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Accepted Manuscript

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PII: S0924-2244(16)30497-6

DOI: 10.1016/j.tifs.2017.02.013

Reference: TIFS 1971

To appear in: *Trends in Food Science & Technology*

Received Date: 2 November 2016

Revised Date: 16 January 2017

Accepted Date: 17 February 2017

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

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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.

Key-words: fruit and vegetable waste; fresh-cut salad; waste management; novel technologies

Highlights

Fruit and vegetable waste has high environmental load and represents a company cost

Reduction, reuse, recycle and energy recovery strategies can be applied to FVW

Up to 40% of fresh-cut salad get wasted during processing

Novel technologies can be useful for sustainable fresh-cut salad waste management

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, & 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 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 & 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). 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, & 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, Sadaoui, & 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, Santos, Moro, Basto, Andrade, & Gonçalves, 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 processing to flour, no residual waste has to be disposed of. However, the main issue is the high cost required for FVW drying, due to the high water content. As a consequence, the production of FVW flour is affordable only if high value-added ingredients and products are developed (Ratti, 2001). Water can also be considered a valuable output of a recycle strategy. To this regard, patented or patent-pending systems able to convert organic material into water are already applied in companies, supermarkets and restaurants. They are based on the hyper-acceleration of aerobic decomposition through the activity of naturally-occurring microorganisms with enhanced degradation capabilities under tightly controlled environmental conditions (Table 1).

The extraction of specific functional compounds from FVW has been largely studied (Table 1). Bioactive compounds as well as oils, fibers and natural dyes are the main targets of this recycle strategy. Structuring agents, mainly referring to colloidal polymers with interesting gelling or viscosant properties, can also be selectively extracted from FVW (McCann, Fabre, & Day, 2011). These compounds are high value-added ingredients derived from a low-cost, easily-available material. The efficiency and sustainability of their extraction has been significantly increased by the application of novel technologies, which guarantee high extraction rate and yield and by concomitantly reducing the need for organic solvents (Herrero, Plaza, Cifuentes, & Ibáñez, 2010). Some recent studies relevant to bioactive extraction (e.g. carotenoids, essential oils, polyphenols, anthocyanins) from FVW using novel technologies include the use of ultrasounds, supercritical carbon dioxide, microwaves and pulsed electric fields (Amiri-Rigi, Abbasi, & Scanlon, 2016; Baysal, Ersus, & Starmans, 2000; Jacotet-Navarro et al., 2016; Rabelo, MacHado, Martínez, & Hubinger, 2016; Zhou, Zhao, & Huang, 2015). For these reasons, extraction of specific compounds from FVW could be an affordable, sustainable and even profitable recycle strategy for industries (Galanakis, 2012; Laufenberg et al., 2003). However, it should be considered that novel technologies often require high initial investment and their industrial application is still limited. Moreover, after the extraction process, relatively high amounts of residual waste have to be still disposed of.

3.4. Energy recovery from FVW

Energy recovery, also called waste-to-energy, is performed in order to recover the energy contained in the waste material (Kothari, Tyagi, & Pathak, 2010). Energy from waste materials can be recovered by several strategies, including thermochemical conversions, such as incineration, pyrolysis and gasification or biochemical strategies, such as anaerobic digestion and fermentation. In the case of FVW, only some of these strategies can be applied (Table 1). In fact, thermochemical conversion strategies are not suitable for waste with high moisture, which is responsible for a really low calorific value (Lin et al., 2011). On the contrary, biochemical conversion strategies are quite efficacious. Anaerobic digestion (AD) has been widely used for organic waste disposal. AD is a method to decompose organic matter using several anaerobic microorganisms under oxygen-free conditions. After the treatment, the end product is represented by biogas (60% methane, 40% carbon dioxide) and digestate (or AD effluent) (Li, Park, & Zhu, 2011; Sheets, Yang, Ge, Wang, & Li, 2015). Biogas can be used to different purposes, including heat, electricity, production of compressed or liquefied natural gas, while the AD digestate, rich in nitrogen, can be used as a fertilizer (Yang, Ge, Wan, Yu, & Li, 2014). However, AD of FVW presents some issues. In fact, FVW is generally characterized by a low potential for biogas production, due to low total solid and high volatile solid fraction that is rapidly hydrolyzed during digestion, leading to rapid acidification and inhibition of digestion process. As a consequence, co-digestion of FVW with other organic wastes is increasingly studied and applied

