Waste minimization and utilization in the food industry: Processing of arctic berries, and extraction of valuable compounds from juice-processing by- products

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Abstract

This research work is focused on the processing of berries into fruit juices from the point of view of waste minimization and environmental best-practice technologies. Environmental best-practice technologies aim to satisfy consumer demands, while the production process is optimised in order to have the least impact on the environment. The optimisation includes the reduced utilization of raw materials, less energy and water use, while, as a result less process waste and effluent is generated. However, in the process design or re-design, special attention is to be given to safety. As a part of the best-practice technologies the more cost-effective and environmentally friendly preservation of the fruit juices by pressure driven membrane processes will be introduced. In cooperation with researchers of the MARAKASSI project, the Laboratory of Mass and Heat Transfer (Department of Process and Environmental Engineering) at the University of Oulu, the implementation of environmental best-practice technologies in fruit juice processing for waste minimization; and development of solid waste utilization methods that are effective, economic, and environmentally friendly are endorsed.

1 Introduction

Environmental legislation has significantly contributed to the introduction of sustainable waste management practices throughout the European Union. For instance, the Landfill Directive forbids disposal of untreated organic waste starting from 1.5.2005. By the year 2010, organic waste disposal has to be reduced by 80 % (European Council 1999). To this end, the Finnish National Waste Plan prescribes that, by the year of 2005, the utilization rate of food industry waste has to be raised to a minimum of 70 % (Ministry of the Environment and the Finnish Environmental Institute 1999).

Considering the challenges in the area of food industry, efforts are to be made to optimise processing technologies to minimize the amount of waste.

2 Finnish berries and their processing

The nordic climate and geographical conditions of Finland allow the cultivation of berries rather than fruits. Arctic berries have been a part of the Finnish diet for centuries. The consumption of berries and berry products (juices, jams, marmalades, jellies, porridges) is indeed very high in Finland; with the most used berries being bilberries, lingon berries, cloudberries, and cranberries. Both cultivated and wild berries are unpolluted and low in energy, and they are also an important source of antioxidant vitamins and fibre. Berries also contain different bio-active components, such as phenolic phytochemicals (flavonoids, phenolic acids, polyphenols) (Häkkinen *et al.* 1999.).

It has been established that consumption of fruits rich in phytochemicals helps to avoid coronary heart disease (Hertog *et al.* 1993), stroke (Keli *et al.* 1996) and lung cancer (Knekt *et al.* 1997). Notable are also the antibacterial properties of berries. The cloudberry (*Rubus chamaemorus*), raspberry (*Rubus idaeus*), and bilberry (*Vaccinium myrtillus*) and crowberry (*Empetrum nigrum*) were effective against all of the bacterial strains tested. Bog bilberry (*V. uliginosum*) inhibited all the gram-positive bacteria, but not gram-negative *E . coli*, *S . aureus*, *B . subtilis* and *M.luteus* (Rauha *et al.* 2000). Figure 1 shows the flavonoid content of different Finnish berries.

