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

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8 **Abstract**

9 *Background*

10 The fruit and vegetable sector generates large amounts of waste. In industrialized countries, **fruit and**
11 **vegetable waste** (FVW) is mainly generated before reaching consumers, due to programmed
12 overproduction and unfulfillment of retailer quality standards. FVW poses environmental problems due
13 to its high biodegradability, represents a loss of valuable biomass and an economic cost for companies.
14 Different reduction, reuse and recycle strategies to tackle FVW have been proposed.

15 *Scope and approach*

16 This review paper summarizes these strategies, underlying their main advantages and pitfalls. In
17 particular, **fresh-cut salad** waste was considered as a particularly challenging FVW, due to its low
18 concentration of nutrients (e.g. polyphenols, pigments, fiber).

19 *Key findings and conclusions*

20 Different management strategies can be successfully applied to FVW. Among them, the extraction of
21 specific functional compounds was found to be one of the most studied in the last years. This suggests
22 that FVW can be considered a source of valuable ingredients and products. To maximally exploit these
23 FVW potentialities, a rational strategy is required. The latter should be developed using a step-
24 procedure including waste characterization, output definition, process design and feasibility study. The
25 application of this procedure to the case of fresh-cut salad waste was presented. Based on the review of
26 currently applied and potential salad **waste management** strategies, an operational scheme for the
27 development of alternative strategies was proposed. This scheme considers the exploitation of
28 traditional and **novel technologies**, even applied in combination, for salad waste valorization.

29
30 **Key-words:** fruit and vegetable waste; fresh-cut salad; waste management; novel technologies

31 **Highlights**

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

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

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

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

36 **1. Fruit and vegetable waste (FVW)**

37 Around 89 million tons of food are wasted annually in the European Union (Stenmarck, Jensen,
38 Quedsted, & Moates, 2016) and this value is expected to further increase by 40% in the next 4 years.

39 Moreover, the World and Agriculture Organization calculated that one-third of the edible parts of food
40 intended for human consumption get lost or wasted (FAO, 2011). The term “food loss” identifies the
41 decrease in edible food mass throughout the part of the supply chain that specifically leads from raw
42 material to food for human consumption. Food losses, thus, take place at production, post-harvest and
43 processing stages in the food supply chain. Food losses occurring at the end of the food supply chain
44 (retail and final consumption) are rather called “food waste”, which relates to retailers’ and consumers’
45 behavior (Manzocco, Alongi, Sillani, & Nicoli, 2016; Parfitt, Barthel, & Macnaughton, 2010).
46 Moreover, the term “food by-products” has been increasingly used. This term notifies that biomass and
47 waste can be properly treated and converted into valuable marketable products (Galanakis, 2012).

48 In the fruit and vegetable sector definitions are more controversial. A widely-used term is “fruit and
49 vegetable waste” or FVW. The latter has been defined as the inedible parts of vegetables that are
50 discarded during collection, handling, transportation and processing (Chang, Tsai, & Wu, 2006).

51 According to the definitions reported above, it should be defined fruit and vegetable loss rather than
52 waste. Panda, Mishra, Kayitesi, & Ray (2016) affirmed that FVW can be generated in different steps of
53 the food supply chain, from farm to fork, including thus both pre- and post-consumer stages. Similarly,
54 Galanakis (2012) used this term to indicate a specific group of plant food wastes, generated along the
55 entire food supply chain (agricultural production, postharvest handling, storage and consumer phase).

56 In this paper, the term FVW will be used to generally indicate fruit and vegetables from processing
57 plants and production sites which are required or intended to be discarded.

58 **2. Main causes of FVW**

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

67 **3. FVW management**

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

78 In the past, FVW was mixed into municipal waste streams and sent to landfills or incinerators (without
79 energy recovery) for final disposal (Nawirska & Kwaśniewska, 2005). However, this is not a good
80 option for FVW, due to its high water content which is, in turn, responsible for microbiological
81 instability, formation of off-odors and leachate (Abu-Qudais, 1996; Lin et al., 2011; Zhang et al.,
82 2007). On the contrary, FVW has a great potential for reuse, recycling, and energy recovery. To this
83 regard, Table 1 reviews the main strategies recently proposed for reducing and valorizing FVW in
84 industrialized countries.

