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A Comparative Life Cycle Assessment Study on Conservation of Semi-Finished Peaches

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Semi-finished products are often used in the case of the high degree of perishability, like, for example, in the case of some fruits. The treatment of those fresh fruits allows the extension of foodstuffs' shelf life, maintaining low the level at which microbial spoilage and deterioration reactions can occur. These semi-finished products are frequently used as starting materials by jams' and marmalades' industries. The Southern Italy industry under study uses two different techniques to produce and preserve semi-finished peaches: one is based on low-pressure superheated steam drying with far-infrared radiation, and one on an ohmic aseptic treatment.
The aim of this work is to use a Life Cycle Assessment (LCA) approach to compare the environmental emissions of those two different production and preservation techniques on two large scale plants. The environmental impacts were evaluated using a detailed LCA analysis, normalizing all the consumptions and emissions to the functional unit (one peaches' kg on a dry basis). Data were analysed using SimaPro 8.5.2 software, whereas the Ecoinvent 3.4 database and information collected from the chosen industrial site were used for the life cycle inventory, according to the reference standard for LCA (i.e., ISO 14040 and 14044).

1. Introduction

Over the years, fruit semi-finished products have become an increasingly popular product for the food industries. Indeed, they allow, starting from the raw material collected from the field, to obtain a product that can be easily processed and stored by food companies (Nimmol et al., 2007). In particular, the extension of the shelf life allows to better manage the seasonal harvest peaks and, therefore, to distribute production over the whole year (De Marco and Iannone, 2017).
Among the fruit semi-finished products, peaches (Prunus persica) have an ethylene production rate (which determines the level of fruit ripening) at 20°C about 32 times higher than that at 0°C (Huy, 2007). This determines a shelf life of the fresh fruit that is very limited and does not respond to industrial needs (Sortino et al., 2017). Therefore, it is preferable to realize a preliminary process capable of transforming peaches into a more stable semi-finished product, which can then be used for all the processes of the modern food industry.
Asia is largest producer of peaches and nectarines then follows Europe (4.23 Mt) (Ingrao et al., 2015). Italy is the leading producer in Europe and the second largest after China (Vines et al., 2015). There are many works that analyse the environmental impacts of the orchard production of peaches (Michos et al., 2012) and processed in particular (Nanaki and Koroneos, 2018). Although there are still few works that analyse in detail the industrial processing processes (Manfredi and Vignali, 2015) and the different techniques that allow the fruit to be used to produce its derivatives (De Marco et al., 2015).
The purpose of this work is to compare the impact of two preservation processes of semi-finished peaches: Low-Pressure Superheated Steam Drying with Far-Infrared Radiation (LPSSD-FIR) and Ohmic Aseptic Treatment (OAT), considering both impacts of the pre and post-production phases of standard lots.

2. LCA methodology

The LCA methodology allows analysing the impact of a process on the realization of a specific asset. Through this information it is possible to compare, also from an environmental point of view, two alternative processes for carrying out the same operation. In this article, in particular, we will consider the extension of the shelf life

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of semi-finished peaches. To carry out this comparison, the classical phases of the LCA methodology have been developed: 1) goal definition and scope of the LCA analysis; 2) functional unit and system boundaries; 3) data collection and life cycle inventory.

2.1 Goal definition and scope of the LCA analysis

The objective of the study is the comparative evaluation of the impacts of two alternative processes for the industrial production of semi-finished peaches. Figure 1 shows the industrial phases of the manufacturing process. Being a comparative study, the boundary considered in this study is limited to the two alternative processes of Aseptic Treatment and Low-Pressure Superheated Steam Drying with Far-Infrared Radiation (LPSSD-FIR). All previous and subsequent processes do not differ significantly and will, therefore, be kept out of the present study.

2.2 Functional unit and system boundaries

As mentioned in the previous paragraph, therefore, the complete process for peach processing and the boundaries of the study object of this work are shown in figure 1. The phases common to the two processes are not included in this study, as they do not significantly impact the comparison. To have an indication of the orders of magnitude of the impacts of the phases not considered in this study, it is possible to consult De Marco's work on apricots (De Marco and Iannone, 2017), a very similar fruit, in terms of consumption and impacts produced by the industrial phases, to that analysed in this study. The functional unit (FU) used is 1 kg of the dried packaged peach semi-finished product.