(Jiang, Heaven, & Banks, 2012; Shen et al., 2013). As a result, industries usually confer their organic waste to centralized biogas production plants (Kothari et al., 2010), dealing with relatively high collection and transport costs (Dereli, Yangin-Gomec, Ozabali, & Ozturk, 2012; Stürmer, Schmid, & Eder, 2011). Moreover, the improper application of AD digestate has led to serious environmental problems such as over-fertilization and pathogen contamination (Nkoa, 2014). Alternatively, other energy-recovery strategies are being studied to decrease FVW management costs and, desirably, to increase the profitability of by-products. To this regard, microbial fuel cells have been recently applied to vegetable waste. This strategy refers to biologically catalyzed electrochemical systems in which the chemical energy of an organic substrate is converted into electrical energy through redox reactions (Pant, Van Bogaert, Diels, & Vanbroekhoven, 2010). However, this strategy is limited to carbohydrate-rich wastes (ElMekawy et al., 2015).

3.5. Rational management of FVW

FVW can be considered a cheap, readily available feedstock for the potential recovery of energy, water and valuable ingredients/products. To maximally exploit these potentialities, an integrated approach to FVW management should be developed by selecting, and eventually combining, the most efficacious strategies of reuse, recycle and energy recovery. Such approach results from the application of a rational 4 step-procedure.

1. Waste characterization: the waste substance is characterized in terms of amount and composition.
2. Output definition: based on the key properties identified in step 1, possible final products of FVW management can be hypothesized.
3. Process design: production processes required to obtained the outputs defined in step 2 are designed.
4. Feasibility study: costs, consumer acceptance, environmental sustainability and adherence to legal requirements of outputs and relevant processes identified in steps 2 and 3 are evaluated.

Following, the case study of fresh-cut iceberg salad (*Lactuca sativa* var. *capitata*) waste will be considered. After presenting the main issues of fresh-cut salad waste, the described step procedure will be applied to outline an operational scheme including possible waste management strategies.

4. A challenging waste: fresh-cut salad

Salad is the most important fresh-cut vegetable, representing 50% of the entire fresh-cut market in Europe and US (Cook, 2015; Rabobank International, 2010), up to 70% in Italy (Casati & Baldi, 2012).

Raw material for the production of fresh-cut salads can be divided in two main categories: whole-head salad (e.g. iceberg salad), representing, in Italy, 60% of the total fresh-cut salad market and baby salads (e.g. rocket salad), that account for the remaining 40% (Casati & Baldi, 2012). The production of fresh-cut salads from whole-heads, presents additional criticisms as compared to that of baby salads. In fact, when processing a whole-head salad, cutting operations are required. Cutting is well known to cause physical damage to vegetable tissue, which, in turn, increases the rate of quality depletion during storage. Moreover, while in baby salad processing the whole leaf is harvested and processed, in the case of whole-head salads, the percentage of usable product is significantly lower due to preliminary removal of external leaves and core (Martínez-Sánchez, Luna, Selma, Tudela, Abad, & Gil, 2012). This is responsible for a huge waste production.

Currently, similarly to other agricultural wastes, salad waste is exploited as soil conditioner, composted to obtain fertilizers and anaerobically digested to produce biogas (Table 1). However, soil conditioning can absorb only a small amount of salad waste, due to the risk of pathogen development as well as soil and water nitrate enrichment, which is regulated by 91/676/CEE directive. Composting is also critical due to the high volume of this waste and to its microbiological instability. Salad has also been reported to have a really low potential for biogas production, due to its composition, rich in cellulosic material and poor in carbohydrates (Zheng, Phoungthong, Lü, Shao, & He, 2013). For this reasons, it has to be transported and co-composted or co-digested with other organic wastes in centralized plants.

4.1. Rational management of salad waste

4.1.1. Waste characterization

Quantification

Quantification of waste is the first step for its characterization. Data here presented were obtained by analyzing salad waste generation in a large Italian company. The latter employs more than 200 workers, has 23 production lines and 9 washing lines for a total of about 20,000 ton per year of processed salad. To this aim, a two-step methodology was developed: (i) identification of unit operations in which waste was generated and (ii) waste quantification. Figure 1 shows the results of the application of this methodology to fresh-cut iceberg salad. Waste generating operations in the salad flow sheet are indicated together with relevant waste amounts, expressed as percentage ratio to total processed salad and their current destination to anaerobic digestion for biogas production.

