced/improved waste collection system, which is yet to be developed. Increasing of food prices is also being questioned! This strategy was opined to make people more reluctant to disposing of food. However, as food insecurity is still present in Estonia, this suggestion has been discarded. Introducing the idea of informal food sharing was considered as well, based on the concepts developed in Germany and Finland (Saarniit, 2016).

Fruit and vegetable waste (FVW) as soil amendments

Soil represents an important natural resource and consists of the minerals (inorganic part), remains of plants and animals, and living organism that reside in it (organic part). Soil pollution is present world over, with common pollutants such as toxic compounds and chemicals; pathogens, radioactive materials, etc. (Mench et al., 2003; Mareddy, 2017). Even though soil contamination represents a significant problem, nowadays there are many effective soil remediation strategies. Soil amendment based practices are low-cost and environmentally safe. These can be efficiently utilized to enhance overall soil quality in terms of its structure and biochemical function, as they enhance soil fertility and promote site condition stabilization (Hartley et al., 2009; Beesley et al., 2014; Maiti, 2019). Today, many countries use fruit and vegetable waste as soil amendments. Composts and charcoal has been utilized in the agri-culture for a long period of time (Banerjee et al., 2017). Their utilization offers various benefits in regards to improvement of soil health (Burgos et al., 2010). However, FVW have high biological instability which leads to growth of microbiological contaminants (Ajila et al., 2012) and its long term effect is questionable which is why periodic re-applications are recommended (Madejón et al., 2009a; Madejón et al., 2009b).

In Estonia, according to Statistics Estonia, average yields of crops have been increasing annually, leading to a higher quantity of fruit and vegetable waste (Statistics Estonia, 2020). The utilization of FVW as soil amendments is still very rare. However, it is widely believed that this will not only reduce the amount of wastes, but it would enhance organic matter and nutrient content of soil, avoid certain negative impact associated with use of inorganic fertilizers and much more (Sharma & Chetani, 2017). The shift to utilization of fruit and vegetable waste is highly encouraged.

Fruit and vegetable flour

Fruit and vegetable flour as heavy metal adsorbents

Food industries generate large amounts of residues during the processing of fruits and vegetables (Ayala-Zavala et al., 2010; Sousa et al., 2011; Ferreira et al., 2015). Despite creating major environmental issues, FVW residues contain large amounts of high-valued bioactive compounds, which have high potential for re-use and recyclability (Sousa et al., 2011; Banerjee et al., 2017; Coman et al., 2019). Raw fruits and vegetables, are quickly subjected to degradation and pathogen contamination due to their high moisture content which makes their utilization restricted (Carle & Schieber 2006;

Plazzota et al., 2017). However, processing of fruits and vegetables residues into the flour can prolong their availability for different kinds of utilization (Ferreira et al., 2015). This makes processing of fruit and vegetable waste into the flour a very attractive option (Laufenberg et al., 2003; Ayala-Zavala et al., 2010; Ferreira et al., 2015). Fruit and vegetable wastes have been processed to flour for different purposes: for food application, pharmaceutical applications and adsorbing pollutants such as heavy metals from water and ground (Njikam & Schiewer, 2012; Roberta et al., 2014; Plazzotta et al., 2017; Santana et al., 2017).

There have been multiple studies, examining the efficacy of the utilization of fruit and vegetable wastes for adsorption of heavy metals. FVW that have been used include: Orange wastes (Pérez Marin et al., 2007), olive oil wastes (Doyurum & Çelik, 2006), banana pith (Low et al., 1995), mandarin peels (Pavan et al., 2006), orange juice and peel wastes (Azouaou et al., 2010, Lasheen et al., 2012), citrus peels (Njikam & Schiewer, 2012), hazelnut shell (Cimino et al., 2000), maize barn (Hasan et al., 2008), etc. It has been established that FVW are efficient heavy metals adsorbents due to their fibrous and porous structure which entraps pollutants (Plazzota et al., 2017). The adsorption is attributed to the specific interaction of pollutants with cellulose, pectin, hemicellulose and lignin obtained from FVW (Hashem et al., 2007; Azouaou & Mokaddem, 2008). The functional carboxylic and the alcoholic hydroxyl groups in cellulose, pectin, hemicelluloses and lignin havean ability to bind heavy metals (Ghimire et al., 2003). In addition sulphate, phosophate and amino groups contained in proteins, carbohydrates and phenolic compounds of FVW contribute to adsorption of heavy metals too (Meena et al., 2005). During the studies conducted to evaluate the potential of utilization of FVW as heavy metal absorbents, besides the efficiency, particular attention was focused on environmental and economic aspects of their utilization. The abundancy and accessibility of FVW has also been accounted (Cimino et al., 2000; Pavan et al., 2006), as well as the influence of several factors that affect adsorption. These factors included contact time, adsorbent mass, initial concentration of heavy metals, initial pH of the solution, particle size of the adsorbent, temperature, etc. (Pavan et al., 2006, Azouaou, 2008).

Fruit and vegetable flour as an ingredient for the formulation of functional food

Fruit and vegetable flour can be used as value added ingredient for the formulation of novel *functional* food products. Fruit and vegetable residues, wastes and by-products represent a rich source of nutritious compounds such as polyphenols, dietary fibres, carotenoids, and vitamins, which are beneficial for human health (Figuerola et al., 2005; Makris et al., 2007; Ajila & Prasada Rao, 2013). They contribute to prevention and treatment of human diseases (Roberta et al., 2014; Heidor et al., 2019; Javed et al., 2019). Several studies have been conducted to evaluate the functional properties, microbiological stability, proximate composition and antioxidant capacity of flour processed from different types of fruit and vegetable wastes. For example: Ferreira et al. (2015) has evaluated functional properties of flour obtained from residues generated during beverage manufacture. The beverage was produced from several fruits and vegetables: orange, watermelon, passion fruit, lettuce, taro, carrot, courgette, mint, spinach, cucumber and rocket. The fruit and vegetable residue flour was used for making of cereal bars and biscuits. Results showed that the obtained flour was suitable for production of functional food. It showed high dietary fibre, mineral and protein content as well as water and oil holding capacity (Udenigwe & Aluko, 2012). In addition, Černiauskiene et al. (2014) have evaluated pumpkin flour as a source of food enrichment in dietary fiber. Bakery based foods prepared from pumpkin flour manifested high content of vitamins, minerals, and dietary fiber (Noor Aziah & Komathi, 2009). Futher on, Juarez-Garcia et al. (2006) used unripe banana fruit for developing of banana flour. Banana flour has been used for producing bread and it was evaluated based on its chemical composition, rate of starch available starch, resistant starch content and digestion *in vitro*. As a comparison, control product based on wheat flour was used. Banana flour had significantly higher protein, dietary fibre and starch content than control bread. It had low glycaemic index, which made it suitable for people with special low caloric requirement use.