85 **3.1. Reduction of FVW**

86 Reduction has the top priority in the waste hierarchy and mostly depend on production practices
87 (Demirbas, 2011). Some of them cannot be easily modified. For example, agricultural production has

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

101 3.2. *Reuse of FVW*

102 Reuse indicates the use of waste materials for other purposes without or with minor modification of
103 their properties (Manzocco et al., 2016). Reuse strategies for FVW are nowadays limited to soil
104 amendment and animal feed (Table 1). Direct reuse of FVW for soil amendment has been reviewed by
105 Clemente, Pardo, Madejón, Madejón, & Bernal (2015). This practice is based on the ability of organic
106 waste to increase properties of polluted soil by immobilizing trace metals and metalloids, preventing
107 their transfer to groundwater and living organism, and promoting the establishment of plants. However,
108 this reuse strategy is often difficult to put into practice due to the high biological instability of FVW,
109 responsible for pathogen growth risk and off-odors generation (Ajila, Brar, Verma, & Prasada Rao,
110 2012). Fiber content of FVW can be exploited to formulate animal feeds with increased nutritional
111 value (San Martin, Ramos, & Zufía, 2016). However, also this reuse strategy is limited by some
112 drawbacks. The high water content, often exceeding 80%, makes these wastes prone to microbiological
113 contamination. A partial drying is thus usually required. In addition, low protein content and high
114 presence of indigestible compounds are not always suitable for animal feed (Clemente et al., 2015).
115 Moreover, composition of vegetable products varies according to season, forcing manufacturers to
116 often change feed formulations (San Martin et al., 2016).

117 3.3. *Recycle of FVW*

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

125 Aerobic composting is an ancient eco-friendly method to convert organic waste into organic fertilizer.
126 However, it is well established that anaerobic digestion (§ 3.4) is a more attractive strategy to produce
127 fertilizers from FVW, due to the energy recovery as biogas (Sharma, Testa, Lastella, Cornacchia, &
128 Comparato, 2000). Processing into flour of FVW has been exploited with different purposes. The
129 fibrous structure and the high contact surface of FVW flour has been used to adsorb pollutants such as
130 dyes and heavy metals from water and ground. To this regard, adsorption is due to both physical
131 entrapment into the porous structure of the vegetable and to specific interaction with the functional
132 groups of cellulose, hemicellulose and lignin (Azouaou, Sadaoui, & Mokaddem, 2008; Hashem,
133 Abdelmonem, & Farrag, 2007). FVW flour has also been used as an ingredient for the formulation of
134 products rich in functional compounds such as polyphenols and fiber (Ferreira, Santos, Moro, Basto,
135 Andrade, & Gonçalves, 2015). The main advantage of this recycle strategy is that valuable products
136 such as adsorbents and functional flours are obtained from low-cost raw materials. Moreover, after
137 processing to flour, no residual waste has to be disposed of. However, the main issue is the high cost
138 required for FVW drying, due to the high water content. As a consequence, the production of FVW
139 flour is affordable only if high value-added ingredients and products are developed (Ratti, 2001). Water
140 can also be considered a valuable output of a recycle strategy. To this regard, patented or patent-
141 pending systems able to convert organic material into water are already applied in companies,
142 supermarkets and restaurants. They are based on the hyper-acceleration of aerobic decomposition
143 through the activity of naturally-occurring microorganisms with enhanced degradation capabilities
144 under tightly controlled environmental conditions (Table 1).

145 The extraction of specific functional compounds from FVW has been largely studied (Table 1).
146 Bioactive compounds as well as oils, fibers and natural dyes are the main targets of this recycle
147 strategy. Structuring agents, mainly referring to colloidal polymers with interesting gelling or viscosant
148 properties, can also be selectively extracted from FVW (McCann, Fabre, & Day, 2011). These