Total wasted salad (W) can be calculated as the sum of wastes generated during preliminary cleaning (W_C), three washing stages (W_{W1}, W_{W2}, W_{W3}) and optical selector (W_{OS}) (eq. 1). However, direct waste weighting was possible only for wastes generated during washing stages and from the optical selector but not for the preliminary cleaning stage, in which external leaves and core were eliminated. In fact, iceberg salad wastes were mixed with those of other vegetables as different raw materials were usually processed in the same day and wastes generated by this preliminary cleaning stage were collected together. In order to quantify waste produced during each production step, an indirect calculation was thus used. Total salad waste (W) was computed as the difference between the amount of total salad accepted after the quality check (S) and the sold one (S_S) (eq. 2).

$$W = W_c + W_{W1} + W_{W2} + W_{W3} + W_{os} \qquad \text{(eq. 1)}$$

$$W = S - S_S \qquad \text{(eq. 2)}$$

$$W = W_C \qquad \text{(eq. 3)}$$

W_C can be thus easily calculated by solving the system of eq. 1 and 2 as it is the only unknown variable. This indirect method was applied to the production of fresh-cut iceberg salad during 3 production months, in which approximately 800 kg of iceberg salad were daily processed. Data indicate that up to 41% of salad was wasted during a typical fresh-cut iceberg salad process, with removal of external leaves and core stage accounting for nearly the total waste production. Waste production in the following unit operations of washing and optical selection resulted, in fact, negligible. In the case of salad heads eq. 1 can be thus simplify to eq. 3. It should be noted that in the case of baby salads, this simplification is no more correct since removal of external leaves and core is not performed. Waste generated by unit operations of washing and optical selection is thus significant, accounting for approximately the 85% and 15% of total waste respectively.

Composition analysis

Once salad waste is quantified, its characterization requires the analysis of its composition, in order to identify exploitable characteristics and support the choice of proper management options (Laufenberg et al., 2003). Water represents more than 92% of iceberg salad fresh weight. The remaining weight fraction is mostly represented by cellular proteins (1.5%) and fibers (1.3%). Minerals such as potassium, calcium and phosphorus as well as vitamins (ascorbic acid being the most present) are also found (USDA National Nutrient Database for Standard Reference, Release 24), along with health-promoting antioxidants polyphenols (Llorach, Martínez-Sánchez, Tomás-Barberán, Gil, & Ferreres, 2008). Eventual salad contaminant content should also be considered. For instance, pesticide residues must be lower than the law level (EC/396/2005). Moreover, some vegetables are prone to nitrate accumulation and maximum nitrate content is established by law (EC/563/2002). Compositional data available in the literature, mainly refer to the edible vegetable portion. By contrast, composition may vary in the different fractions of iceberg salad. Fresh-cut iceberg salad fractions (edible, core and external leaves) were thus characterized. Table 2 reports data relevant to percentage weight, dry matter, fiber and total polyphenol content of iceberg salad fractions, determined twice on at least four replicated samples of 1 kg salad heads. Dry matter and total dietary fiber were determined using gravimetric method (AOAC, 2000) and AOAC international method (985.29, 1997) respectively; Folin-Ciocalteau method was used for determining the total polyphenol content of lettuce waste aqueous extracts (Llorach, Tomás-Barberán, & Ferreres, 2004). Data suggest that iceberg salad waste fractions (core and external leaves) have an interesting polyphenol content and are particularly rich in fiber, in agreement with both relevant literature and official composition databases (Llorach et al., 2004; USDA National Nutrient Database for Standard Reference, Release 24).

4.1.2. Output definition

Table 3 reports outputs obtained by currently applied and potential strategies for salad waste management. As previously anticipated (§ 4), current strategies for salad waste management present high costs. Alternative salad waste management strategies are thus required.

To this regard, really few studies are available on alternative salad waste management options other than its use for anaerobic co-digestion (Bouallagui, Lahdheb, Ben Romdan, Rachdi, & Hamdi, 2009; Garcia-Peña, Parameswaran, Kang, Canul-Chan, & Krajmalnik-Brown, 2011; Lin et al., 2011). Neverthelss, different studies conducted on FVW other than salad and on edible salad (not waste) highlight several alternative outputs that can be obtained from salad waste (Table 3).