These are just few of the many studies that have been conducted with the aim of investigating the potential of processing fruit and vegetable residues into the functional flour. All of these studies have showed that using FVW flour for development of functional food and products is a sustainable low-cost method, which is beneficial for environment and human health. However, the major issue related to utilization of fruit and vegetable flour is that fruit and vegetable waste has high water content. Therefore, for the production of the FVW flour, fruit and vegetable waste needs to undergo the process of drying which can be highly time-consuming and can affect FVW composition and content (Plazzotta et al., 2017).

The scope of using FVW flour for potential food and pharmaceutical applications, as well as for removal of heavy metals from water and ground, is gradually increasing world over. Estonia, being a small country produces enormous amounts of wastes and by-products from industries linked with apple, potato, beetroot, carrot, pumpkin, sea buckthorn, and other production. These wastes and by-products, which are rich in bioactive compounds (e.g. polyphenols, dietary fiber, natural pigments, etc.) can be processed into value added flour and can be fortified with bakery-based products or can be used for developing other novel food and feeds.

Fruit and vegetable waste in food industry

FVW is widely used in food industry. Today, there are many new functional food products containing fruit and vegetable waste on the market and their production is increasing every day (Kowalska et al., 2017; Donno et al., 2018; Majerska et al., 2019). FVW have been commonly used as natural food additives. It was observed that artificial additives, which have been used in the food industries up until recently, can be very harmful for human health, especially when in high doses. This is why the interest for natural food additives has increased (Schilderman et al., 1995; Wadhwa & Bakshi 2013; Quintin et al., 2019). Certain extracts from FVW, such as anthocyanin from eggplant, betalains from beetroot, anthocyanins from banana bract, lycopene from tomato by-products have been used as potential natural food colorants in the modern food industry (Pazmiño-Durán et al., 2001; Rizk et al., 2014; Gengatharan, et al., 2015; Faustino et al., 2019). In addition, agro-food by-products, have been used as preservatives, anti-oxidants, texturizing agents, emulsifiers, bulking agents, firming agents, etc. (Faustino et al., 2019).

FVW has been also utilized in the production of juices (Laufenberg et al., 2003), jellies (Madhav & Pushpalatha, 2006), and jams (Singh et al., 2009). They are also added in the production of herbal and fruit teas (Wadhwa & Bakshi, 2013; Majerska et al., 2019), and in making of alcoholic beverages. For example, apple pomace has been used for the production of cider and beer (Benvenutti et al., 2019; Way et al., 2019; Gultip & Jokshi, 2000). Black currant, bilberry, chokeberry and grape pomace have been valorised for making of wine, while apple and grape pomace showed potential as additives for improvement of its taste too (Majerska et al., 2019). The potential of certain fruit and vegetable waste, such as orange peel and apple pomace have been evaluated for production of brandy (Gultip & Jokshi, 2000). In addition, wastes from pineapple, banana and certain vegetable waste have been utilized for vinegar production (Fatima & Mishra, 2015; Aye, 2016; Chakraborty et al., 2018). Some of the FVW has proven to positively affect dairy products (de Souza de Azevedo et al., 2018; Majerska et al., 2019). Saraç & Dogan (2016) established that incorporation of dietary fibre extracted from stone pear, celery root, celery leaves, spinach and oranges into the production of butter, made butter easily spreadable, more firm, and it extended its shell life. Besides showing positive effects on dairy products, FVW can be used as their replacement for production of food products for lactose intolerant people. The incidence of lactose intolerance has grown in recent years. Certain fruit wastes are reported to be probiotic food cariers due to their high content of vitamins, minerals, antioxidants and the absence of dairy allergens (Majerska et al., 2019). For example, Vodnar et al. (2019) did a study of using bioactive compounds from agro-industrial waste for production of probiotic juices. In addition, Ouhrabková et al. (2010) did a study on utilization of vegetable raw materials for producing probiotic dairy-like food. The study showed that obtained products containing raw vegetable material could be used as a replacement to cow's milk.

FVW is successfully utilized for improvement of meat products too. For example, Fernández- López et al. (2008), conducted a study based on adding fibre obtained from orange to dry fermented sausage. The fibre did not affect flavour, it promoted the growth of necessary microflora andit decreased the levels of nitrite. It also extended its shell-life (O'Shea et al., 2012). Viuda-Martos et al. (2010) from their established that adding of orange fibre reduced the growth of pathogens in the sausage and retarded the oxidation, extending its use (O'Shea et al., 2012). Apple and fresh plum pomace have also been successfully added to meat products, increasing its antioxidant capacity, nutritional value and extending its shelf-life (Henriquez et al., 2010; O'Shea et al., 2012; Lorenzo et al., 2017). In the study conducted by Sánchez-Alonso (2007), addition of grape pomace dietary fibre to fish, enhanced its health and sensory properties, improved its water retention capacity and retarded lipid oxidation (Sánchez-Alonso et al., 2007).

Overall, from the available literature, it is clear that there is a huge variety of successful ways in which fruit and vegetable wastes, by products and their extracts can be incorporated into food for human consumption. FVW improves food's nutritional quality, sensory characteristics and enhances its health properties as well. In Estonia, fruit and vegetable wastes and by products are gradually being considered as ingredients in food industries. Currently there are ongoing studies evaluating the potential of FVW for development of value added products and functional food. Fruit and vegetable wastes included in the studies are mostly apple, beetroot, potato, and carrot wastes since these fruits and vegetables are readily available and abundant in the country.

