Value-added use of fruit residues

In a nutshell

Summary

It is best practice to dispose of the fruit residues of the production process by following the priority cascade:

- recovery of valuable products, whenever feasible: e.g. pectin (from citrus and peach residues), fine chemicals (beta-carotenoids from carrot residues) and multifunctional food ingredients (from carrot, orange and apple residues) that can be used in bakery products,
- use of the fruit residues as animal feed, if there are any local livestock or animal feed producers interested in this by-product,
- use of the fruit residues as anaerobic digestion co-substrate in an already existing anaerobic digestion plant nearby or plan the construction of a new anaerobic digestion system together with other nearby organisations producing organic waste that could be processed in an anaerobic digestion plant (e.g. livestock farmers).

Target activities

All food and beverage manufacturing	Processing of coffee	Manufacturing of olive oil	Manufacture of soft drinks	Manufacture of beer
Production of meat products	Manufacture of fruit juice	Cheese making	Manufacture of bread, biscuits and cakes	Manufacture of wine

Applicability

This best practice is applicable to all manufacturers of fruit juice, providing that local conditions (e.g. availability of local livestock to feed, presence of anaerobic digestion plants) allow the implementation of the options listed above.

Environmental performance indicators

- Fruit residue exploitation rate (%): total amount of fruit residues used for recovery of valuable products (e.g. pectin, essential oils), as animal feed or as co-substrate in an anaerobic digestion plant.

Benchmarks of excellence

- 100 % of the fruit residues are used for the recovery of valuable products (e.g. pectin, essential oils), as animal feed or as co-substrate for anaerobic digestion.

Description

The fruit processing industries are concentrated mainly in southern Europe, most of them are small and/or medium size and they generate a considerable amount of fruit residues. For example, citrus processing industries generate a large amount of orange peels for example, which makes up approximately 45-65% of the original citrus fruit weight. CRES (2014) demonstrated that the average annually processed amount of citrus fruits is approximately 2,500 kt. Hence, assuming that 50% of the production process becomes waste then the amount of organic residues is approximately 1,250 kt.

Manufacturers of fruit juice can dispose of their fruit residues in a number of ways, attempting to follow the order of priority cascade which includes:

- recovery of valuable products, whenever feasible, e.g., production of pectin (from citrus and peach residues), fine chemicals (beta-carotenoids from carrot residues) and multifunctional food ingredients (from carrot, orange and apple residues) that can be used in bakery products, etc. (Petruccioli et al., 2011).
- use of the fruit residues as animal feed: this option depends on the availability and requirements of local livestock or animal feed producers interested in this by-product.
- use of the fruit residues as anaerobic digestion co-substrate in an already existing anaerobic digestion plant nearby or plan the construction of a new anaerobic digestion system together with other nearby organisations producing organic waste that could be processed in an anaerobic digestion plant (e.g. livestock farmers).

Obviously, the availability of local options significantly affects the process(es) chosen.

The use of fruit residues for animal feed is a well-established practice while this best practice describes in more detail the potential benefits of the use of fruit residues as co-substrate for biogas production in agro-industrial biogas plants or in anaerobic digesters dedicated to treating sludge from wastewater treatment plants (WWTP). This concept, taking into consideration the example of orange juice production, is illustrated in Figure 1 and below.

Figure 1: Citrus residues as co-substrate for biogas production (CRES, 2014)

h

Image not found or type unknown

The most common option for making use of orange residue is as animal feed. However, the high moisture content of fresh citrus waste results in high transportation costs, while the high biodegradability levels limit their use as fresh feed in the surrounding areas. Therefore the orange residue can be processed anaerobically (as a co-substrate) in order to generate electricity, heat and compost (Figure 1).

