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Life Cycle Assessment of Apple Powders Produced by a Drum Drying Process

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This work aimed at evaluating the environmental performances of apple powders production based on a life cycle approach. Fruit powders are convenient, easy to handle and can be used to prepare several products such as snacks, beverages, bakery goods and baby foods. To preserve fruit nutritional properties, mainly three drying methodologies are used: convective or direct (for example, spray drying), indirect or contact (for example, drum drying), and freeze drying (lyophilisation). Among them, drum drying is often used in the case of large and continuous productions because of the simple structure of the dryers, less failure and low maintenance costs.
In this work, a Life Cycle Assessment (LCA) study was performed to evaluate the environmental impacts of the industrial phases of apple powders production, obtained by a drum drying process. The system boundaries covered the industrial stages of the process, the distribution and the waste disposal (gate-to-gate and gate-to-grave approach). The materials and energy consumption and the emissions to air, soil and water were reported to the chosen functional unit (1 package of apple powder). Data were analysed using SimaPro 8.0.3 software and the Ecoinvent database, in accordance with the reference standard for LCA (i.e., ISO 14040-14044) to identify environmental key performance indicators (KPIs).

1. Introduction

This work is related to the environmental impacts of the industrial phases of apple powders production, obtained by a drum drying process. Fruit powders are ideal ingredients in sauces, baby foods, extruded cereal products, fruit puree (Pszczola, 2003), because they are convenient and easy to handle (Jakubczyk et al., 2010). The most used drying methods may be classified in direct, indirect and freeze-drying. In the convective or *direct drying*, hot air is used to dry the fruit. Air heating increases the driving force for heat transfer and accelerates drying. The spray drying is an example of this kind of drying. In the contact or *indirect drying* (drum drying, for example), the heat is transferred through a hot wall; in this case, the wall temperature and the contact times have to be properly fixed in order to avoid the product degradation. In the lyophilisation or *freeze-drying*, the water contained in the fruit is frozen prior to drying and is then sublimed below water melting point. Each drying technique presents advantages and disadvantages. Drum drying, for example, is used in the case of large and continuous productions, because of the simple structure of the dryers, less failure and low maintenance costs. The main stages that have to be considered in the apple powders' production are the agricultural phase (related to apples cultivation), the industrial stages (from fruit's storage to drying), packaging, distribution and waste disposal. Life cycle assessment (LCA) has been largely used in many industrial sectors, such as, bioplastics (Petchprayul et al., 2012) or biodiesel (Wibul et al., 2012). The food industry, being a large user of energy, contributes significantly to total carbon dioxide emissions (Roy et al., 2009); therefore, in the last years, several papers aimed at evaluating the environmental impacts in some food branches were published. For example, LCA has been used to evaluate the environmental impact related to the production of wine (Iannone et al., 2014), tomato products (Karakaya and Özilgen, 2011) or fruit products (Cerutti et al., 2014). LCA is an internationally recognized and ISO standardized accounting tool to quantify the environmental impacts of a product, a process or a service throughout its life cycle, by identifying,

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quantifying and evaluating all the resources consumed and all the emissions and wastes released in an analysis known as a "from cradle to grave". In the last years, only few LCA analyses on fruit cultivation stage or on the whole production of derivatives, like fruit juice, were performed. Among the different fruits, the most studied one from the environmental profile have been oranges (citruses in general) and apples. Coltro et al. (2009) performed a LCA study on orange cultivation, following a “cradle to gate” approach. A LCA study on citrus-based products, like juices and essential oil, was performed by Beccali et al. (2009) according to a “cradle to market” approach; subsequently, the same authors deepened the last study with a sensitivity analysis and improvement scenarios (Beccali et al., 2010). Apples cultivation was, in more than one paper, studied making an environmental analysis. For example, Milà i Canals et al. (2006) applied LCA to three commercial apple orchards in New Zealand and identified environmental improvement opportunities in horticultural systems, considering that growers’ technique exerts considerable impact on the LCA results. Cerutti et al. (2013), using a cradle-to-gate approach, investigated the production of three apple cultivars, considering three different functional units: the production of 1 t of fruit, the growth of 1 ha of orchard, and the earning of €1000 income by the grower. The analysis of the state of the art underlines that a limited attention has been paid to the production of apple-based derivatives, such as juices or powders. Therefore, the aim of this study is to present the results of a LCA analysis of apple powders production, considering all the industrial stages.