Extraction of bioactive compounds from fruit and vegetable waste (FVW)

FVW represents a highly underexploited resource of valuable bioactive compounds and phytonutrients such as dietary fibers, polyphenols, pigments, enzymes, sugar derivatives, vitamins, minerals and oils (Sagar et al., 2018; Coman et al., 2019). These compounds and nutrients can be used in a wide range of different industries. Some of them have proven health effects, which include antimicrobial, anticancer, antiviral, anti-mutagenic, antioxidant and cardio protective activities (Dilas et al., 2009; Banerjee et al., 2017; Vodnar et al., 2017; Sagar et al., 2018). In addition, they have proven useful in food, cosmetics, pharmaceutical, paper and textile industries (Laufenberg et al., 2003; Galankis, 2012; Banerjee et al., 2017; Sagar et al., 2018). The process of extraction is being constantly improved by the application of novel technologies (Herrero et al., 2010; Sagar et al., 2018). These novel technologies and their modifications are introduced into the methodology with the aim of maximizing the yield and rate of the target compounds, clearing the compounds from toxic substances and impurities, providing grade nature of the final product and avoiding any functionality loss during processing (Galanakis, 2012).

Dietary fibres

Dietary fibre represent biomolecules, resistant todigestion by gastrointestinal enzymes. They include cellulose, hemicellulose, pectic substances, beta glucans, resistant dextrin, inulin, gums, chitosan oligosaccharides, lignin, etc. (Mudgil, 2017). Based on their water solubility, dietary fibre can be soluble and insoluble (Dhingra et al., 2012). FVW dietary fibre are largely used in various industries. They manifest wide range of health promoting activities. They contribute to prevention and treatment of diabetes, cardiovascular diseases, obesity and pancreatic, colon and colorectal cancer (Ferguson, 2005; Figuerola et al., 2005; Nawirska & Kwasniewska, 2005; Evans et al., 2019; Koulouris et al., 2019; Villanueva-Suárez et al., 2019). Recently there has been a lot of interest in FVW lignocellulosic biomass and bioactive polysaccharides and their renewable sources. This could be due to newly found approaches for valorisation of cellulose, hemicelluloses, pectin and lignin. The utilization of cellulose has extended to biomedical section. Nowadays, it is often utilized for medical diagnostics and cancer screenings (Ratajczak & Stobiecka, 2019). In addition, it has also been used as pharmaceutical excipient (Domínguez-Robleset al., 2019), filler in solid oral dosage formulations (Credou & Berthelot, 2014; Banerjee et al., 2017), and for drug delivery, in wound dressings, tissue engineering scaffolds and bio-imaging (Du et al., 2019; Fu et al., 2019). It is also frequently used in the food industries, and for the extraction of phenolic compounds from grape pomace (Drider et al., 1994; Meyer et al., 1998; Sagar et al., 2018). For production of cellulose, following fruit and vegetable waste is often used: citrus peels (Güzel & Akpınar, 2019), banana waste (Elanthikkal et al., 2010), potato peel (dos Santos et al., 2012; Sagar et al., 2018), mandarin peel (Hiasa et al., 2014), etc.

Pectin, successfully extracted from a varied source of FVW has been widely used in food industry. Apart from that, it is often utilized in pharmaceutics, mostly as thickening agent and for production of products preventing diarrhoea (Rabbani et al., 2001; Liu et al., 2003; Banerjee et al., 2017). It also used for biomedical applications: for drug and gene delivery, tissue engineering and wound healing (Munarin et al., 2012). Resistant starch, obtained from fruit waste such as banana peel, jackfruit seeds, durian waste and mango kernel, like hemicelluloses, can only be digested in colon and its fermentation results in many health benefits too (Fuentes-Zaragoza, et al., 2010; Banerjee et al., 2017; Ho & Wong, 2019).

Proteins

FVW represents a good source of proteins as well. Their content is especially high in seeds (Banerjee et al., 2017). Apart from fruit and vegetable seeds, pea straws (Wadhwa & Bakshi, 2013), potato peels, avocado waste; (Chitturi et al., 2013) cabbage leaves; carrot pomace, apple pomace, citrus peel, green pea peels, mango peel, pineapple peel, tomato solid waste, pea pods, orange peel, cauliflower leave, and others have a good amount of proteins too (Mamma & Christakopoulos, 2014; Bakshi et al., 2016; Sharma et al., 2016; Sagar et al., 2018). Certain fruit and vegetable waste have more than 20% of crude protein, which is why they are used as ruminant feed. These include, cabbage leaves, bottle gourd pulp, potato vines, radish leaves sugar beet leaves and snow peas (Bakshi et al., 2016). Apart from contributing to nutritional value of animal feed, certain proteins exhibit potential health beneficial activities, and this the reason they are extracted from FVW. For example, kiwifruit seed has been used for the extraction of actinidin. This enzyme is responsible for digestion of proteins in small intestines. Due to its probiotic activities, it is commonly added to dairy products (Puglisi et al., 2012, Boland, 2013).

Enzymes

Enzymes represent biomolecules, which contribute to various industries. For example, amylases is abundantly used in food industries for the production of fruit juices, cheese, chocolate cakes and syrups (Laufenberg et al., 2009; Toumi et al., 2016; Sagar et al., 2018). It is used in pharmaceuticals, brewing, and textile industries (Saini et al., 2017). The most common FVW used for production of amylases are: bananapeel (Oshoma et al., 2019), orange peel (Uygut & Tanyildizi, 2018), potato peels (Pereira et al., 2017), date wastes (Acoureneet al., 2014; Sagar et al., 2018), rice bran, wheat bran (Almanaa et al., 2019), and mango kernels (Kumar et al., 2013; Sagar et al., 2018). Invertase is used for the production of invert sugar, artificial sweeteners, chocolates, lactic acid, glycerol, candies and confectionary (Sagar et al., 2018; Veana et al., 2018; Mashetty & Biradar, 2019). The production of this enzyme using fruit and vegetable waste, also requires the presence of sucrose, lactose and fructose (Sagar et al., 2018). FVW that has been so far used is pineapple peel (Oyedeji et al., 2017); pomegranate peel (Uma et al., 2012); papaya peel (Chelliappan & Madhanasundareswari, 2013). Apart from food industry, it is used for production of pharmaceutical products and extension of shell life of products (Kumar & Kesavapillai, 2012; Panda et al., 2016). Pectinase is commonly used for making of wine and fruit juices (New et al., 2018; Nighojkar et al., 2019). It is also applied for extraction of pigments (Munde et al., 2017) and essential oils from FVW (Sagar et al., 2018; Castilho et al., 2000). Additionally, it plays a role in production of good quality paper (Ahlawat et al., 2008; Rebello et al., 2017), for fermentation of coffee and tea and for treatment of pectic waste (Kashyap et al., 2001; Rebello et al., 2017). Citrus waste peel (Ahmed et al., 2016); banana peel (Sethi et al., 2016); mango peel (Kuvvet et al., 2019); sugarcane bagasse (Biz et al., 2016.), pineapple stem (Kavuthodi & Sebastian, 2018), have been used for the production of pectinases. An example of using FVW for production of enzymes is given in Table 1.