Anaerobic co-digestion is a technically feasible option to make use of orange residues, for producing renewable energy. Orange peel shows high methane potential, high anaerobic biodegradability and kinetics degradation. Ruiz et al., (2011) showed a maximum orange peel specific biogas production of 1,100 L/kg TS (total solids). Complete orange degradation is achieved after 11 days. Muscolo (2011) demonstrated that 1 m^3 of citrus pulp weighs approximately 0.4 tonnes and has a potential biogas yield of 147 m^3. Therefore, assuming that the methane percentage in the biogas ranges from 50 to 80%, the heating value ranges from 4,500 to 6,500 kcal/m^3 as well. Ruiz-Fuertes et al., (2007) mentioned that the orange pulp's potential for biogas formulation is approximately 700-750 Nl biogas/kg VS (volatile solids) with a methane content of 52%.

Anaerobic digestion technology offers a high flexibility for treating different forms of citrus residues (e.g. peels and pulp) and in different states of decomposition. The main advantages of AD include the limited production of biological sludge, the low nutrient requirement and the high efficiency of methane production; which can be used as an energy source for on-site heating and electricity generation (Nallathambi, 2009).

Despite the good characteristics of citrus residues as co-substrate for biogas production, they contain D-limonene, unless it was previously extracted using one of the now well-known technologies for its recovery e.g. FMC (Citrech, 2015). D-limonene is an essential oil that is a well-known antimicrobial agent but the co-digestion of citrus residues with other organic waste prevents the possible inhibition caused by the limonene. The maximum percentage of citrus residues to keep methane production high and stable is a topic that should be defined in each blending of co-substrates (Martin et al., 2010).

The most common strategy for orange juice companies is to create synergies or reach agreements with local waste managers, other orange juice companies, farms or urban WWTPs with anaerobic digesters or biogas plants capable of treating citrus residues in co-digestion with the bio-waste they usually treat (sewage sludge, manure, other substrates). Co-digestion consists of using complementary organic substrates, mainly waste with no-cost (or limited options for further use), as co-substrates to significantly increase the biogas productivity in their facilities and thus obtain more income from the energy produced. The use of citrus residues has given good results in co-digestion in either WWTPs with AD systems or agro-industrial biogas plants (Martin et al. 2010; Martin et al., 2013). The production of economically valuable biogas boosts the agreements between orange juice companies producing orange peel and waste managers.

Silvestre et al. (2010) studied sewage sludge anaerobic digestion with orange peel (12% of volatile solids input) and other organic wastes in a semi-continuous anaerobic system. The biogas production from sewage sludge and orange residues increased 286% compared with the biogas production using only sewage sludge. Additionally, the organic matter removal efficiencies increased from 50% (sewage sludge anaerobic digestion) to 68% (sewage sludge co-digestion).

Despite the fact that orange peels provide a significant biomethane potential, low pH, low micronutrients content and high content of essential oils (if not previously extracted), they cannot be used as the only feedstock (mono-substrate) in an AD plant. Therefore, co-digestion is highly recommended for achieving stable processes. Table 1 shows an example of a more balanced composition of 1:3 feeding mixtures with cattle manure.

Table 1: Characteristics of orange residues and 1:3 feed mixture with cattle manure used by the GSR AD plant* (Ruiz-Fuertes M.B et al., 2007)

Parameter	Orange residue:Cattle manure (1:3 dry basis)
Total solids (TS) (%)	11.2
Volatile solids (VS) (%ST)	88.0

Anaerobic biodegradability	Very good
C/N ratio	35.0
Biomethane potential (L biogas/kg VS)	370.0
pH	7.0
Alkalinity	High
Micronutrients	Good
Essential oils (5)	<0.5

*As mentioned in the text above, orange waste is not suitable as mono-substrate for AD, it is recommended it be used as co-substrate.