149 compounds are high value-added ingredients derived from a low-cost, easily-available material. The
150 efficiency and sustainability of their extraction has been significantly increased by the application of
151 novel technologies, which guarantee high extraction rate and yield and by concomitantly reducing the
152 need for organic solvents (Herrero, Plaza, Cifuentes, & Ibáñez, 2010). Some recent studies relevant to
153 bioactive extraction (e.g. carotenoids, essential oils, polyphenols, anthocyanins) from FVW using novel
154 technologies include the use of ultrasounds, supercritical carbon dioxide, microwaves and pulsed
155 electric fields (Amiri-Rigi, Abbasi, & Scanlon, 2016; Baysal, Ersus, & Starmans, 2000; Jacotet-
156 Navarro et al., 2016; Rabelo, MacHado, Martínez, & Hubinger, 2016; Zhou, Zhao, & Huang, 2015).
157 For these reasons, extraction of specific compounds from FVW could be an affordable, sustainable and
158 even profitable recycle strategy for industries (Galanakis, 2012; Laufenberg et al., 2003). However, it
159 should be considered that novel technologies often require high initial investment and their industrial
160 application is still limited. Moreover, after the extraction process, relatively high amounts of residual
161 waste have to be still disposed of.

162 **3.4. Energy recovery from FVW**

163 Energy recovery, also called waste-to-energy, is performed in order to recover the energy contained in
164 the waste material (Kothari, Tyagi, & Pathak, 2010). Energy from waste materials can be recovered by
165 several strategies, including thermochemical conversions, such as incineration, pyrolysis and
166 gasification or biochemical strategies, such as anaerobic digestion and fermentation. In the case of
167 FVW, only some of these strategies can be applied (Table 1). In fact, thermochemical conversion
168 strategies are not suitable for waste with high moisture, which is responsible for a really low calorific
169 value (Lin et al., 2011). On the contrary, biochemical conversion strategies are quite efficacious.
170 Anaerobic digestion (AD) has been widely used for organic waste disposal. AD is a method to
171 decompose organic matter using several anaerobic microorganisms under oxygen-free conditions. After
172 the treatment, the end product is represented by biogas (60% methane, 40% carbon dioxide) and
173 digestate (or AD effluent) (Li, Park, & Zhu, 2011; Sheets, Yang, Ge, Wang, & Li, 2015). Biogas can be
174 used to different purposes, including heat, electricity, production of compressed or liquefied natural
175 gas, while the AD digestate, rich in nitrogen, can be used as a fertilizer (Yang, Ge, Wan, Yu, & Li,
176 2014). However, AD of FVW presents some issues. In fact, FVW is generally characterized by a low
177 potential for biogas production, due to low total solid and high volatile solid fraction that is rapidly
178 hydrolyzed during digestion, leading to rapid acidification and inhibition of digestion process. As a
179 consequence, co-digestion of FVW with other organic wastes is increasingly studied and applied

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

191 **3.5. Rational management of FVW**

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

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

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

207 **4. A challenging waste: fresh-cut salad**

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

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

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

228 **4.1. Rational management of salad waste**

229 *4.1.1. Waste characterization*

230 *Quantification*

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

239 Total wasted salad (W) can be calculated as the sum of wastes generated during preliminary cleaning
240 (W_C), three washing stages (W_{W1} , W_{W2} , W_{W3}) and optical selector (W_{OS}) (eq. 1). However, direct waste

241 weighting was possible only for wastes generated during washing stages and from the optical selector
242 but not for the preliminary cleaning stage, in which external leaves and core were eliminated. In fact,
243 iceberg salad wastes were mixed with those of other vegetables as different raw materials were usually
244 processed in the same day and wastes generated by this preliminary cleaning stage were collected
245 together. In order to quantify waste produced during each production step, an indirect calculation was
246 thus used. Total salad waste (W) was computed as the difference between the amount of total salad
247 accepted after the quality check (S) and the sold one (S_S) (eq. 2).