2. LCA methodology

2.1 Goal and scope definition

Goal definition is a very important step in an LCA study, because the choices made at this stage influence the entire study. The aim of this study is to analyse through a life cycle approach the environmental impacts related to the production of apple powders produced in Italy and exported in the whole country. Figure 1 represents a scheme of the industrial powders production chain.

2.2 Functional unit

The definition of the functional unit (FU) is based, according to the ISO 14040:2006, as the quantified performance of a product that is used as a reference unit; it is the quantity or mass of the product under analysis, and it is a reference to which all the inputs and outputs have to be related. The functional unit chosen for this study is one 3 kg-weight apple powder package.

2.3 System boundaries

The system boundaries of the analysis were set from apple transportation to the company to apple powders distribution and waste disposal. All the activities, the processes and the materials used in the industrial apple powders stages were taken into account. The proposal study refers to a "from gate to gate” and “from gate to grave" process, regarding, in particular, the preliminary stages, drying, packaging, distribution and waste disposal. In Table 1, the main activities of the observed process are reported.

2.4 Life cycle inventory (LCI)

The life cycle inventory (LCI) is one of the most effort-consuming step and consists on the activities related to the search, the collection, and interpretation of the data necessary for the environmental assessment of the observed system. The Ecoinvent database was employed as the principal source of background data and the LCA study was conducted using the LCA software SimaPro 8.0.3 in accordance with the reference standard for LCA (i.e., ISO 14040-14044).

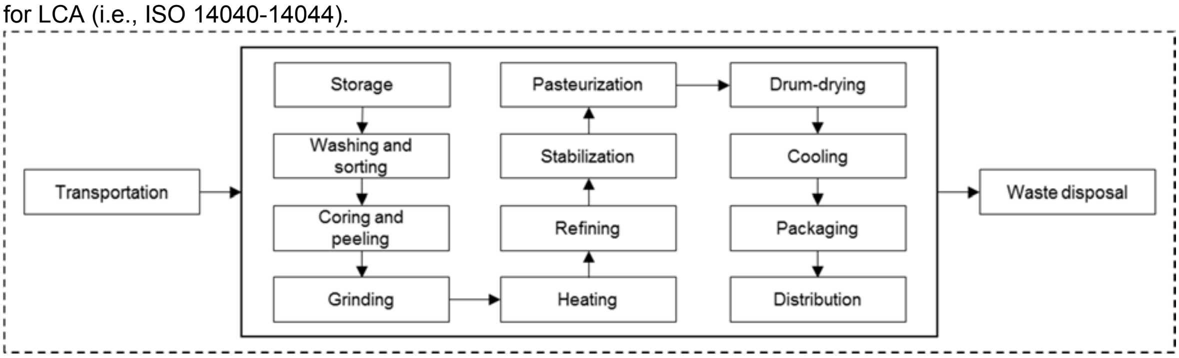

Figure 1: Scheme of the industrial apple powders production chain.

Table 1: Process details and assumptions

Process	Characteristics and details
Apples supply to facility	Transport by truck, 40 t from Val d'Aosta, Piemonte, Veneto and Trentino
Energy supply to facility	Italian energy mix low voltage
Storage	T = 4 °C; t = 24 h; Energy supply for cooling process
Washing and sorting	Energy and water supply
Coring and peeling	Energy supply
Grinding	Energy supply, ascorbic acid addition
Heating	T = 90 °C; Energy and water supply
Refining	Energy supply
Stabilization	Citric acid addition
Pasteurization	T = 103 °C; Energy and water supply
Drum drying	T = 140 °C; t = 15 s; Energy and water supply
Cooling	T = 20 °C; Energy supply for cooling
Packaging	Energy supply, supporting materials and components supply
Waste disposal	Energy supply, natural resources use for recycling and composting