Other studies also support the need to co-digest citrus residues with other organic wastes, in order to stabilise the AD process. For instance, the Probiogas project found that the maximum percentage of citric residues to be added to manure for AD is 10 %, due to the fact that in the industrial trials the residues had two to four times more limonene than in the lab studies. Moreover, in the same study, it was found that the results for biogas production from AD are better when the citrus residues are added without trituration, which makes their handling easier at industrial level (Probiogas project, 2010)

Environmental benefits

The appropriate management of fruit residues, trying to follow the order of priority mentioned above, allows firstly the achievement of 'hidden' environmental benefits. In fact, extracted components can be used to substitute ‘virgin’ components which otherwise, through their own production, transportation and so on, would have been responsible for further environmental impacts. The same would apply for using the fruit residues as animal feed, since this would avoid producing other feed from other natural resources.

Finally, the use of fruit residues as co-substrate for biogas production contributes to the reduction of the environmental impacts caused by inappropriate management. In particular, landfilling significant amounts of fruit residues may cause the release of uncontrolled leachates, which will eventually result in the pollution of groundwater sources.

Moreover, the anaerobic digestion process generates biogas which can then be employed for the generation of renewable electricity and heat. Therefore, the use of biogas as a renewable source of energy prevents the consumption of non-renewable resources, such as fossil fuels and the corresponding CO_2 emissions.

Side effects

The environmental impact of fruit residues transportation from the fruit juice facility to livestock or to the biogas plant (fuel consumption and exhaust gases) is the main cross-media effect of this technique. However, these impacts are common to all alternatives which imply the treatment of wastes in external installations (feed preparation, composting) or disposal in landfill.

Applicability

This best practice is applicable to all manufacturers of fruit juice, however, the availability of the different options for using fruit residues outlined in this best practice largely depend on the local conditions e.g. availability of nearby AD plant and willingness to cooperate. The agreement between the fruit juice plant and the AD plant will depend on several factors such as the availability and price of other local organic wastes, the transportation distance, the profitability of electricity produced from biogas, etc.

Regarding technical aspects, the presence of essential oils in orange residues and consequently in the AD reactor should also be taken into account in the actual operation of the plant. As mentioned earlier, despite the good characteristics of citrus residues as co-substrate for biogas production, they contain D-limonene, an essential oil that is a well-known antimicrobial agent. The co-digestion with other organic waste prevents the inhibition caused by limonene. The maximum percentage of citrus residue to keep methane production high and stable is a topic that should be defined in each blending of co-substrates (Martin et al., 2010).

Economics

The economic feasibility of the agreement between parties (e.g. orange juice plant and waste manager) will depend mainly on the economics. The main costs are related to the transport of the fruit residues to the livestock or biogas plant (distance) and the market price allocated to the fruit residues, which can depend on the cost of other available organic wastes with similar characteristics. The profits obtained by biogas plants using fruit residues are related to increased biogas production thanks to the anaerobic process being kept stable (depending on local conditions).

Driving forces for implementation

The main driving forces for managing the fruit residues appropriately are the environmental benefits and the potential economic benefits achievable thanks to the potential market value of the:

- useful products which can be extracted.
- fruit residues used as feed or co-substrate for AD.

Reference organisations

Granja San Ramón" (GSR). Cattle farm for milk production, biogas and organic fertilisers production. The company is located in Valencia, Spain.

The public organisation responsible for the wastewater treatment in the Comunidad Valenciana (EPSAR) uses citrus waste as co-substrate for anaerobic digestion sludge, in order to improve electricity generation. The WWTP is sited in Alzira (Spain)

Literature

- Bampidis V.A. and Robinson P.H. (2006), Citrus by-products as ruminant feeds: A review, Animal Feed Science and Technology, 128, 175 - 217.
- Calsamiglia S., Ferret A. and Bach A. (2004), Tablas FEDNA de valor nutritivo de Forrajes y Subproductos fibrosos húmedos, Fundación para el Desarrollo de la Nutrición Animal, Madrid, 70.
- Citrech 2015. Available at: http://www.citrech.it/eng/Tech_en.html, accessed April 2015
- CRES (2014), Anaerobic digestion, Anaerobic Digestion Network, AnDigNet, available at: http://www.cres.gr/andignet/technologies_anaer.htm, accessed November 2014.