Table 1. Production of enzymes using fruit and vegetable waste (FVW)

Enzymes	Purpose	FVW used for enzyme production
Amylases	Food industries for the production of fruit juices, cheese, chocolate cakes and syrups (Laufenberg et al., 2009; Toumi et al., 2016; Saini et al., 2017); pharmaceutical, brewing and textile industries (Saini et al., 2017).	Banana peel (Oshoma et al., 2019); orange peel; (Uygut & Tanyildizi, 2018); potato peels (Pereira et al., 2017); date waste (Acoureneet al., 2014; Sagar et al., 2018), rice bran, wheat bran (Almanaa et al., 2019); mango kernels (Kumar et al., 2013; Sagar et al., 2018)
Invertase	Production of invert sugar, artificial sweeteners, chocolates, lactic acid, glycerol, candies and confectionary (Sagar et al., 2018; Veana et al., 2018; Mashetty & Biradar, 2019), production of pharmaceutical products and extension of shell life of products (Kumar & Kesavapillai, 2012; Panda et al., 2016; Sagar et al., 2018).	Pineapple peel (Oyedeji et al., 2017); pomegranate peel (Uma et al., 2012); papaya peel (Chelliappan & Madhanasundareswari, 2013)
Pectinase	Production of wine and fruit juices (New et al., 2018; Nighojkar et al., 2019); for extraction of pigments (Munde et al., 2017) and essential oils from fruit and vegetable wastes (Castilho et al., 2000; Sagar et al., 2018); production of good quality paper (Ahlawat et al., 2008; Rebello et al., 2017), for fermentation of coffee and tea and for treatment of pectic waste (Kashyap et al., 2001; Rebello et al., 2017).	Citrus waste peel (Ahmed et al., 2016); banana peel (Sethi et al., 2016); mango peel (Kuvvet et al., 2019); sugarcane bagasse (Biz et al., 2016.), pineapple stem (Kavuthodi & Sebastian, 2018)
Cellulases	Textile industry, for production of detergents, food industry (Imran et al., 2016); industrial biontechnology (Bajaj & Mahjan, 2019)	Potato peel (Taher et al., 2019); orange waste (Srivastava et al., 2017); Pineapple peel (Oyedeji & Ojekunle, 2018); cucumber peel, banana peel (Viswanath et al., 2018);
Xylanases	Paper, biofuel industry, food industry, textile industry; as supplement to animal feed (Kumar et al., 2018; Singh, 2019),	Banana peel (Zehra et al., 2020); passion fruit peel (Martins et al., 2018); cassava peels (Olanbiwoninu & Odunfa, 2016);orange peel (Silva et al., 2018)

Lipids

FVW are also rich in lipids or the oils. For example: the orange peels (Boukroufa et al., 2015), fennel waste (Cautela et al., 2019); apple and pear seed (Yukui, 2009), mango seed (Yadav et al., 2017), apricot seeds (Stryjecka et al., 2019), tomato seeds (Giuffrè et al., 2017), lemon peel (Ciriminna et al., 2017), represent a good source of oil. Oil extracted from FVW exhibits antioxidant, anti-cancer, anti-inflammatory, antimicrobial and immunomodulatory activities (Pérez et al., 2011; Bhalla et al., 2013; Ayoub et al., 2017; Geraci et al., 2017; Moosavy et al., 2017; Irshad et al., 2019). In addition, it can manifest anti-obesity properties and hypolipidemic effects as well (Yang et al., 2018). It used as an ingredient of skin healing creams, due to its moisturizing properties (Mandawgade & Patravale, 2008; Banerjee et al., 2017), and in pharmacology as a reagents for producing products that contribute to good digestion (Njoroge et al., 2005; Wadhwa & Bakshi, 2013).

Polypenols

Today there is a great interest in polyphenols and their induction in the everyday diet and products. They manifest many important biological health properties such as, scavenging free radicals, prevention of oxidation reactions in foodand prevention of oxidative stress (Popa et al., 2008; Ignat et al., 2011; Deng et al., 2012; Sagar et al., 2018). FVW represent a valuable source of polyphenols. They exibit anti-cancer, anti-viral, anti-bacterial, anti-inflammatory, and anti-oxidative effects (Colomer et al., 2017; de Albuquerque et al., 2019; Fratianni et al., 2019; Musarra-Pizzo et al., 2019). Their use is also considered for prevention of neurodegenerative diseases (Renaud & Martinoli, 2019). In Table 2, phenolic compounds of certain fruit and vegetable wastes can be seen.

Table 2. Phenolic compounds present in selected fruit and vegetable wastes

Commodity	Type of waste	Phenolic compounds	Reference
Apple	Pomace	Hydroxycinnamates, phloretin glycosides, quercetin glycosides, catechins, procyanidins	Foo & Lu, 1999; Lommen et al., 2000; Schieber et al., 2001; Sagar et al., 2018
Apple	pulp	Protocatechuic acid (+)-Catechin, Chlorogenic acid (−)-Epicatechinp-Coumaric acid, Phloridzin	Veberic et al., 2005
Apple	peel	Ferulic acid, caffeic acid, p-coumaric acid	Leontowicz et al., 2007; Saini et al., 2019
Banana	peel	Hydroxycinnamic acids: Ferulic acid; Ferulic acid-hexoside; Sinapic acid; p-cumaric acid methylester Flavonols: Rutin, Quercetin -7-rutinoside; Quercetin -3-rutinoside; Kaempferol-3-rutinosid; Kaempferol-7-rutinoside; Isorhamnetin-3- rutinoside; Myricetin-3-rutinoside; Laricitrin-3-rutinoside; Syringetin-3-rutinoside Flavan-3-ol monomers: (+)-Catechin, Epicatechin, Gallocatechin	Rebello et al., 2014; Waghmare & Kurhade, 2014; Passo Tsamo et al., 2015b; Vu et al., 2018
Bilberry	leaves	Caffeic acid, myricetin-3-O-galactoside	Teleszko & Wojdyło, 2015; Sagar et al., 2018
Blueberry	peel	Epicatechin, catechin, cyanidin 3-glucoside, gallic acid Chlorogenic acid	Deng et al., 2012; Saini et al., 2019
Beetroot	peel	tryptophane, p-coumaric and ferulic acids, cyclodopa glucoside derivatives	Kujala et al., 2001; Deo et al., 2018
Carrot	pomace	Carotene (α and β), chlorogenic acid, dicaffeoylquinic acids	Schieber et al., 2001; Zhang & Hamauzu, 2004; Wadhwa & Bakshi, 2013; Sagar et al., 2018