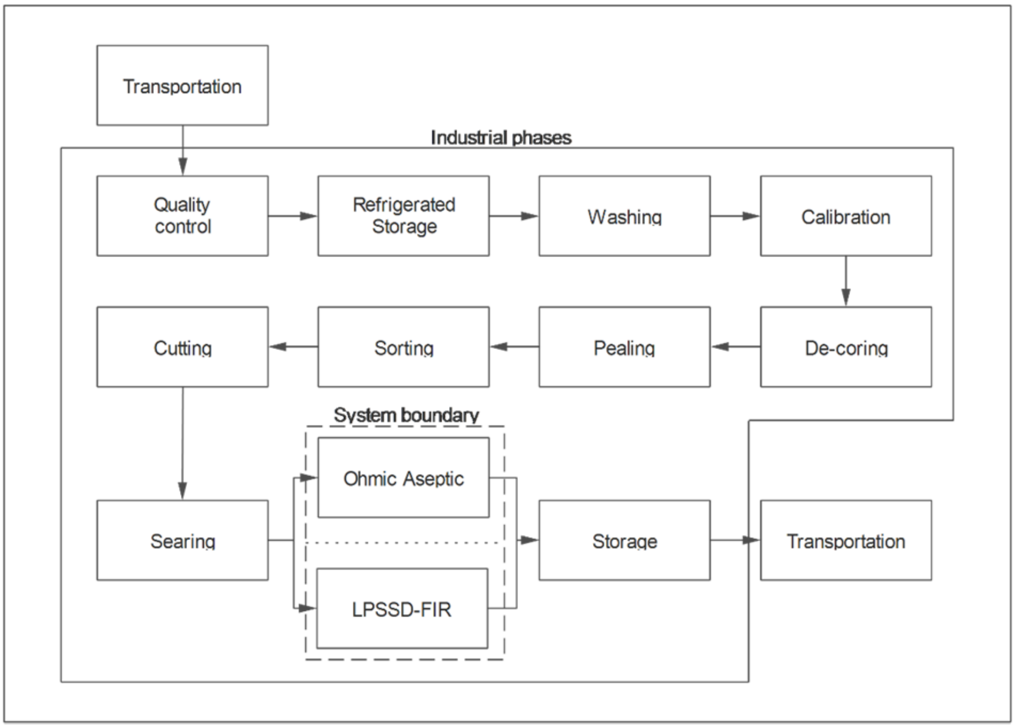

Figure 1: System boundary.

2.3 Data collection and life cycle inventory

The synthetic details of the processes are shown in table 1.

In particular, the aseptic packaging process is based on the principle of continuous sterilization (or pasteurization) of the product and subsequent packaging in an aseptic environment (see figure 2). The main phases of the process are: (1) plant sterilization, (2) continuous heat treatment, (3) cooling, (4) aseptic transport to the packaging machine, (5) aseptic packaging, (6) hermetic sealing of the containers, (7) transportation, (8) storage, (9) plant washing. The cubed fruit is allowed to flow into a feed tank and mixed with water (T = 60°C) and citric acid (85% fruit, 25% liquid) to adjust the pH (3.6-4.2) according to the temperature sterilization and product quality requirements. A small percentage of ascorbic acid is also added to prevent the onset of oxidation. Fruit and liquid are set in motion by a piston pump. Downstream of the pump, an ohmic heater raises the temperature of the fluid followed by a pause of a few minutes to allow the temperature to be homogenized and therefore the sterilization process. The subsequent cooling phase takes place inside an exchanger in counter current water. The temperature goes from 90-100°C to 25-35°C. At the exit the product is sent to the aseptic tank which has the function of decoupling the continuous sterilization process with the discontinuous filling process of the aseptic bags. The filling chamber is kept at a temperature of 100°C through a continuous jet of steam in order to avoid contamination during the filling phase. The filled sack is transported to the warehouse and stored at room temperature. The plant works continuously for about 10 hours and needs to be sterilized at start-up and washed at the end of production.