In particular, the consumption of mixed fruit and vegetable fresh juices has dramatically increased over the last years, due to the high nutritional value of these products (Raybaudi-Massilia, Mosqueda-Melgar, Soliva-Fortuny, & Martín-Belloso, 2009). Different vegetables have been included into juice formulation, including spinach, carrot and celery (Bhardwaj & Pandey, 2016; Pop, Muste, Mureșan, & Jula, 2014). A fresh functional juice containing iceberg salad could be thus a possible output of a salad waste reuse strategy.

Moreover, recycling of salad waste could provide large amounts of water as main output. The latter could be of great interest whithin the fresh-cut production process, which is actually particularly water-intensive (Manzocco et al., 2015). Water can actually be obtained by aerobic conversion of waste or by physical separation. To this regard, salad waste drying could be implemented to concomitantly produce not only huge amounts of water but also functional flour or natural adsorbents (Ferreira et al., 2015; Pavlovic, Nikolic, Milutinovic, Dimitrijevic-Brankovic, Siler-Marinkovic, & Antonovic, 2015). Finally, salad has been recently reported to contain interesting bitter and gelling compounds, as well as polyphenols (Llorach et al., 2004; Mai & Glomb, 2016; Roversi, Ferrante, & Piazza, 2016). The production of functional ingredeients based on these compounds could be thus a further output of salad waste recycle.

4.1.3. Process design

Once the main output of the waste management strategy is defined, relevant production process should be designed. To obtain products with tailored characteristics, proper processes should be developed, including the eventual application of novel sustainable technologies.

Pressure-based technologies such as high static pressure (HP), high pressure homogenization (HPH) and high-pressure carbon dioxide (HP-CO_2) have been proposed for fresh juice production and could thus be exploitable for the production of novel functional juices containing salad (Koutchma, Popovi, Ros-polski, & Popielarz, 2016). Innovative drying technologies such as microwaves (MW) and supercritical fluids (SC-F) could offer the possibility of drying salad wastes at low cost, while obtaining a microbiologically pure water (Brown, Fryer, Norton, Bakalis, & Bridson, 2008; Feng, Yin, & Tang, 2012). Similarly, ultrasounds (US), supercritical carbon dioxide (SC-CO_2), pulsed electric fields (PEF) and MW could be applied to salad waste for the extraction of bioactives, colorants and gelling materials at mild temperature conditions, to maximally preserve ingredient properties. To this regard, Solana, Boschiero, Dall'Acqua, & Bertucco (2014) and Solana, Mirofci, & Bertucco (2016) produced polyphenols and glucosinate functional extracts, suitable for functional foods and nutraceutical, from rocket salad using supercritical carbon dioxide extraction (Table 3).

4.1.4. Feasibility study

To select a strategy for salad waste management, relevant costs must be evaluated. The cost of currently applied salad waste management strategies is directly proportional to waste transport and disposal. According to Figure 1, in a typical Italian company, salad waste is often delivered to a centralized biogas plant. The latter is generally located within a 20-km distance from the production site in order to reduce transport cost. In such a case, management of 1 ton of waste would be associated to an average cost of 0.80 € and 60 € for transport and disposal respectively. Based on these data, it can be easily calculated that processing 1 ton of iceberg salad with a 35% waste generation (Figure 1) would cost about 22.00 €. This cost is expected to increase with the distance between production site and disposal center. Waste management cost is also strongly affected by the nature of processed salad. For instance, baby salads are characterized by a waste amount approximately 10-fold lower than that of whole-head salads and, consequently, by a waste management cost around 2.00 €/ton of processed salad. In a typical Italian company, approximately equal amounts of whole-head and baby salads are processed, leading to an average waste management cost of at least 10.00 €/ton of processed salad. It has to be underlined that such salad waste management often represents a net cost for companies, due to the risible or null return in terms of biogas or AD digestate to be used as fertilizer.

On the contrary, strategies based on the exploitation of salad waste for producing water and functional foods and ingredients could be actually profitable. In fact, circumstantial considerations about the high water management costs in a typical fresh-cut process suggest that the implementation of a water recovery strategy could result into a significant process cost reduction (Manzocco et al., 2015). Similarly, functional ingredients for food and cosmetics are reported to have high market potential, due to the increase consumer demand for natural healthy products (Huang, Yang, & Wang, 2013). The possibility to use waste derivatives in different industrial sectors also depends on their fulfilment of current legislation as well as on availability of a normative framework specifically developed to support the exploitation of these novel ingredients.