However, the majority of the processes and materials information required for the analysis are specific of the observed system and the collection of these data was performed using questionnaires, phone and personal interviews for each industrial phase of the apple powders chain production. For the waste disposal, we assumed that all the organic wastes were composted, whereas the polyethylene packaging was recycled. For each unit process within the system boundary, input data, such as energy, water, natural sources and output data in terms of emission to air, water and soil were collected. Table 2 lists the main energy and direct material input to the product systems under study of a 3 kg apple powder package. Based on the emissions estimated in the LCI analysis, the environmental impacts were calculated using the Impact 2002+ method.

3. Results and discussion

The purpose of this study consists in the interpretation of the data collected through the LCI phase, and in the evaluation of the impact related to the production of apple powders using a drum drying process on four damage categories: human health, ecosystem quality, climate change and resources. According to the life cycle impact assessment methodology IMPACT 2002+, several midpoint categories are used to link all types of LCI results to those damage categories. In particular, the *human health* is affected by carcinogens, non-carcinogens, respiratory inorganics, respiratory organics, ionizing radiations and ozone layer depletion; the *ecosystem quality* is affected by aquatic ecotoxicity, terrestrial ecotoxicity, aquatic acidification, aquatic eutrophication, terrestrial acidification/nitrification and land occupation; the *climate change* is quantified using the global warming potential; the *resources* are affected by non-renewable energy consumption and mineral extraction. In Figure 2, the relative contributions of the main phases during apple powder production on each impact category are reported. The industrial phases and the transportation are the stages that mainly contribute to the different emissions (raw materials have a considerable impact only for the aquatic eutrophication); considering that the emissions related to the transportation are strictly linked with the apples' source and with the distribution range, and therefore cannot be lowered, an in-depth analysis of the contributions of each industrial phase on some of the impact categories was made.

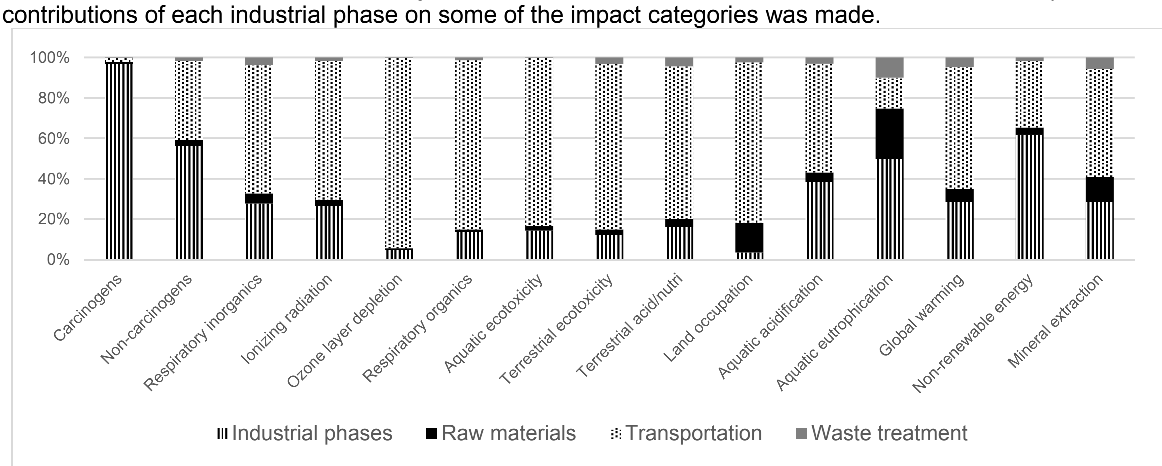

Figure 2: Relative contributions of the main stages in the apple powders production on different midpoint categories.