Table 1: Process details and assumptions

Process	Characteristics and details
Plant sterilization	T = 120°C; t = 45 min; energy and water supply
Ohmic aseptic treatment	T=90°C; t=120 s; energy, water and ascorbic and citric acid supply
Packaging	Energy, supporting materials and components supply
Plant washing	Water, soda, acid, energy supply
Plant set-up	Energy and water supply
LPSSD-FIR treatment	T = 80 °C; P = 7 kPa; t = 8400 s; energy and water supply
Packaging	Energy, supporting materials and components supply

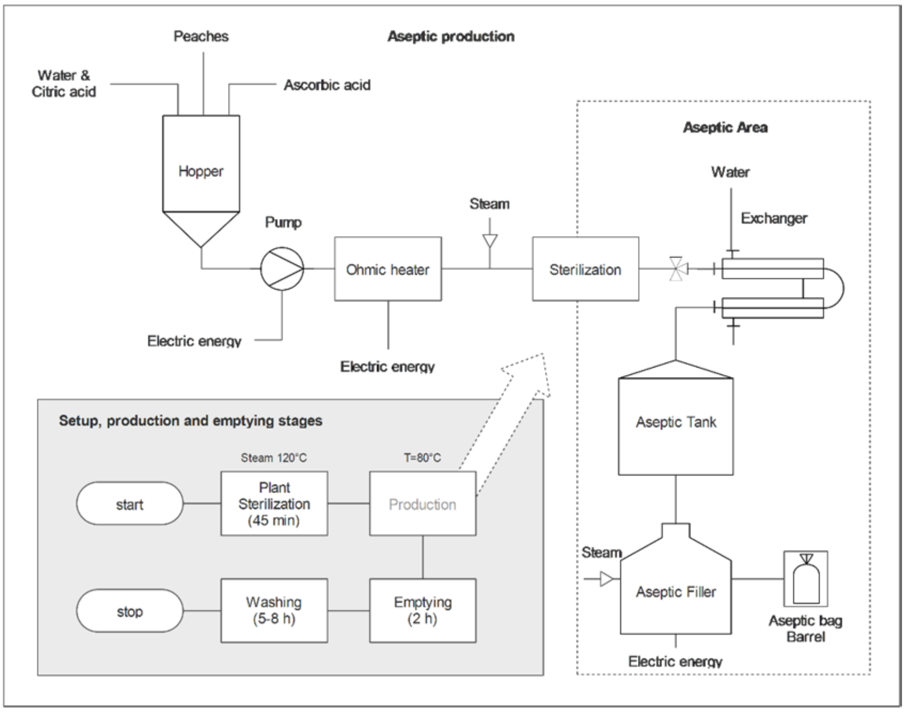

Figure 2: Flowsheet of the aseptic process.

The second treatment for fruit semi-finished products is LPSSD-FIR. A slower process than the previous one, but which guarantees good product quality. The presence of the FIR reduces dehydration times (Nimmol et al., 2007). The system (see figure 3) consists of a boiler that produces the superheated steam necessary for the process (Temp. 80 ° C, 120 min., 26 kg / h of steam). Before processing the peaches with steam, the semi-finished products are irradiated for 5 minutes with an infrared lamp (P = 650 W, 5 min.) which raises the temperature and facilitates subsequent drying. At the same time, a fan agitates the air to make the temperature homogeneous throughout the chamber and the vacuum pump maintains the pressure at 7 kPa. The process ends after about 120 minutes when the moisture content of the semi-finished product is about 5%. At the end of the process, the peaches are packed in polyethylene bags and stored at room temperature in cardboard containers.
The LCA study was conducted using the SimaPro 8.5.2 software in accordance with the ISO 14040-14044 standard. Data regarding the emissions of energy sources and raw materials were extracted from the Ecoinvent database 3.4. While all other consumption information has been derived from direct observation

and/or through design calculations. Table 2 lists the main energy and direct material input to the product systems under the study of 1 kg packaged dried peaches.

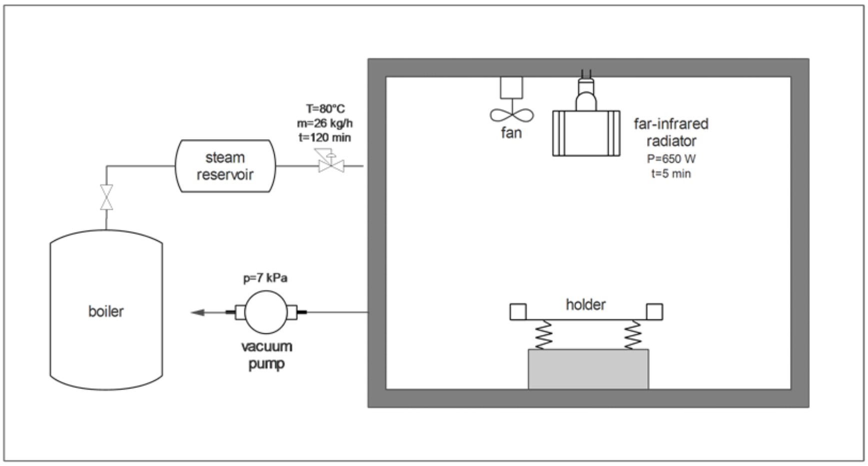

Figure 3: Flowsheet of the LPSSD-FIR process.