Investment costs for implementing new salad waste management strategies (e.g. plants and equipment) could represent an issue for the companies. Nevertheless, a return on the investment has to be expected. Beside tangible profit deriving from improved water management and/or value added ingredients/food production, non tangible benefits could also come from the opportunity the company may have to build an eco-friendly image. In fact, raised public interest about environmental and sustainability issues is expected to greatly drive consumer choices toward foods produced by novel eco-friendly technologies, reducing water consume and waste amounts (Vermeir & Verbeke, 2006).

4.1.5. An operational scheme to develop possible salad waste management strategies

An integrated operational scheme including possible energy recovery, recycle and reuse strategies for salad waste management is shown in Figure 2. This operational scheme could be used to identify new profitable and sustainable strategies. In particular, once salad waste is quantified, characterized, and outputs defined, sustainable processes, either conventional, such as anaerobic digestion for biogas production, or innovative, such as supercritical bioactive extraction, can be considered to develop tailored products.

The selection of a waste management strategy over another should be driven by the following selection criteria:

- investment cost in equipment and human competence;
- return of investment;
- maximal waste exploitation and profitability;
- consumer acceptance and company image upgrade;
- adherence to legal requirements.

Based on the peculiar characteristics of the company and the environment in which it operates, different management strategies, even in combination, should be identified by proper economic evaluation and life cycle analysis. For instance, companies growing different vegetables and processing different products, including fresh-cut salads, juices and/or preserves, could find economically advantageous to set up an internal biogas plant where different organic material are profitably converted into biogas and fertilizers. By contrast, for a company mainly producing fresh-cut salads, implementing on-site extraction of bioactive compounds, colorants and gelling agents could be more sustainable and even profitable. Residual waste could be either anaerobically digested or dried. In the first case, energy would be recovered starting from a material already exploited for its high value compounds. In the second one, novel sustainable drying technologies could be applied. After a proper purification treatment, water could be reintroduced in the production process and the residual flour, rich in fiber, used as functional ingredient for food and animal feed or as a pollutant adsorber.

5. Conclusions

Management of fruit and vegetable waste (FVW) is an important issue that requires to be adressed by modern society, due to the environmental impact and the high value of this waste. Among FVW, salad waste is particularly challenging due to its high water content. Nevertheless, different waste management strategies could be efficaciously applied. Among them, the ideal strategy maximally exploits salad waste as a source of both value added compounds, such as polyphenols and fiber, and water. This would reduce the environmental impact of salad waste and even turn it into a profitable material for the company. To achieve this goal, traditional strategies such as anaerobic digestion and composting could be combined with novel sustainable technologies, including those based on supercritical fluids, ultrasounds and pressure. However, the development of such waste management strategies should be economically sustainable for the companies and in agreement with law requirements. Based on this considerations, an integrated approach involving researchers, companies and legislator seems to be crucial to develop cost-effective and environmentally sustainable strategies for salad waste management.

Acknowledgement

This research was supported by Ministero dell'Istruzione, dell'Università e della Ricerca (Prot. 957/ric 28/12/2012) "Long Life, High Sustainability". Project 2012ZN3KJL.

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Figure captions

Figure 1. Fresh-cut iceberg salad waste (W) flow in a typical Italian company. Waste-generating operations are identified (C, W1, W2, W3 and OS). Waste amounts are expressed as percentage ratio to total salad accepted after the quality check (S).
COLOR IN PRINT IS **NOT** REQUIRED

Figure 2. Operational scheme for fresh-cut salad waste management, based on characherisation, output definition, process design and feasibility study.
COLOR IN PRINT IS **NOT** REQUIRED

Table 1. Main strategies of FVW management according to different authors.