248

$$249 \quad W = W_c + W_{W1} + W_{W2} + W_{W3} + W_{os} \quad (\text{eq. 1})$$

$$250 \quad W = S - S_S \quad (\text{eq. 2})$$

$$251 \quad W = W_C \quad (\text{eq. 3})$$

252

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

263

264 *Composition analysis*

265 Once salad waste is quantified, its characterization requires the analysis of its composition, in order to
266 identify exploitable characteristics and support the choice of proper management options (Laufenberg
267 et al., 2003). Water represents more than 92% of iceberg salad fresh weight. The remaining weight
268 fraction is mostly represented by cellular proteins (1.5%) and fibers (1.3%). Minerals such as
269 potassium, calcium and phosphorus as well as vitamins (ascorbic acid being the most present) are also
270 found (USDA National Nutrient Database for Standard Reference, Release 24), along with health-
271 promoting antioxidants polyphenols (Llorach, Martínez-Sánchez, Tomás-Barberán, Gil, & Ferreres,
272 2008). Eventual salad contaminant content should also be considered. For instance, pesticide residues

273 must be lower than the law level (EC/396/2005). Moreover, some vegetables are prone to nitrate
274 accumulation and maximum nitrate content is established by law (EC/563/2002). Compositional data
275 available in the literature, mainly refer to the edible vegetable portion. By contrast, composition may
276 vary in the different fractions of iceberg salad. Fresh-cut iceberg salad fractions (edible, core and
277 external leaves) were thus characterized. Table 2 reports data relevant to percentage weight, dry matter,
278 fiber and total polyphenol content of iceberg salad fractions, determined twice on at least four
279 replicated samples of 1 kg salad heads. Dry matter and total dietary fiber were determined using
280 gravimetric method (AOAC, 2000) and AOAC international method (985.29, 1997) respectively;
281 Folin-Ciocalteu method was used for determining the total polyphenol content of lettuce waste
282 aqueous extracts (Llorach, Tomás-Barberán, & Ferreres, 2004). Data suggest that iceberg salad waste
283 fractions (core and external leaves) have an interesting polyphenol content and are particularly rich in
284 fiber, in agreement with both relevant literature and official composition databases (Llorach et al.,
285 2004; USDA National Nutrient Database for Standard Reference, Release 24).

286

287 4.1.2. Output definition

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

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

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

302 Moreover, recycling of salad waste could provide large amounts of water as main output. The latter
303 could be of great interest within the fresh-cut production process, which is actually particularly water-
304 intensive (Manzocco et al., 2015). Water can actually be obtained by aerobic conversion of waste or by

305 physical separation. To this regard, salad waste drying could be implemented to concomitantly produce
306 not only huge amounts of water but also functional flour or natural adsorbents (Ferreira et al., 2015;
307 Pavlovic, Nikolic, Milutinovic, Dimitrijevic-Brankovic, Siler-Marinkovic, & Antonovic, 2015).
308 Finally, salad has been recently reported to contain interesting bitter and gelling compounds, as well as
309 polyphenols (Llorach et al., 2004; Mai & Glomb, 2016; Roversi, Ferrante, & Piazza, 2016). The
310 production of functional ingredients based on these compounds could be thus a further output of salad
311 waste recycle.

312

313 *4.1.3. Process design*

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

317 Pressure-based technologies such as high static pressure (HP), high pressure homogenization (HPH)
318 and high-pressure carbon dioxide (HP-CO₂) have been proposed for fresh juice production and could
319 thus be exploitable for the production of novel functional juices containing salad (Koutchma, Popovi,
320 Ros-polski, & Popielarz, 2016). Innovative drying technologies such as microwaves (MW) and
321 supercritical fluids (SC-F) could offer the possibility of drying salad wastes at low cost, while obtaining
322 a microbiologically pure water (Brown, Fryer, Norton, Bakalis, & Bridson, 2008; Feng, Yin, & Tang,
323 2012). Similarly, ultrasounds (US), supercritical carbon dioxide (SC-CO₂), pulsed electric fields (PEF)
324 and MW could be applied to salad waste for the extraction of bioactives, colorants and gelling
325 materials at mild temperature conditions, to maximally preserve ingredient properties. To this regard,
326 Solana, Boschiero, Dall'Acqua, & Bertucco (2014) and Solana, Mirofci, & Bertucco (2016) produced
327 polyphenols and glucosinate functional extracts, suitable for functional foods and nutraceutical, from
328 rocket salad using supercritical carbon dioxide extraction (Table 3).