Table 2: Life cycle inventory of semi-finished peaches' production.

Industrial Phase	Input/Output	Unit	Ohmic aseptic	LPSSD-FIR
Treatments	Electricity	kWh	2.34E-01	6.84E-01
with sterilization	Citric acid	kg	2.00E-04	
and washing	Ascorbic acid	kg	3.77E-03	
	Soda	kg	7.02E-03	
	Water	kg	2.56E+00	2.76E+00
	Methane	m^3	1.09E-02	2.51E-01
	Output			
	Aseptic peaches	kg	1.00E+00	1.00E+00
	Waste	kg	4.04E-02	
	Water	kg		3.16E+00
Packaging	Polyethylene sack	kg		5.01E-03
	Packaging film	kg		4.01E-02
	Cardboard	kg		8.42E-03
	Pallet	kg	1.34E-01	3.48E-02
	Metallic barrel	kg	3.42E-02	
	Aseptic sack	kg	3.21E-02	
	Output			
	Packed peaches	kg	1.00E+00	1.00E+00

3. Results and discussion

The objective of the study is the comparison of the data collected through the LCI phase between the two different processes for the preservation of semi-finished peaches. The first comparison concerns the 18 midpoint categories defined by ReCiPe V.1.13: Climate change (CC), Ozone depletion (OD), Terrestrial acidification (TA), Freshwater eutrophication (FE), Human toxicity (HT), Photochemical oxidant formation (POF), Particulate matter formation (PMF), Terrestrial ecotoxicity (TET), Freshwater ecotoxicity (FET), Marine ecotoxicity (MET), Ionising radiation (IR), Agricultural land occupation (ALO), Urban land occupation (ULO), Natural land transformation (NLT), Water depletion (WD), Metal depletion (MRD), Fossil depletion (FD). Emissions in terms of normalized midpoint categories are shown in table 3. Figure 2, on the other hand, shows the same values in percentage terms to highlight the differences with respect to the maximum value of the single category. From Figure 2 it is evident that, in relative percentage terms, the aseptic process has the greatest impact on fossil fuel consumption (FD) and climate change (CC), while the LPSSD-FIR has the greatest impact on terrestrial toxicity (TET) and radiation (IR). The water depletion category, on the other hand, is zero for both processes. If the water is consumed, but also released very close to the point of consumption, one may argue the water is not lost, and in that case the water use does not result in any shortages (Goedkoop et al., 2009).

In terms of endpoint categories, figure 3 shows the cumulated normalized values for the two processes. The aseptic ohmic process is definitely the most impactful due to the auxiliary chemical materials used, the metal barrel and the aseptic bag that make the impact on resource use, on the ecosystem and on human health much more significant than the LPSSD-FIR.

Table 3: ReCiPe Midpoint (H) V1.13 results for semi-finished peaches' prod. Data are referred to the FU.

Midpoint category	Unit	Ohmic aseptic	LPSSD-FIR
CC	kg CO_2 eq	3,26E-04	6,38E-05
OD	kg CFC-11 eq	4,69E-06	2,33E-06
TA	kg SO_2 eq	2,41E-04	2,68E-04
FE	kg P eq	7,98E-04	1,05E-03
ME	kg N eq	6,94E-05	6,51E-05
HT	kg 14DCB eq	5,22E-04	4,03E-04
POF	kg NMVOC	1,34E-04	2,81E-05
PMF	kg PM_{10} eq	2,35E-04	1,27E-04
TET	kg 14DCB eq	3,79E-05	9,25E-05
FET	kg 14DCB eq	1,38E-03	2,35E-03
MET	kg 14DCB eq	1,62E-03	2,62E-03
IR	kBq U^{235} eq	6,96E-06	1,67E-05
ALO	m^2y	1,36E-05	2,44E-05
ULO	m^2y	2,76E-05	1,62E-05
NLT	m^2	5,84E-04	7,52E-04
WD	m^3	0,00E+00	0,00E+00
MRD	kg Fe eq	9,50E-05	4,05E-05
FD	kg oil eq	7,26E-04	9,52E-05

