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Review

Fruit and vegetable waste management and the challenge of fresh-cut salad

Stella Plazzotta, Lara Manzocco*, Maria Cristina Nicoli

Department of Agricultural, Food, Environmental and Animal Sciences, University of Udine, Via Sondrio 2/A, 33100 Udine, Italy

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ABSTRACT

Background: The fruit and vegetable sector generates large amounts of waste. In industrialized countries, **fruit and vegetable waste** (FVW) is mainly generated before reaching consumers, due to programmed overproduction and unfulfillment of retailer quality standards. FVW poses environmental problems due to its high biodegradability, represents a loss of valuable biomass and an economic cost for companies. Different reduction, reuse and recycle strategies to tackle FVW have been proposed.
Scope and approach: This review paper summarizes these strategies, underlying their main advantages and pitfalls. In particular, **fresh-cut salad** waste was considered as a particularly challenging FVW, due to its low concentration of nutrients (e.g. polyphenols, pigments, fiber).
Key findings and conclusions: Different management strategies can be successfully applied to FVW. Among them, the extraction of specific functional compounds was found to be one of the most studied in the last years. This suggests that FVW can be considered a source of valuable ingredients and products. To maximally exploit these FVW potentialities, a rational strategy is required. The latter should be developed using a step-procedure including waste characterization, output definition, process design and feasibility study. The application of this procedure to the case of fresh-cut salad waste was presented. Based on the review of currently applied and potential salad **waste management** strategies, an operational scheme for the development of alternative strategies was proposed. This scheme considers the exploitation of traditional and **novel technologies**, even applied in combination, for salad waste valorization.

1. Fruit and vegetable waste (FVW)

Around 89 million tons of food are wasted annually in the European Union (Stenmarck, Jensen, Quested, & Moates, 2016) and this value is expected to further increase by 40% in the next 4 years. Moreover, the World and Agriculture Organization calculated that one-third of the edible parts of food intended for human consumption get lost or wasted (FAO, 2011). The term "food loss" identifies the decrease in edible food mass throughout the part of the supply chain that specifically leads from raw material to food for human consumption. Food losses, thus, take place at production, post-harvest and processing stages in the food supply chain. Food losses occurring at the end of the food supply chain (retail and final consumption) are rather called "food waste", which relates to retailers' and consumers' behavior (Manzocco, Alongi, Sillani, & Nicoli, 2016; Parfitt, Barthel, & Macnaughton, 2010). Moreover, the term "food by-products" has been increasingly used. This term notifies that biomass and waste can be properly treated and converted into valuable marketable products (Galanakis, 2012).

In the fruit and vegetable sector definitions are more controversial. A widely-used term is "fruit and vegetable waste" or FVW. The latter has been defined as the inedible parts of vegetables that are discarded during collection, handling, transportation and processing (Chang, Tsai, & Wu, 2006). According to the definitions reported above, it should be defined fruit and vegetable loss rather than waste. Panda, Mishra, Kayitesi, and Ray (2016) affirmed that FVW can be generated in different steps of the food supply chain, from farm to fork, including thus both pre- and post-consumer stages. Similarly, Galanakis (2012) used this term to indicate a specific group of plant food wastes, generated along the entire food supply chain (agricultural production, postharvest handling, storage and consumer phase).

In this paper, the term FVW will be used to generally indicate

* Corresponding author.
E-mail address: lara.manzocco@uniud.it (L. Manzocco).

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fruit and vegetables from processing plants and production sites which are required or intended to be discarded.

2. Main causes of FVW

According to FAO estimation (FAO, 2011) pre-consumer phases are particularly critical in terms of FVW generation. To this regard, Segrè and Falasconi (2011), reported that, in Italy, up to 87% of fruit, vegetable and cereals are discarded before reaching consumer. Causes may be different. In developing countries, wastes are mainly generated in agricultural production, post-harvest and distribution stages, due to seasonality that leads to unsaleable gluts and to the absence of proper conservation strategies for perishable crops. Wastes in agricultural production dominate also in industrialized countries. In this case, however, they are mostly due to post-harvest evaluation of crops on the basis of quality standards requested by retailers and to programmed overproduction (FAO, 2011; Segrè & Falasconi, 2011).

3. FVW management

FVW poses disposal and environmental problems, due to its high biodegradability. In addition, it represents a loss of valuable biomass and nutrients as well as an economic loss. For these reasons, in the last years, great attention has been focused on the development of policies and methods for its management (Laufenberg, Kunz, & Nystroem, 2003, 2006/12/EC). In general, waste management "is the collection, transport, recovery and disposal of waste, including the supervision of such operations" (2006/12/EC) and the waste management system consists of "the whole set of activities related to handling, disposing or recycling waste materials". Waste management strategies can be classified with respect to the final disposition of waste and ordered according to their priority: minimization and prevention (reduction) of waste generation, recycling and reuse, energy recovery and landfilling. This option list in order of priority is commonly known as waste hierarchy (Demirbas, 2011).