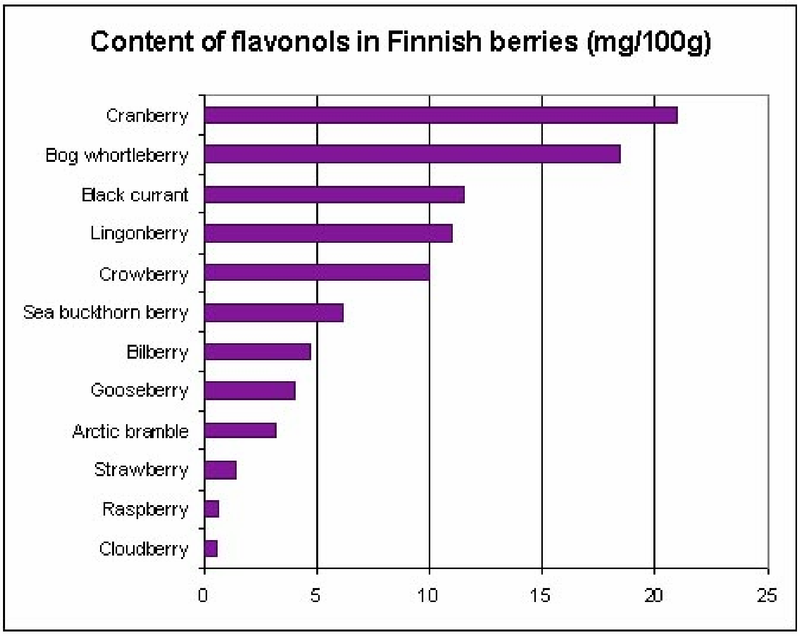

Figure 1 Flavonol content of Finnish berries (Häkkinen *et al.* 1999)

In the following, the principles of waste minimization will be introduced and the critical points of fruit juice processing from the perspective of waste generation will be analysed. As an example for clean processes, a complex method for fruit juice concentrate production has been carried out by application of membrane technology.

3 Waste minimization in the waste management hierarchy

The primary aim of waste legislation is the prevention of waste generation. Waste prevention refers to three types of practical actions, i.e., strict avoidance, reduction at source, and product re-use. However, waste prevention does not only include the reduction of absolute waste amounts but also avoidance of hazards and risks because safety is also of major concern. Considering the waste management options, at the top of the hierarchy stands waste minimization that includes (Riemer & Kristoffersen 1999):

- waste prevention i.e. reduction of waste by application of more efficient production technologies;
- internal recycling of production waste;
- source-oriented improvement of waste quality, e.g. substitution of hazardous substances;
- re-use of products or parts of products, for the same or other purpose.

Figure 2 illustrates the position of the European Environmental Agency (EEA) on waste minimization.

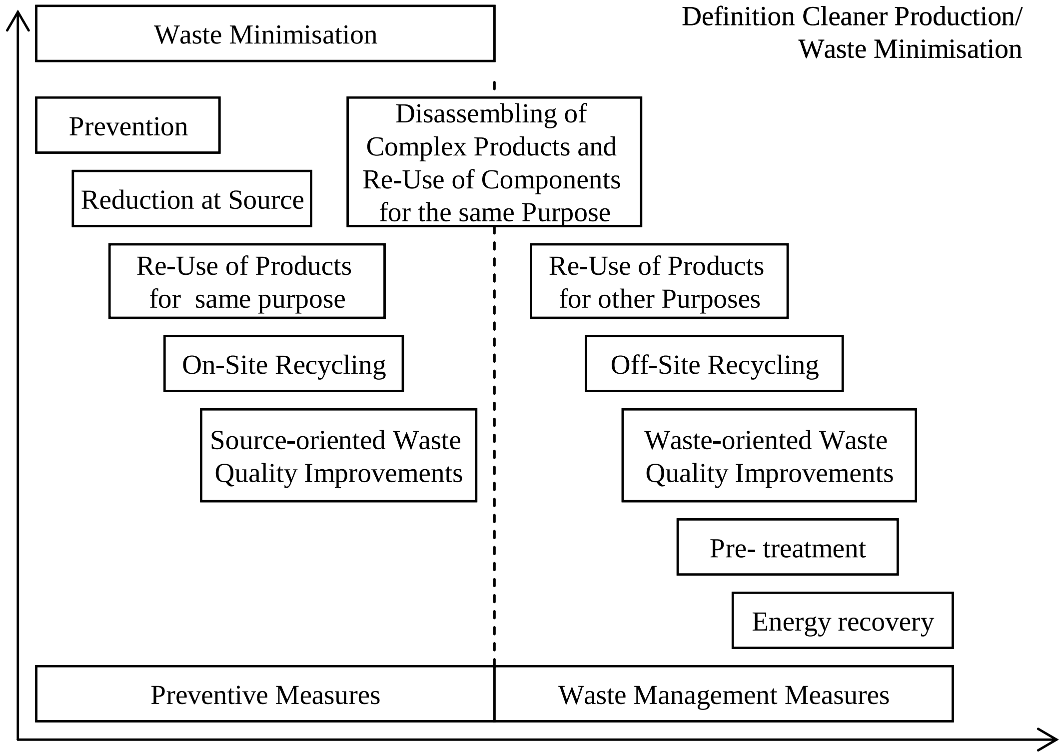

Figure 2 Waste minimization vs. waste management measures (Riemer & Kristoffersen 1999)