329

330 *4.1.4. Feasibility study*

331 To select a strategy for salad waste management, relevant costs must be evaluated. The cost of
332 currently applied salad waste management strategies is directly proportional to waste transport and
333 disposal. According to Figure 1, in a typical Italian company, salad waste is often delivered to a
334 centralized biogas plant. The latter is generally located within a 20-km distance from the production
335 site in order to reduce transport cost. In such a case, management of 1 ton of waste would be associated
336 to an average cost of 0.80 € and 60 € for transport and disposal respectively. Based on these data, it can

337 be easily calculated that processing 1 ton of iceberg salad with a 35% waste generation (Figure 1)
338 would cost about 22.00 €. This cost is expected to increase with the distance between production site
339 and disposal center. Waste management cost is also strongly affected by the nature of processed salad.
340 For instance, baby salads are characterized by a waste amount approximately 10-fold lower than that of
341 whole-head salads and, consequently, by a waste management cost around 2.00 €/ton of processed
342 salad. In a typical Italian company, approximately equal amounts of whole-head and baby salads are
343 processed, leading to an average waste management cost of at least 10.00 €/ton of processed salad. It
344 has to be underlined that such salad waste management often represents a net cost for companies, due
345 to the risible or null return in terms of biogas or AD digestate to be used as fertilizer.

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

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

362

363 *4.1.5. An operational scheme to develop possible salad waste management strategies*

364 An integrated operational scheme including possible energy recovery, recycle and reuse strategies for
365 salad waste management is shown in Figure 2. This operational scheme could be used to identify new
366 profitable and sustainable strategies. In particular, once salad waste is quantified, characterized, and
367 outputs defined, sustainable processes, either conventional, such as anaerobic digestion for biogas

368 production, or innovative, such as supercritical bioactive extraction, can be considered to develop
369 tailored products.

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

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

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

389

390 **5. Conclusions**

391 Management of fruit and vegetable waste (FVW) is an important issue that requires to be addressed by
392 modern society, due to the environmental impact and the high value of this waste. Among FVW, salad
393 waste is particularly challenging due to its high water content. Nevertheless, different waste
394 management strategies could be efficaciously applied. Among them, the ideal strategy maximally
395 exploits salad waste as a source of both value added compounds, such as polyphenols and fiber, and
396 water. This would reduce the environmental impact of salad waste and even turn it into a profitable
397 material for the company. To achieve this goal, traditional strategies such as anaerobic digestion and
398 composting could be combined with novel sustainable technologies, including those based on

399 supercritical fluids, ultrasounds and pressure. However, the development of such waste management
400 strategies should be economically sustainable for the companies and in agreement with law
401 requirements. Based on this considerations, an integrated approach involving researchers, companies
402 and legislator seems to be crucial to develop cost-effective and environmentally sustainable strategies
403 for salad waste management.

404

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408

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667

668

669 **Figure captions**

670 **Figure 1.** Fresh-cut iceberg salad waste (W) flow in a typical Italian company. Waste-generating
671 operations are identified (C, W1, W2, W3 and OS). Waste amounts are expressed as percentage ratio to
672 total salad accepted after the quality check (S).

673 COLOR IN PRINT IS NOT REQUIRED

674 **Figure 2.** Operational scheme for fresh-cut salad waste management, based on characterisation, output
675 definition, process design and feasibility study.