Strategy	Output	Waste origin	References
Reduction			
Alternative processing of substandard items	Fruit and vegetable derivatives	Substandard apple and grapes	Grewal et al., 1988
Market of substandard items	Low cost fruit and vegetables	Substandard fruit and vegetables	http://itm.marcelww.com/inglorious/ media.loblaw.ca/English/media-centre/press-releases/press-release-details/2016/More-products-more-locations-no-name-Naturally-Imperfect-produce-line-expanded-to-meet-customer-demand/default.aspx
Food rescue programs	Fruit and vegetables distributed to hungry people	Fruit and vegetable surplus	Schneider, 2013
Reuse			
Direct use	Products for soil amendment	Olive, mushrooms	Clemente et al., 2015
Minor changes (partial dehydration, trimming)	Fiber-enriched animal feed	Mixed fruit and vegetables	San Martin et al., 2016
Recycle			
Composting	Fertilizers	Mixed fruit and vegetables	Chang et al., 2006; Choy, Wang, Qi, Wang, Chen, & Wang, 2015
Processing into flour	Green and low cost adsorbents for pollutants in wastewaters	Orange, citrus, banana, olive, apricot	Annadurai, Juang, & Lee, 2002; Azouaou et al., 2008; Daifullah & Girgis, 1998; Pavlovic et al., 2015
	Flour rich in antioxidants, phenols, minerals and fiber	Tropical fruit, orange	de Oliveira et al., 2009; Ferreira et al., 2015; Larrauri, 1999
Conversion into water	Water for industrial facilities	Mixed fruit and vegetables	http://www.eco-wiz.com/ecoDigester.php http://www.enviropuresystems.com/index.php http://www.wastetowater.com.au/
Extraction of specific compounds	Bioactive extracts		
	Flavonoids and bio-sugars	Onions	Choi, Cho, Moon, & Bae, 2015
	Antioxidants and antimicrobials	Fresh-cut fruit	Ayala-Zavala, Rosas-Domínguez, Vega-Vega, & González-Aguilar, 2010
	Oils		
	Essential oils	Citrus fruit	Bustamante et al., 2016
	Oils for food, biodiesel, pharmaceutical and cosmetic sectors	Watermelon, melon, red currant, pomegranate, grape, apple	Górnaś, Soliven, & Segliņa, 2015; Górnaś & Rudzińska, 2016
	Fiber extracts		
	Reinforced biopolymers	Banana	Zini & Scandola, 2011
	Bioplastics	Pineapple, banana	Elain et al., 2016; Jabeen, Majid, Nayik, & Yildiz, 2015
	Cellulose nanofibers	Carrot	Piccinno, Hischier, Seeger, & Som, 2015
	Dietary fiber	Apple, cherry, chokeberry, black currant, pear, carrot	Nawirska & Kwaśniewska, 2005
	Natural dyes	Raspberries, black carrots, currants, onions	Bechtold, Mussak, Mahmud-Ali, Ganglberger, & Geissler, 2006
	Structuring agents	Apple, carrot	McCann et al., 2011; Roversi et al., 2016; Roversi, Radaelli, & Piazza, 2015
Energy Recovery			
Anaerobic digestion	Biogas Fertilizers	Mixed fruit and vegetables	Han & Shin, 2004; Kim, 2004; Lin et al., 2013; Shen et al., 2013; Zhang et al., 2007
Bio-electrochemical systems	Electrical energy	Carbohydrate-rich vegetables	ElMekawy et al., 2015

Table 2. Main characteristics of iceberg salad fractions.

Fraction	**Relative weight (g/100 g fw)**	**Dry matter (g/100 g fw)**	**Fiber (g/100 g dw)**	**Total polyphenols (mg GAE eq/g dw)**
Edible	55.8 ± 2.3	5.6 ± 0.6	20.2 ± 1.2	2.4 ± 0.3
Core	31.7 ± 3.1	6.8 ± 0.8	32.8 ± 0.9	2.1 ± 0.2
External leaves	11.8 ± 5.4	5.1 ± 0.4	28.9 ± 1.0	1.9 ± 0.6

[fw, dw] data expressed on fresh weight (fw) or dry weight (dw) basis.

Table 3. Outputs of applied and potential strategies suggested in the literature for salad waste management.