In the past, FVW was mixed into municipal waste streams and sent to landfills or incinerators (without energy recovery) for final disposal (Nawirska & Kwaśniewska, 2005). However, this is not a good option for FVW, due to its high water content which is, in turn, responsible for microbiological instability, formation of off-odors and leachate (Abu-Qudais, 1996; Lin et al., 2011; Zhang et al., 2007). On the contrary, FVW has a great potential for reuse, recycling, and energy recovery. To this regard, Table 1 reviews the main strategies recently proposed for reducing and valorizing FVW in industrialized countries.

3.1. Reduction of FVW

Reduction has the top priority in the waste hierarchy and mostly depend on production practices (Demirbas, 2011). Some of them cannot be easily modified. For example, agricultural production has necessarily to be higher than sales forecast, in order to face eventual harvest losses due to natural phenomena (Segrè & Falasconi, 2011). On the contrary, some practices can be definitely modified. It has been estimated that huge amounts of fruit and vegetables are wasted because products do not fulfill quality standards set by retailers or consumers (Mena, Adenso-Diaz, & Yurt, 2011). This small-sized or misshaped fruit and vegetables are usually defined "substandard". Different strategies have been proposed and implemented to tackle waste of substandard fruit and vegetables. The latter have been traditionally downgraded to the production of alternative fruit and vegetable derivatives (e.g. juices, vinegar) (Grewal, Tewari, & Kalra, 1988). Moreover, an interesting initiative in this direction is being carried out by the campaign "Inglorious Fruit and Vegetables" and the line "No Name® Naturally Imperfect™", launched in 2015 by the French retailer Intermarchè and the Canadian one Loblaw, respectively. They address the FVW issue by selling substandard fruit and vegetables, while reducing costs for consumers (Table 1). In addition, the so defined "food rescue programs" collect perishable food, including fruit and vegetable surplus, and donate it to hungry people.

3.2. Reuse of FVW

Reuse indicates the use of waste materials for other purposes without or with minor modification of their properties (Manzocco et al., 2016). Reuse strategies for FVW are nowadays limited to soil amendment and animal feed (Table 1). Direct reuse of FVW for soil amendment has been reviewed by Clemente, Pardo, Madejón, Madejón, and Bernal (2015). This practice is based on the ability of organic waste to increase properties of polluted soil by immobilizing trace metals and metalloids, preventing their transfer to groundwater and living organism, and promoting the establishment of plants. However, this reuse strategy is often difficult to put into practice due to the high biological instability of FVW, responsible for pathogen growth risk and off-odors generation (Ajila, Brar, Verma, & Prasada Rao, 2012). Fiber content of FVW can be exploited to formulate animal feeds with increased nutritional value (San Martin, Ramos, & Zufía, 2016). However, also this reuse strategy is limited by some drawbacks. The high water content, often exceeding 80%, makes these wastes prone to microbiological contamination. A partial drying is thus usually required. In addition, low protein content and high presence of indigestible compounds are not always suitable for animal feed (Clemente et al., 2015). Moreover, composition of vegetable products varies according to season, forcing manufacturers to often change feed formulations (San Martin et al., 2016).

3.3. Recycle of FVW

Strategies based on the recovery of waste materials after a major modification of their characteristics are defined as recycle (Williams & Anderson, 2006). Because of its intrinsic characteristics (high content of water and fiber, low protein content), a substantial modification of FVW is usually required to maximally exploit its potentialities. Recycle of FVW offers thus more possibilities than its reuse (Table 1). Recycle strategies for FVW can be divided into strategies in which the whole waste mass is recycled (composting, processing to flour, conversion into water) and strategies in which specific compounds are extracted.

Aerobic composting is an ancient eco-friendly method to convert organic waste into organic fertilizer. However, it is well established that anaerobic digestion (§ 3.4) is a more attractive strategy to produce fertilizers from FVW, due to the energy recovery as biogas (Sharma, Testa, Lastella, Cornacchia, & Comparato, 2000). Processing into flour of FVW has been exploited with different purposes. The fibrous structure and the high contact surface of FVW flour has been used to adsorb pollutants such as dyes and heavy metals from water and ground. To this regard, adsorption is due to both physical entrapment into the porous structure of the vegetable and to specific interaction with the functional groups of cellulose, hemicellulose and lignin (Azouaou & Mokaddem, 2008; Hashem, Abdelmonem, & Farrag, 2007). FVW flour has also been used as an ingredient for the formulation of products rich in functional compounds such as polyphenols and fiber (Ferreira et al., 2015). The main advantage of this recycle strategy is that valuable products such as adsorbents and functional flours are obtained from low-cost raw materials. Moreover, after