676 COLOR IN PRINT IS NOT REQUIRED

677

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
Conversion into water	Flour rich in antioxidants, phenols, minerals and fiber Water for industrial facilities	Tropical fruit, orange Mixed fruit and vegetables	de Oliveira et al., 2009; Ferreira et al., 2015; Larrauri, 1999 http://www.eco-wiz.com/ecoDigester.php http://www.enviropuresystems.com/index.php http://www.wastetowater.com.au/
Extraction of specific compounds	Bioactive extracts		
	<i>Flavonoids and bio-sugars</i>	Onions	Choi, Cho, Moon, & Bae, 2015
	<i>Antioxidants and antimicrobials</i>	Fresh-cut fruit	Ayala-Zavala, Rosas-Domínguez, Vega-Vega, & González-Aguilar, 2010
	Oils		
	<i>Essential oils</i>	Citrus fruit	Bustamante et al., 2016
	<i>Oils for food, biodiesel, pharmaceutical and cosmetic sectors</i>	Watermelon, melon, red currant, pomegranate, grape, apple	Górnaś, Soliven, & Segliņa, 2015; Górnaś & Rudzińska, 2016
	Fiber extracts		
	<i>Reinforced biopolymers</i>	Banana	Zini & Scandola, 2011
	<i>Bioplastics</i>	Pineapple, banana	Elain et al., 2016; Jabeen, Majid, Nayik, & Yildiz, 2015
	<i>Cellulose nanofibers</i>	Carrot	Piccinno, Hischier, Seeger, & Som, 2015
	<i>Dietary fiber</i>	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	Mixed fruit and vegetables	Han & Shin, 2004; Kim, 2004; Lin et al., 2013; Shen et al., 2013; Zhang et al., 2007
Bio-electrochemical systems	Fertilizers Electrical energy	Carbohydrate-rich vegetables	ElMekawy et al., 2015

3 **Table 2.** Main characteristics of iceberg salad fractions.

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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

4 ^{fw, dw} data expressed on fresh weight (fw) or dry weight (dw) basis.

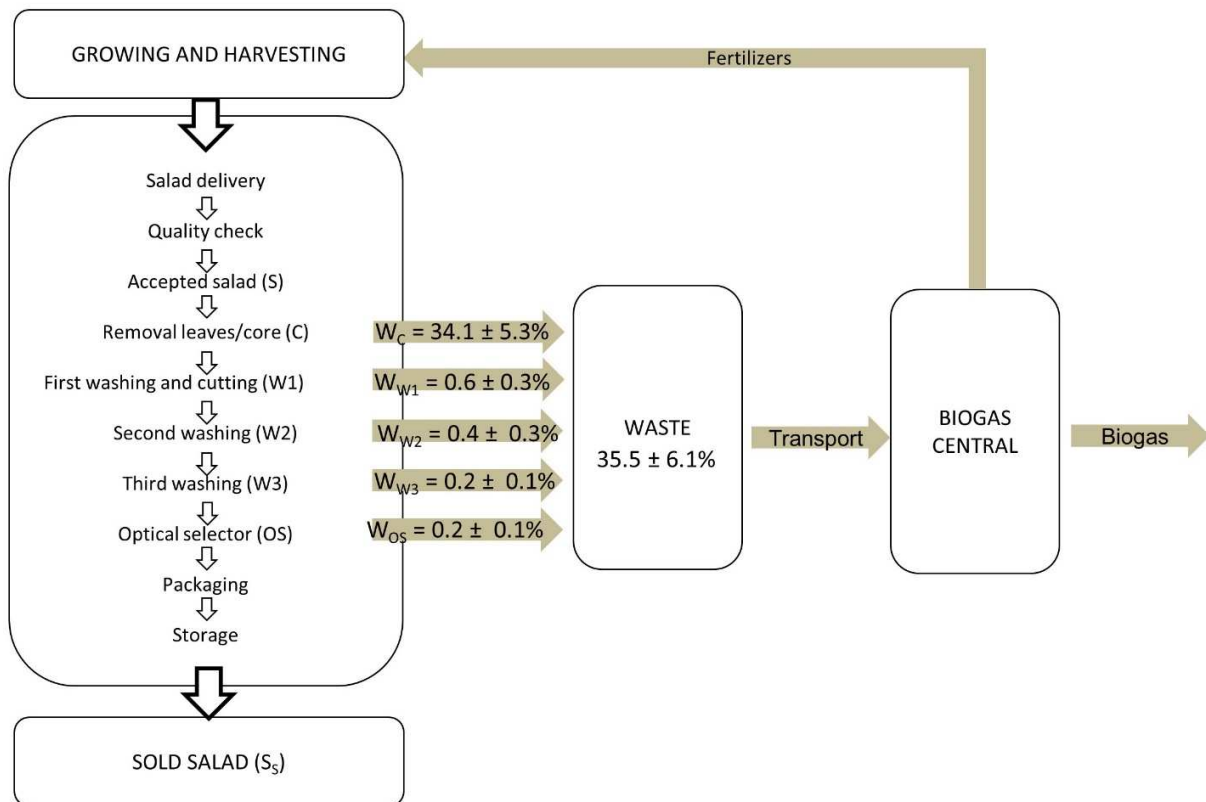
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6 **Table 3.** Outputs of applied and potential strategies suggested in the literature for salad waste management.