4 The environmental impacts of the food sector

While it is true that the principle of waste prevention is universally accepted, the practice has lagged far behind. Food industry will also have to concentrate on waste avoidance as well as utilization of process wastes. Application of clean technologies enhances the safety and quality of the product as well as reducing the energy requirements and environmental impact of the food industry. The main environmental impacts of the food sector are aquatic, atmospheric and solid waste emissions. By choosing proper separation technology, wastewater treatment is usually carried out and is implemented in process installations. The atmospheric emissions are mainly caused by extensive energy use. The food industry consumes a great deal of energy for heating buildings, processes, and process water, for refrigeration and for the transportation of raw materials and products. The increased share of renewable energy sources could slowly reduce the amount of conventional fossil fuel utilization.

Solid by-products and wastes are also generated in high amounts in the food industry. The main treatment method of solid wastes is, at present, composting. Recovery and re-use of by-products and wastes as raw materials is another option. However, microbiological quality and safety is always of major concern.

4.1 Analysis of fruit processing and evaluation of waste minimization potential

From an environmental point of view, processing of berries produces large amounts of effluents and solid waste. In fruit juice processing large amounts of water are used, mainly for cleaning purposes. Due to hygienic and food safety considerations, most of the utilized water is drinking water quality and the amount of water effluent can be up to 10 m^3/tonnes of raw material. The water is used for raw material washing, plant and equipment cleaning, and other industrial utilization. The resultant wastewater has a high organic content, containing parts of the fruits, cleaning agents, salts and suspended solids.

As the amount and quality of the effluent greatly influences the economic feasibility of a company, efforts should be made to minimize the use of water and therefore to (World Bank 1996):

- use dry methods such as vibration or air jets to clean raw fruit;
- separate and re-circulate process wastewaters;
- minimize the use of water for cleaning purposes;
- remove solid wastes without the use of water; and
- use counter-current systems where washing is necessary.

Solid wastes usually originate from pre-treatment – washing and sorting –, and they consist of damaged fruits, stems and stalks. A major source of solid waste generation is the pressing process, in which peels, seeds, pulps are separated from the fruit juice. There is a large unused potential in the juice processing wastes, as they contain a sizeable amount of healthy substances, such as flavonoids, colours and pectins.

Finland's gross value of fruit and vegetable juice production was €120.6 million in 2001 (Finnish Food and Drink Industries' Federation statistical review 2003). According to the Handbook for the prevention and minimization of waste and valorisation of by-products in European agro-food industries (2002), the amount of solid waste from generated in juice processing is 121 911 t/ year.

The Finnish MARAKASSI project, co-ordinated by Viikki Food Centre at the University of Helsinki, initialized a network of small- and medium-sized berry, vegetable and mushroom processing companies. The project is financed by the European Agricultural Guidance and Guarantee Fund and, in its initial stage, mapped the technology development needs of participating companies. One of the findings of the MARAKASSI project was that member companies are increasingly facing the problem of the treatment and disposal of solid waste from food processing. For example, the skins of potatoes are a source of problems, and potato processing companies are interested in the development of utilization pathways to eliminate soluble starch from wastewater, as they tend to clog the pipes (Marakassi 2002)

Another perceived innovative technology development need is called upon for the utilization of solid wastes from the juice pressing operation. The remaining waste after the berry pressing and separation process steps, i.e. peels and seeds, do contain valuable compounds such as flavonoids or aromatic oils. When applying proper extraction technology, i.e. super-critical fluid extraction, these healthy compounds can be recovered and applied either by the food industry, or the cosmetic or pharmaceutical industries.