Table 2 (continued)

Chokeberry	leaves	(−) epicatechin, neochlorogenic acid, chlorogenic acid, quercetin-3-O-rutinoside, quercetin-3-O-robinobioside, quercetin-3-O-galactoside	Teleszko & Wojdyło, 2015; Sagar et al., 2018
Citrus fruits	peel	Naringin, hesperidin, neohesperidin, diosmin, luteolin, sinensetin, rutin, kaempferol, quercetin, Caffeic acid, chlorogenic acid, ferulic acid, sinapic acid, p-coumaric acid β-carotene, zeaxanthin, lutein, β-cryptoxanthin, Neochrome, lutein, β-cryptoxanthin, β-citraurin, luteoxanthin, cryptochrome, ξ-carotene	Coll et al., 1998; Agócs et al., 2007; Wang et al., 2008; Matharu et al., 2016; Sagar et al., 2018; Saini et al., 2019
Cucumber	peel	Chlorophyll, Pheophytin, Phellandrene, Caryophellene	Zeyada et al., 2008
Cranberry	leaves	(+) Catechin, procyanidin B1, (−) epicatechin, myricetin-3-xylopiranoside, quercetin-3-O-galactoside, dimethoxymyricetin-hexoside, methoxyquercetin-pentoside	Teleszko & Wojdyło, 2018; Sagar et al., 2018
Garlic	husk	Ferulic acid, gallic acid, hydroxybenzoic acid, caffeic acid, p-coumaric acid, Di-Ferulic acid, chlorogenic acid, Caffeic acid-O-glucoside, Coumaroylquinic acid, Coumaric acid-O-glucoside, Caffeoylputrescine	Kallel et al., 2014
Grapes	seed	Procyanidins Epicatechin, gallic acid, chlorogenic acid, catechin, cyanidin 3-gluco- side, homogentisic acid, protocatechuic acid, -p-hydroxybenzoic acid	Deng et al., 2012; Saini et al., 2019
Grapes	Pomace	Quercetin, Gallic acid, Protocatechuic acid, Luteolin, (+)-Catechin, (-)-Epicatechin, Vanillic acid, Kaempferol, Syringic acid, p-Coumaric acid, Ellagic acid	Sanhueza et al., 2017
Guava	peel	Catechin, Epicatechin, Kaempferol, Quercetin Myricetin, Rutin, Hydrate, Naringin, Apigenin	Marina & Noriham, 2014
Eggplant	peels	Delphinidin-3-rutinoside-5-glucoside, cyanidin-3-rutinoside, delphi- nidin-3-rutinoside, malvidin-3-rutinoside-5-glucoside, petunidin- 3-rutinoside	Ferarsa et al., 2018; Saini et al., 2019
Kiwifruit	peel	Gallic acid, Protocatechuic acid, Catechin, P-hydroxybenzoic acid, Chlorogenic acid, Vanillic acid, Caffeic acid, L-epicatechin, Syringic acid, coumaric acid, Rutin, Phlorizin, Quercetin, Kaempferol	Wang et al., 2018
Mango	Seed kernel	Gallates, gallotannins, gallic acid, ellagic acid	Arogba, 2000; Schieber et al., 2001; Sagar et al., 2018
Mango	peel	Catechin, Epicatechin, Kaempferol, Quercetin Myricetin, Rutin, Hydrate, Naringin, Apigenin gallic and ellagic acids	Wadhwa & Bakshi., 2013; Marina & Noriham, 2014

Table 2 (continued)

Quince	leave	(+) Catechin, procyanidin B1, procyanidin B2, procyanidin C1, 4-O-caffeoylquinic acid, kaempferol-3-O-rutinoside, kaempferol-3-O-glucoside, quercetin-3-O-galactoside, quercetin-3-O-rutinoside	Benzarti et al., 2015; Teleszko & Wojdyło, 2015
Olive	leaves	Oleuropein, apigenin 7-glucoside, rutin, vanillin, vanillic acid, Caffeic acid, luteolin 7-*O*-glucoside, luteolin 4'-*O*-glucoside, hydroxytyrosel	Ryan et al., 2002
Olive	peel	Luteolin- 7-glucoside, rutin, olueropein, nuzenhide, dimethyl oleuropein	Ryan et al., 2002
Onion	skin	Quercetin 3,40-O-diglucoside and quercetin 40-O-monoglucoside	Zeyada et al., 2008
Papaya	Seeds	Chlorogenic acid, Caffeic acid Ferulic acid, p-Hydroxybenzoic acid, p-Coumaric acid, Myricetin, Quercetin, Kaempferol-3-O-glycoside, Kaempferol, Quercetin 3-O-glycoside	Castro-Vargas et al., 2019
Pomegranate	Seeds, Peel	Anthocyanins, ellagic acid, gallic acid, punicalin, punicalagin	Akhtar et al., 2015; Deo et al., 2018; Zivkovic et al., 2018; Saini et al., 2019
potato	peel	Chlorogenic, gallic, protocatechic and caffeic acids, p- Hydroxybenzoic, Vanillic acid chloregenic acid isomer II	Zeyada et al., 2008
Red beet	peel	ltryptophane, p-coumaric and ferulic acids, cyclodopa glucoside derivatives	Kujala et al., 2001,
Tomato	peel	Cis-lycopene, Beta carotene, Trans-lycopene, Lutein Ascorbic acid, Quercetin. Kaempferal	Zeyada et al., 2008

Organic acids

With regard to organic acids, citric and lactic acids are the most known representatives. They are abundantly used in food, cosmetic and pharmaceutical industries. Citric acid can be produced using kiwifruit peel (Hang et al., 1987); apple pomace (Dhillon et al., 2011; Sagar et al., 2018); cacao pod husk (Vriesmann et al., 2012): pineapple waste (Imandi et al., 2008) via use of fungi *Aspergillus niger* and yeast such as *Yarrowia lipolytica* (Imandi et al., 2008; Sagar et al., 2018). Lactic acid, however, is produced using *Lactobacillus casei, Lactobacillus delbrueckii, and Lactobacillus plantarum* along with apple peel (Gullon et al., 2008); mango waste (Jawad et al., 2013); wheat bran, wheat straw, bread waste, (Ghaffar et al., 2014; Panesar & Kaur, 2015), potato peel, green peas, cassava residues and sweet corn as the substrates (Ray et al., 2008; Mudaliyar et al., 2012; Sagar et al., 2018).