- De Blas C., Mateos G.G. and García-Rebollar P. (2010), Tablas FEDNA de composición y valor nutritivo de alimentos para la fabricación de piensos compuestos (3ª edición), (FEDNA tables of composition and nutritive value of foods for the manufacturing of compound feeds (3rd Edition), Fundación Española para el Desarrollo de la Nutrición Animal, Madrid, 502.
- EPSAR (2013), Personal communication.
- Kammoun Bejar A., Boudhrioua Mihoubi N. and Kechaou N. (2012), Moisture sorption isotherms – experimental and mathematical investigations of orange (Citrus sinensis) peel and leaves, Food Chem. 132, 1728–1735.
- Mahmood A.U., Greenman J. and Scragg A.H. (1998), Orange and potato peel extracts: analysis and use as Bacillus substrates for the production of extracellular enzymes in continuous culture, Enzyme Microbial Technol., 22, 130–137.
- Martín M.A., Fernández R., Serrano A. and Siles J.A. (2013), Semi-continuous anaerobic co-digestion of orange peel waste and residual glycerol derived from biodiesel manufacturing, Waste Management 33(7), 1633–1639.
- Martin M.A., Siles J.A., El Bari H., Chica A.F. and Martín A. (2010), Biomethanization of orange peel waste, Bioresource Technology, 101(23), 8993-8999.
- Morton J. (1987), Orange. In: Fruits of Warm Climates, Miami, 134–142.
- Muscolo A. (2011), Biogas for bioenergy, powerpoint presentation in better Exchange 2011, 30-31st May, in the German Capital Region – Energy, available at: http://de.amiando.com/eventResources/m/B/z1tA35o7s1PTdM/Biogas_for_Energy.pdf, Accessed November 2014.
- Nallathambi G.V. (2009), Biomass estimates, characteristics, biochemical methane potential, kinetics and energy flow from Jatropha curcus on dry lanas, Biomass and bioenergy 33, 589 - 596.
- Petruccioli M., Raviv M., Di Silvestro R., Dinelli G. (2011). Agriculture and Agro-Industrial Wastes, By-products, and Wastewaters: Origin, Characteristics, and Potential in Bio-Based-Compounds Production. Comprehensive Biotechnology. Vol 6, 531-545.
- Probiogas project (2010). Available at: http://www.probiogas.es/ Accessed April 2015.
- Ruiz B. and Flotats X. (2014), Citrus essential oils and their influence on the anaerobic digestion process: An overview, Waste Management, 34, 2063-2079.
- Ruiz Fuertes M.B. (2007), Estudio de la producción de metano en la co-digestión anaerobia de naranjas y estiércol de vacuno, MSc thesis, Dpt. Chemical Engineering, Technical University Valencia.
- Ruiz-Fuertes M.B., Kaiser F., Andrade-Montealegre D.P., Póvez A. and Gronauer A. (2007), Methane Yield Improvement in Anaerobic Co-Digestion of Valencia Late Oranges and Cattle Manure (poster prsentation), in proceedings from: 11th IWA World Conference on Anaerobic Digestion, Brisbane, Australia, 23-27 September.
- Silvestre G., Fernández B. and Bonmatí A. (2010), Synergies in the Anaerobic co-digestion of sewage sludge with the organic Fraction of municipal Solid Waste, in proceedings from: Congreso Internacional sobre suelos y material orgánica a partir de residuos, Valladolid, Spain.
- Wilkins M.R., Suryawati L., Maness N.O. and Chrz D. (2007), Ethanol production by Saccharomyces cerevisiae and Kluyveromyces marxianus in the presence of orange-peel oil, World J Microbiol. Biotechnol., 23(8), 1161–1168.