5 Application of membrane processes for waste minimization

Membrane technology is based on a thin physical barrier through which materials can either pass (the permeate) or be rejected and retained (the retentate) due to a driving force that can be pressure difference, concentration gradient, temperature gradient, and/or electrical potential difference. Appropriately-used membrane separation can provide financial savings and conserve resources. Maximum benefits are obtained when one or both the output streams from the membrane system are recycled or re-used, thereby reducing process materials requirement and minimising waste disposal costs. Compared with conventional processing, membrane technology has many advantages. By implementing membranes, the separated substances are often recoverable in a chemically unchanged form and are therefore easily re-used. Membrane separation units are compact and their modular construction means that they can be scaled up or down easily.

Membrane filtration processes offer new ways of food processing to fulfil the consumer demand for healthy food rich in valuable components and preserved without chemical additives. With the application, the process becomes simpler, shorter and takes place at lower temperatures, therefore the valuable and heat-sensitive compounds are not lost to any great extent. State-of-the-art membrane technology methods offer the possibility to enhance food safety, and reduce the energy consumption and the environmental impact of food processing. Membrane separations are applied:

- concentration (removal of a diluting solvent such as water);
- purification (separation of contaminants);
- fractionation (resolution into two or more component substances).

The pressure driven membrane processes are divided based on the membrane pore size to:

- micro-filtration (0.1-10 μm)
- ultra-filtration (0.01-0.1 μm)
- nano-filtration (1-10 nm)
- reverse osmosis (0.1-1 nm)

Typical food industrial applications of micro-filtration are:

- cold sterilization of beverages
- clarification of fruit juices, beers and wines
- continuous fermentation
- separation of oil- water emulsions
- wastewater treatment

Applications of ultra-filtration are:

- concentration of milk
- recovery of whey proteins
- recovery of potato starch and proteins
- concentration of egg
- clarification of fruit juices and alcoholic beverages.

Main application of nano-filtration:

- removal of micro-pollutants
- water softening
- wastewater treatment.

Typically reverse osmosis is used in:

- desalination
- concentration of food juice and sugars
- concentration of milk.

When operating a membrane system, optimal conditions should be found. The measurement of the process efficiency can be the selectivity and the permeate flux. Flux is typically expressed as volume or mass per unit membrane area per unit time, for example litres/m^2/hour. Temperature can affect flux significantly. Operating at high flux levels means that less membrane area is required and economies can be made in terms of capital, operating and membrane replacement costs.

5.1 Juice concentration with membranes

Preservation of fruit juices also contributes to waste minimization by the means of avoiding the spoilage of the product. The traditional preservation methods are based the addition of chemicals or physical methods such as pasteurisation, evaporation. Comparing to the evaporation, which is widely used for fruit juice concentrate production, energy efficiency is of great importance. The end- product is clean and of good quality, while the by-product of the final concentration step is a clear water that can be re-used in a process, e.g. for the first rinse of the berry fruits or for floor washing purposes.

A complex method based on pressure-driven membrane technologies was carried out for grape juice processing (Figure 3) at Szent István University, Department of Food Engineering (Pap 2003). A two-stage process resulted in a fruit juice concentrate, while the valuable compounds were retained in the juice.