Pigments

Today, there are many known pigments that exibit health properties. One of them is lycopene, a carotenoid, extracted fromtomato pomace (Knoblich, et al., 2005). Lycopene has antioxidant properties and is known for its contribution to treating cancer, especially prostate, but also lung, colon and breast cancer (Lin et al., 2011b; Grabowska et al., 2019; Jiang et al., 2019a; Jiang et al., 2019b; Kim et al., 2019; Sen, 2019). It also prevents cardiovascular diseases and some chronic conditions (Costa-Rodrigues et al., 2018; Cheng et al., 2019; Grabowska et al., 2019). Betalains from beet root peel also showanti-cancer, anti-inflammatory, anti-bacterial activities, and prevent cardiovascular diseases (Lechner & Stoner, 2019; Rahimi et al., 2019a; Rahimi et al., 2019b; Vijaya & Thangaraj, 2019).

Extraction methods

In Fig. 1, some of the common conventional and non-conventional extraction methods used are depicted. Bioactive compounds can be extracted via various methods: such as soxhlet extraction, maceration, hydro-distillation, solvent extraction, etc (Khoddami et al., 2014; Sagar et al., 2018). Novel technologies include greener methods such as supercritical fluid extraction, ultrasonication, micro-wave assisted extraction, pressurized liquid extraction, pulse electric field and ionic liquid extraction. Even though, the extraction of bioactive compounds is a promising FVW utilization strategy, there is still a need for improvement of novel technologies to obtain high yields of bioactive compounds. In Estonia, under the ERA Chair in Valortech at EMU, there are ongoing studies related to optimization of extraction processes and identification of valuable bioactive compounds from local FVW. Besides, works are being undertaken towards development of livestock feed, value added products, etc.

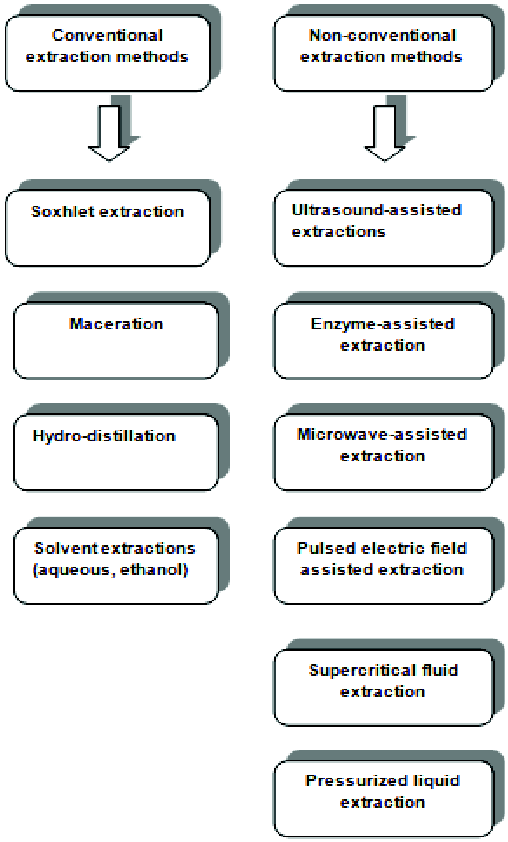

Figure 1. Conventional and Non-conventional extraction methods.

Energy recovery

Providing of a clean and renewable energy source is essential to meet the present day global sustainability challenge. With increasing of population, followed by an increased demand of energy and shortage of fossil fuels, new strategies for energy production are necessary. Waste material shows potential for production of biogas and bio-alcohols via thermochemical, physico-chemical and biochemical strategies (Kothari et al., 2010; Plazzotta et al., 2017; Velebil et al., 2019). Utilizing large quantities of wastes for production of energy is also vital from an environmental point of view as it represents a solution to their disposal in landfills (Sheets et al., 2015). Recently, biodegradable waste has become an important part in production of biogas, bioenergy and biofuel (Spalvins & Blumberga, 2017; Velebil et al., 2019). The concept of bio-refineries is largely being considered. Bio-refineries represents facilities where fuels, power, heat and value added chemicals are generated using biomass as feedstock. Bio-refineries are created with the aim of contributing to circular economy and reducing the utilization of fossil fuels, which negatively affect environment. In a study conducted by Cristóbal et al. (2018), techno/economic and profitability analysis of the bio-refinery was estimated by calculating the cost – (total capital investment and costs of manufacturing) as well as revenues and profitability. Biomass was evaluated for their utilization in bio-refineries for four agricultural food products which included studies on extractions from potato (phenolic acids and glycoalkaloids), tomato (lycopene and β-carotene), olive (phenolic compounds, fatty acids methyl ester and squalene) and orange waste (essential oils, pectin and phenolics). The results showed that value-added product market price to be important in to estimate the profitability of the bio refinery, and different FVW to have a varied potential with regard to generation of bio-energy.

In addition, several other FVW wastes have been investigated for their suitability for energy recovery and its utilization has been evaluated from economic and environmental point of view. For example, Dubrovskis & Plume (2017) conducted a study to evaluate pumpkin, marrow and apple wastes for production of biogas. The study concluded that all of the wastes are suitable for biomethane production. However, there are certain issues that still need to be overcome concerning the use of FVW for energy recovery (Jiang et al., 2012; Plazzotta et al., 2017). Some of these issues are FVWs high content of volatile solids which can readily get hydrolysed, leading to low pH levels and inhibition of anaerobic digestion (Plazzotta et al., 2017). In addition, the organic fraction of fruit and vegetables wastes include 75% sugars and hemicelluloses, 9% cellulose and 5% lignin (Jiang et al., 2012). Even though, these compounds can contribute to large production of energy, their preferable and balanced mixture needs to be met so anaerobic digestion can be successfully performed (Jiang et al., 2012). It is recommended that fruit and vegetable waste be co-digested organic wastes as well. There have been several studies with successful application of co-digestion (Jiang et al., 2012; Shen et al., 2013). Lin et al. (2011a) reported co-digestion of FVW with food waste. The result showed that co- digestion of FVW and FW, with their proper ratio, improved the stability of anaerobic digestion and achieved higher biogas production (Lin et al., 2011a). However, utilization of the waste for energy recovery has faced several additional challenges. Anaerobic digestion based technologies are significantly less efficient comparing to current fossil fuel strategies. It is quite clear that a lot more research needs to be done so the anaerobic digestion of waste reaches its full potential. It is also important for people to understand the necessity of the utilization of renewable energy resources, as fossil fuel reserves are running out and their negative impact is threatening the environment. Nonetheless, utilization of waste for energy production has excellent potential and it needs to be further encouraged. With future advancements, waste to energy technologies can be completely viable, economically sustainable and the solution to current environmental problems.