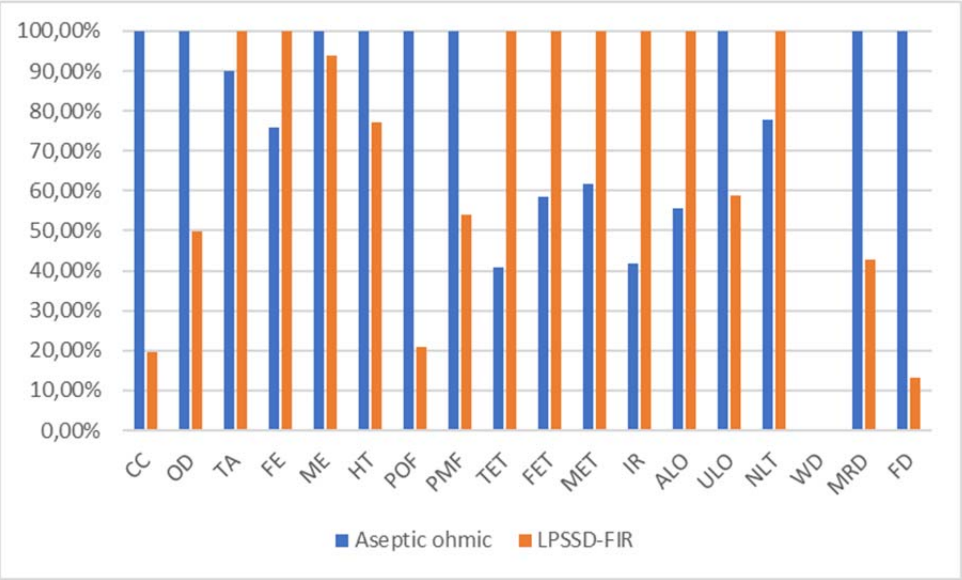

Figure 2: Relative contributions of semi-finished peaches production per FU.

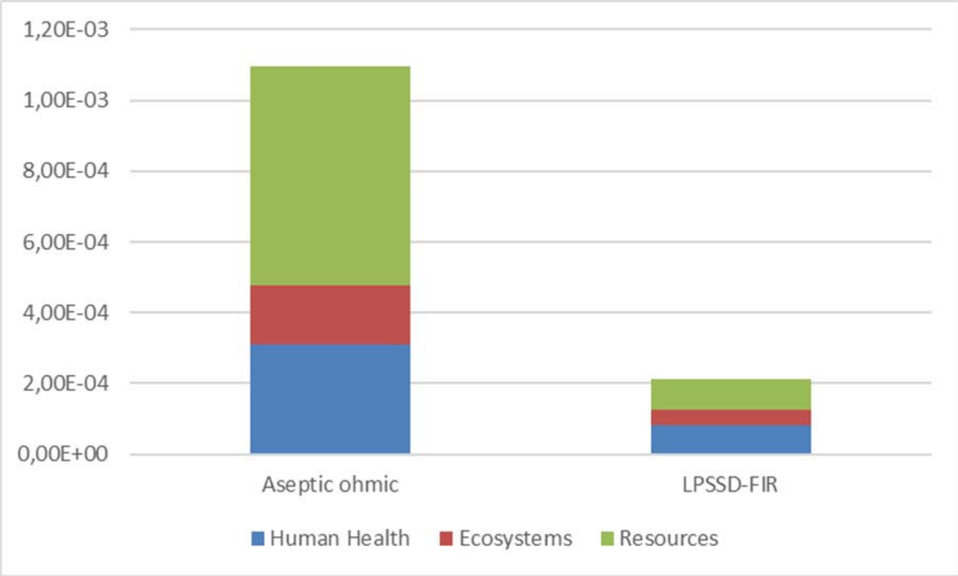

Figure 3: Total environmental impact according to the ReCiPe V1.13 endpoint method (normalized).

4. Conclusions

This study carried out a comparative analysis between the aseptic ohmic process and Superheated Low-Pressure Steam Drying with Far-Infrared Radiation (LPSSD-FIR) for the production of semi-finished peaches in terms of environmental impact according to the Europe ReCiPe H method. The study has shown that the aseptic ohmic process, considering all the pre-production and post-production operations and the use of additives and packaging materials, impacts more significantly on the environment.

Further development of the work could be a study to determine the impact of the plant scale on emissions (De Marco et al., 2017).

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