Output	**References**
Applied strategies	
Soil conditioner	Lukić, Huguenot, Panico, Fabbricino, Van Hullebusch, & Esposito, 2016
Fertilizer	Himanen & Hänninen, 2011
Biogas	Garcia-Peña et al., 2011; Lin et al., 2011
Potential strategies	
Functional juice	Pop et al., 2014
Water for industrial facilities	Brown et al., 2008
Functional flour	Ferreira et al., 2015
Green adsorbents for dyes	Pavlovic et al., 2015
Bitter compounds	Mai & Glomb, 2016
Structuring agents	Roversi et al., 2016
Polyphenolic extracts	Llorach et al., 2004; Solana et al., 2016

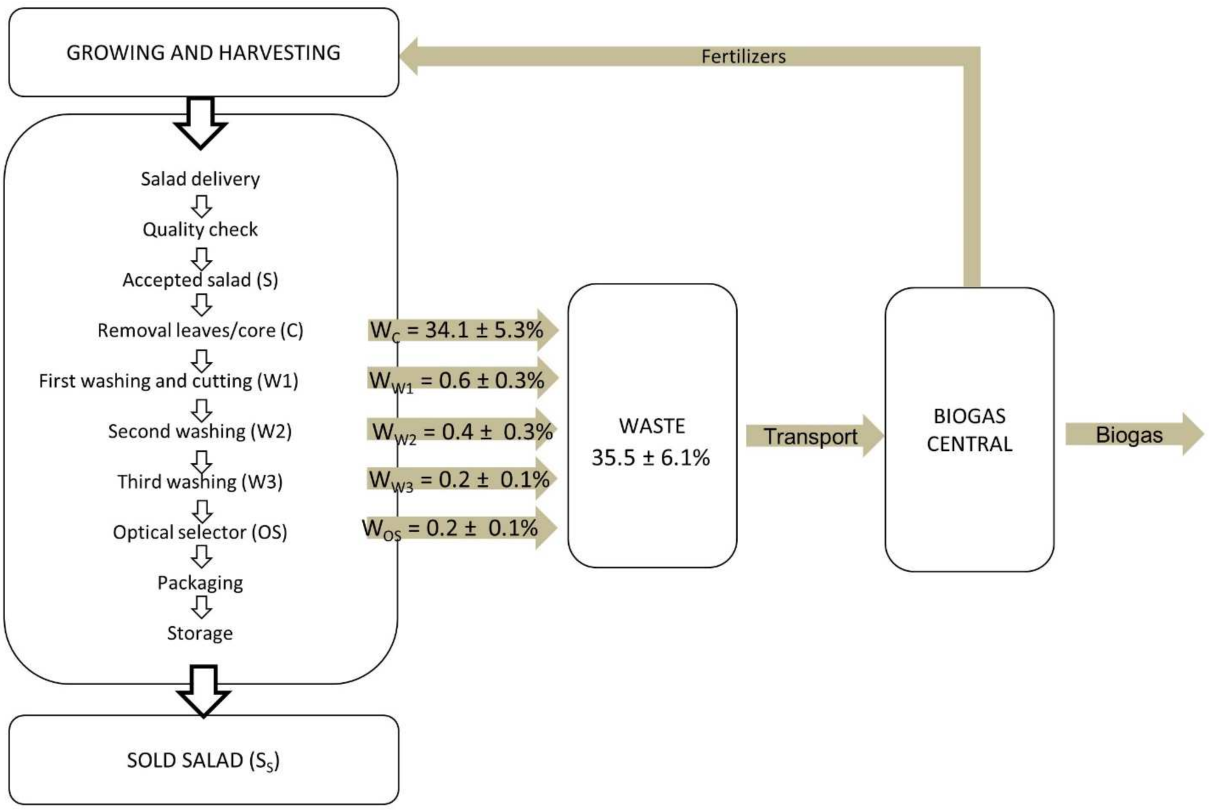
GROWING AND HARVESTING
Fertilizers
Salad delivery
Quality check
Accepted salad (S)
Removal leaves/core (C)
First washing and cutting (W1)
Second washing (W2)
Third washing (W3)
Optical selector (OS)
Packaging
Storage
W_C = 34.1 ± 5.3%
W_{W1} = 0.6 ± 0.3%
W_{W2} = 0.4 ± 0.3%
W_{W3} = 0.2 ± 0.1%
W_{OS} = 0.2 ± 0.1%
WASTE
35.5 ± 6.1%
Transport
BIOGAS
CENTRAL
Biogas
SOLD SALAD (S_S)

Figure 1.