In Estonia, valorisation of FVW and by-products remains highly underutilized especially in the production of energy via anaerobic digestion. However, renewable energy strategies are largely being studied and hence FVW can be applied for biogas production at appropriate levels. To the authors knowledge, there are several studies and projects that are ongoing at the local universities in Estonia for the development of biogas production using agricultural wastes. Nevertheless, as opined previously, the number of scientific publications are still lagging behind comparing to publications in other country such as France, Germany, Spain, Sweden, or Denmark (Luna del Risco, 2011).

Animal/livestock Feed

With the future increase of population, it is expected that an increased demand of food and especially animal products will follow. This will result in a huge demand in animal feed as well. However, animal feed production is already today facing certain challenges, especially in developing countries (Wadhwa & Bakshi, 2013; Bakshi et al., 2016). FVW represents an excellent source of nutrients, and they can be an solution to meet the ever increasing demands for livestock feeds (Mahgoub et al., 2018; Valdez-Arjona & Ramírez-Mella, 2019). Utilization of FVW for animal feed production would not only enhance food security (Bakshi et al., 2016), but also can contribute to mitigation of environmental pollution related to current waste disposal methods (landfilling). In addition, it would reduce the cost of feeding which is economically beneficial for farmers (Wadhwa & Bakshi, 2013). It could consequently decrease the competition between human and animal nutrition (Mirzaei-Aghsaghali & Maheri-Sis, 2008).

FVW can be incorporated into animal feed either as main feed ingredients such as citrus pulps; as dietary supplements with an aim to achieve a particular function like tomato pulp; or as antioxidants or ingredients with more purpose – like olive pomace (Kasapidou et al., 2015). There are various examples of successful incorporation of FVW onto animal feed. For example, some of the fresh forms of FVW can be fed to ruminants ad libitum. These include: baby corn husk, cabbage waste, pea vines, PP (empty pea pods), cull snow peas, and SC husk due to their high protein content (Bakshi et al., 2016). Further, banana peel is considered to add nutritional value to livestock feed, too. It is a good source of minerals, proteins and fibre (Hassan et al., 2018). Bottle gourd peel, pea husk, potato, eggplant and pumpkin peel have been established as promising feed resources (Hossain et al., 2015). Cabbage waste has been added to feed of ruminants, rabbits and poultry due to its high protein content (Bakshi et al., 2016). Cull carrots are commonly used as ruminants feed, while carrot flakes and dehydrated carrots are often given to horses as treats (Bakshi et al., 2016). In addition, Alzawqari et al. (2016) conducted a study on evaluating adding of sweet orange peel and lemongrass leaves to poultry. Even though the addition of this waste had very little effect on the chicken, it improved blood metabolites and antioxidant status (Alzawqari et al., 2016). Dried citrus peel has been proven to be a good cereal substitute to feed the dairy cattle, lactating ewes and gestating sows-without altering milk yield or its composition (O'Sullivan et al., 2003; Assis et al., 2004). Rapeseed pomacehas been successfully added to diet of lactating cows, too, and its inclusion increased the fatty acid content of milk (Musayeva et al., 2016). However, even though fruit and vegetable waste provide a number of benefits when used for production of animal feed, there are certain disadvantages that need to be taken into account as well. Due to their high moisture and microbial loads, FVW is more quickly to spoil, making them often subject to time consuming processes such as drying and ensiling (Kasapidou et al., 2015; Bakshi et al., 2016). Drying process can often result in severe decrease of valuable bioactive compounds and changes to FVW characteristics due to exposure to high temperatures in a long period of time (Kampuse et al., 2018). This is why several factors need to be considered prior to FVW being subjected to it. Furthermore, FVW composition depends on their physical form (peels, seeds, stems, stones, pulp etc.), the processing technology of the raw material, storage, and handling conditions. It is necessary for FVW composition to be analysed prior to incorporation into animal feed (Kasapidou et al., 2015). Still, feeding animals with agriculture waste and by-products is considered an efficient way to upgrade low quality materials into high quality foods (Elferink et al., 2008). Nonetheless, they remain an underexploited source for the dietary supplementation of farm animals, which is why there is a need for further detailed research on FVW's function, bioavailability and efficacy as feed additives. In Estonia, utilization of FVW for development of livestock feed and thereby their waste management strategies is yet to be utilized to satisfactory levels. The potential of FVW and by-products in production of livestock feed in Estonia is gradually being recognized, however there are certain legal requirements that needs to be considered and overcome. Nonetheless, in the industrial sector in Estonia, post processing, certain fruits and vegetable wastes are readily available in adequate quantities that are not only affordable but suitable to be incorporated in animal diets. These can provide the necessary nutrients required for production of livestock feed. Potato, pumpkin, rapeseed cake, apple pomace wastes specifically stands out as rich source of vital nutrients.

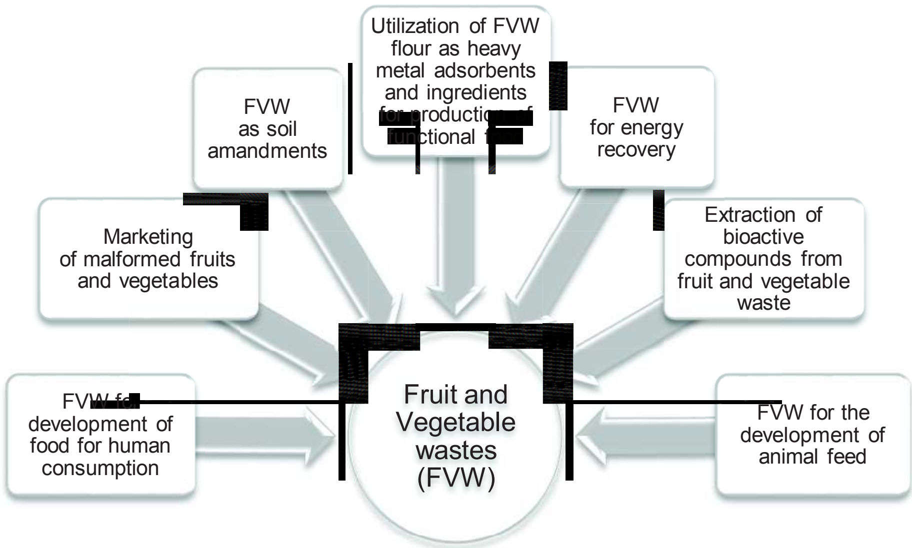

Figure 2. Current fruit and vegetable waste management strategies.