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

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**Figure 1.**

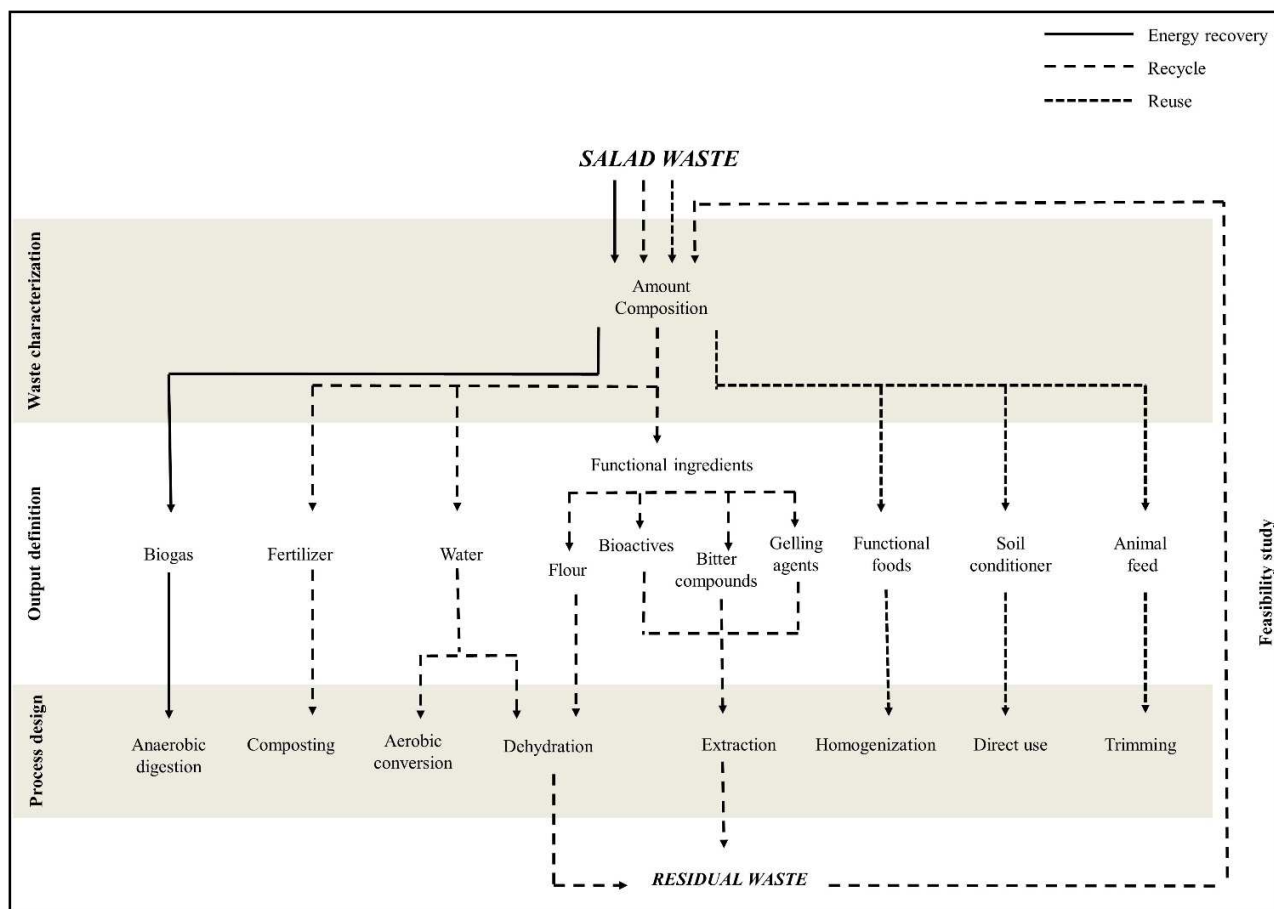


Figure 2.

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

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