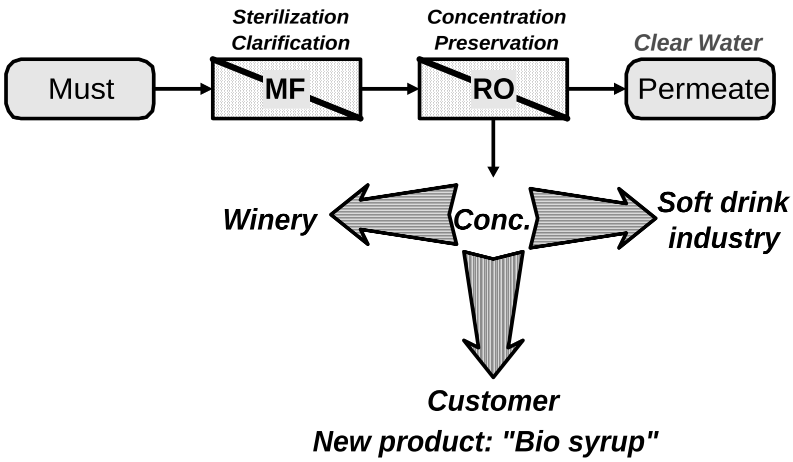

Figure 3 Complex method for fruit juice processing (Pap 2003)

As a first step, micro-filtration was applied as a pre-treatment for clarification and sterilisation of juice samples. Microbiological experiments and sensory analysis was carried out to prove the efficiency of the process step. Based on the microbiological experiments on YEPD sterile medium that allows the growth of all types of micro-organisms, a 6 order of magnitude decrease in the total cell number was achieved.

Independent analysers performed profile analysis of micro-filtered juice samples. They analysed the taste and smell of grape juice samples. The analysis took place in a special laboratory, where the analysers were seated in separate cubicles and performed the evaluation aided by a computer programme. The following effects were observed on the juice properties after clarification (Pap 2003):

- Loss of the original taste and smell to a certain extent;
- The appearance of the filtered musts was enhanced;
- Due to lower side taste intensity, the taste of the treated samples was preferred.

As a next processing step, reverse osmosis was applied for concentration, i.e. preservation of the fruit juice. During the filtration procedure, water is removed from the juice as permeate; while the sugar content is enhanced in the retentate, therefore preservation occurs. The measurement of total solids by refractometer was carried out continuously and antocyanin analysis by spectrophotometer was done. Based on these results, concentration has been achieved and the antocyanins were retained in the juice by 99.4 %.

The conclusions of the work were that application of membrane technologies in fruit juice processing can help to make the procedure cost effective, and environmentally sound. In the future, the application of this process will be tested on Finnish berry juices. However, because of the higher pectin content and higher acidity of berry juices, the application is challenging. The high pectin content can cause fouling of the membranes due to their molecular weight, which may mean that the concentration procedure might fail. Therefore, an enzymatic pectin breakdown will be carried out before the membrane filtration procedure.

Studies have shown that berry juices have high organic acid content, and low fermentable sugar content (Viljakainen 2003). Due to this, the development of berry products is limited. Berry wine production is especially challenging, given that fermentation necessitates sugar addition. However, this results in aroma weakening of the berry wine. To improve the application of berry juices, malolactic fermentation was tested and found to be a promising way for acidity reduction without the loss of natural sugar content (Ibid.).

4.2 SFE for recovery of valuable compounds from solid waste

Promising technology was found in supercritical fluid extraction (SFE) with natural CO_2 for the recovery of valuable compounds and can be considered as an environmentally friendly solvent-free extraction method that results in minimal oxidative and thermal stress. With SFE, high-value oils as well as aromas can be fully recovered in their natural composition. For these high-value compounds, SFE is not only the most favourable but also the least expensive method of production.

After the quantitative and qualitative analysis of Finnish berry processing by-products, laboratory tests for the recovery of aroma compounds, flavonoids from peels, as well as seed oil recovery by SFE method will be performed.

5 Conclusions

This study focused on waste minimization in fruit juice processing. The combined efforts of waste minimization during the production process, environmentally friendly preservation of the product, and utilization of side-products would substantially reduce the amount of waste, as well as boost the environmental profile of fruit juice processing industry.

The importance of the berry juices in a healthy diet is highlighted, and a cost-effective and environmentally friendly process technology is introduced. Earlier results showed great efficiency of the membrane process in grape juice processing, and based on these experiences, tests will be carried out for berry juices. An unused potential exists in berry wastes regarding valuable compounds originating from the pressing process. The peels are rich in health-promoting flavonoids and aroma compounds, while the seeds contain oils that can be recovered.

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