Trends in FVW management in Estonia

In Fig. 2, current FVW management strategies that can be employed in Estonia is depicted. Unfortunately, there is not a lot of data about the management of FVW in Estonia. This is because the data on the waste generation in Estonia lacks in availability and consistency (ETC/RWM, 2007) (Moora, 2009). However, it is known that bio-degradable waste, and among it, fruit and vegetable waste as well, represents the fraction of municipal waste which causes the most number of issues (Blonskaja, et al., 2014). This is attributed to current inefficient processes of sorting, collection and treatment of bio-degradable waste which are neither economically nor environmentally effective (Blonskaja et al., 2014).

Overall, the Baltic countries are struggling to keep up with other EU countries when it comes to strategies implemented by Circular Economy (Grigoryan & Borodavkina, 2017). For example, the recycling is not nearly as applied in Baltics as it is in other parts of EU (Grigoryan & Borodavkina, 2017). In addition, according to Eurostat data, only 14% of the household waste was recycled in Estonia (Horbach, 2015). However, compared to the other Baltic countries, in Estonia only 16% of waste is landfilled and 64% incinerated (Grigoryan & Borodavkina, 2017). With adoption of The Landfill Directive 1999/31/EC member States, including Estonia, have been compelled to develop new methods of waste management. The Landfill Directive, 1999/31/EC, implemented in 2001, focuses on reducing and preventing disposal of bio-waste in landfills. It encourages the member states to utilize the waste management strategies that support Circular Economy. According to Directive (EU) 2018/850, which is amending Directive 1999/31/EC, by 2030, all member states are required to prevent all the waste, which can be recovered or recycled from going to landfill. By 2035, it is expected that all the member states reduce the amount of municipal wastes disposed of in landfills to 10% or less.

With the aim of estimating amount, quality and energy potential of biodegradable waste, the data about biodegradable waste produced in Estonia from 2002 to 2012 is reported (Blonskaja et al., 2014). In this study, the collected data was from all of the 15 Estonian counties, but the study concentrated on Tallinn and Harju County as this is where most of the biodegradable waste are generated. The major portion of the biodegradable wastes came from the kitchen which comprised of FVW, prepared foods, cooked and uncooked meats and fish, cheese, egg wastes, bread, coffee grinds, tea bags, etc. (Blonskaja et al., 2014). This study established that biodegradable wastes remains underutilized and that it can represent to be good resource for composting and production of renewable energy production, in Estonia.

Regarding the utilization of bio-wastes for composting and production of biochar, it has been estimated that in EU countries, only one third of the bio-waste is used, regardless of the existing compost markets (Meyer-Kohlstock, et al., 2015). There has been a study conducted by Arcadis Belgium nv and Eunomia, in 2010 with the aim of estimating bio/waste potentials and their future developments in all 28 member states of EU (Meyer-Kohlstock et al., 2015). This study also provided data on bio-waste utilization for compost and biogas in 2008 (Meyer-Kohlstock et al., 2015).

Incineration of biodegradable wastes such as FVW has been considered to be one of the successful applications of waste management in Estonia, contributing to reduction of biodegradable waste disposed of in landfills. Incineration has been widely applied and it has been reported that the amount of burned waste and produced electricity and heat energy has been largely increasing in Estonia (SEI, 2017). However, according to Frans Timmermans, recycling is much preferable to incineration (Grigoryan & Borodavkina, 2017). It was estimated that Estonia to hold high potential for the production of biogas. However, this is still not applied to the levels on which it could be (Luna del Risco, 2011). Even though the incorporation of fruit and vegetable waste to animal feed and food seems like a promising strategy for reducing waste of fruit and vegetables, it faces legal challenges. According to Regulation (EC) No 178/2002 of the European Parliament and of the Council, food for human consumption and animal feed are not allowed to contain residues or any potential contaminants (NSW, 2017).

CONCLUSION

Recent years have seen progress in the research of fruit and vegetable waste management strategies. Fruit and vegetable waste (FVW) and by-products show high potential for re-use, recycle and recovery in Estonia. As it can be concluded from this article, there are many implemented strategies presently available aimed towards tackling the fruit and vegetable wastes generated in the agri-food supply chain. However, their complete potential to produce value added compounds and products remains in the infancy stage, especially in the Estonian context. Some of these strategies include utilization of fruit and vegetable wastes as organic soil amendments; their valorization as FVW flour, as heavy metals adsorbents, ingredient for production of functional food for humans and livestock feed; energy recovery or bio-refineries, and much more. In addition, FVW represent a highly unexploited source of bioactive compounds. The recovery of these bioactive compounds through various extraction techniques allows their utilization in food, cosmetics and pharmaceutical industries. Extraction technique are constantly being improved for achieving higher yield and rate of compounds as well as for clearing the compounds from toxic substances and impurities, providing grade nature of the final product and avoiding any functionality loss during processing. However, Estonia is still not fully using the opportunities offered by a circular economy. There is not much information about FVW management, but it is evident that majority of the bio-wastes and by-products of food industries remains underutilized. Some of the underutilized resources that remains underexplored in Estonia include wastes and by-products generated from pumpkin, potatoes, berries, apple, mixture obtained from processing industries, rapeseed husk, and much more. Further, in majority of the instances, bio-waste is mainly incinerated in Estonia. However, there are many novel strategies of using bio waste such as composting, producing biogas or biofuel, bioethanol, etc. which need to be further considered and applied.

Nonetheless, all of the mentioned, globally used FVW management strategies face certain disadvantages and restrictions. An extensive research is required for further standardization, improvement, and development of novel cost effective sustainable strategies for reducing of agri-food wastes in Estonia. In conclusion, FVW management is highly limited, leaving the gap for new ideas, and novel efficient green techniques, which will allow optimal utilization of FVW and by-products in Estonia.

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