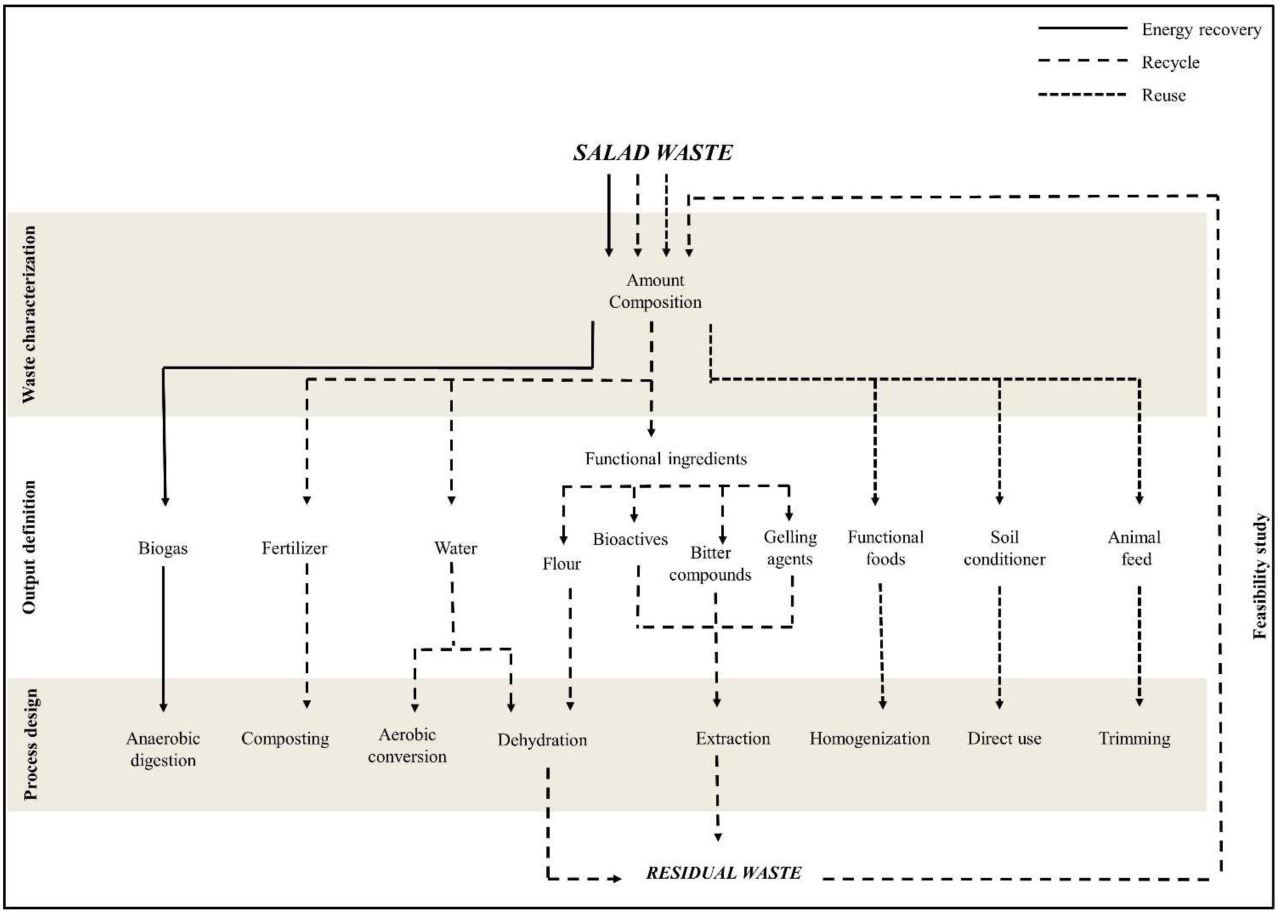
Energy recovery
Recycle
Reuse
SALAD WASTE
Waste characterization
Amount
Composition
Output definition
Functional ingredients
Biogas
Fertilizer
Water
Flour
Bioactives
Bitter compounds
Gelling agents
Functional foods
Soil conditioner
Animal feed
Process design
Anaerobic digestion
Composting
Aerobic conversion
Dehydration
Extraction
Homogenization
Direct use
Trimming
RESIDUAL WASTE
Feasibility study

Figure 2.

Highlights

Fruit and vegetable waste has high environmental load and represents a company cost

Reduction, reuse, recycle and energy recovery strategies can be applied to FVW

Up to 40% of fresh-cut salad get wasted during processing

Novel technologies can be useful for sustainable fresh-cut salad waste management