Table 2: Life cycle inventory of the main inputs for the apple powder production.

Industrial Phase	Input	Unit	
Transportation	Transport by truck	tkm	1.80E+01
Storage	Apples	kg	2.11E+01
	Transport by fork lift	tkm	2.11E-03
	Electricity for cooling	MJ	9.08E-01
Washing	Apples	kg	2.11E+01
	Water	kg	1.33E+00
	Transport by fork lift	tkm	2.11E-04
	Electricity	MJ	5.00E-02
	Output		
	Wastewater	kg	1.33E+00
Sorting	Apples	kg	2.07E+01
	Transport by conveyor belt	tkm	6.20E-04
	Electricity	MJ	3.42E-02
	Output		
	Discarded apples	kg	1.03E+00
Coring and peeling	Apples	kg	1.96E+01
	Electricity	MJ	2.28E-01
	Output		
	Cores and peels	kg	2.16E+00
Grinding	Apples	kg	1.75E+01
	Ascorbic acid	kg	2.38E-02
	Electricity	MJ	6.92E-02
Heating	Apple flesh	kg	1.75E+01
	Water	kg	1.21E-01
	Fuel for heating	kg	1.46E-01
	Output		
	Soot	kg	2.70E+00
Refining	Apple flesh	kg	1.75E+01
	Electricity	MJ	6.93E-02
	Output		
	Wet wastes	kg	8.75E-01
Stabilization	Apple flesh	kg	1.66E+01
	Citric acid	kg	5.82E-03
Pasteurization	Apple flesh	kg	1.66E+01
	Water	kg	1.32E-01
	Fuel for heating	kg	7.97E-02
	Output		
	Soot	kg	1.47E+00
Drum drying	Apple flesh	kg	1.66E+01
	Fuel for drying	kg	1.18E+00
	Output		
	Soot	kg	2.18E+01
	Water	kg	1.36E+01
Cooling	Apple powder	kg	3.00E+00
	Electricity for cooling	MJ	3.48E-01
Packaging	Apple powder	kg	3.00E+00
	Electricity	MJ	1.28E-02
	Polyethylene packaging	kg	3.00E-02
	Output		
	Packed apple powder	p	1
Distribution	Transport by lorry	tkm	1.06E+00
	Transport by barge tanker	tkm	1.25E+00
Waste management	Polyethylene packaging	kg	3.00E-02

Indeed, the impact of each industrial phase on human health was evaluated in terms of carcinogens (C) and non-carcinogens (NC) (both expressed in kg of chloroethylene eq. into air); the one on ecosystem quality in terms of aquatic acidification (AA, expressed in kg of sulphur dioxide eq. into air) and aquatic eutrophication (AE, expressed in kg of phosphate ion eq. into water); the one on climate change in terms of global warming potential (GWP, expressed in kg of carbon dioxide eq. into air) and the one on resources in terms of non-renewable energy (NRE, expressed in MJ crude oil eq.). The contribution of each industrial phase to the emissions for the different midpoint categories are shown in Figure 3, whereas the single values are reported in Table 3. Among the industrial phases, the drum drying is the one that mainly affects all the studied impact categories. Its high values are due to the high quantity of water that has to be removed because, during that operation, the water content shifts from a value of 82.5 % in the apple flesh to a residual value of 3 % in the apple powder. For example, considering the effect on human health, the contribution of the drum drying is equal to 81.7 % of the total carcinogens emissions (Figure 3a) and to 76.4 % of the total non-carcinogens emissions (Figure 3b). In the case aquatic acidification (Figure 3c), the contribute of drum drying is equal to 67.6 %, whereas, for the aquatic eutrophication (Figure 3d), also the storage at 4 °C has a considerable effect (the contribute of drum drying is equal to 37.7 %, the one of storage at 38.6 %). Also the global warming potential is equally influenced by the two stages (38.2 % for the drum drying and 40.8 % for the storage), whereas, for the non-renewable energy, the drum drying mainly contributes to the impacts with a percentage of 72.7 %.

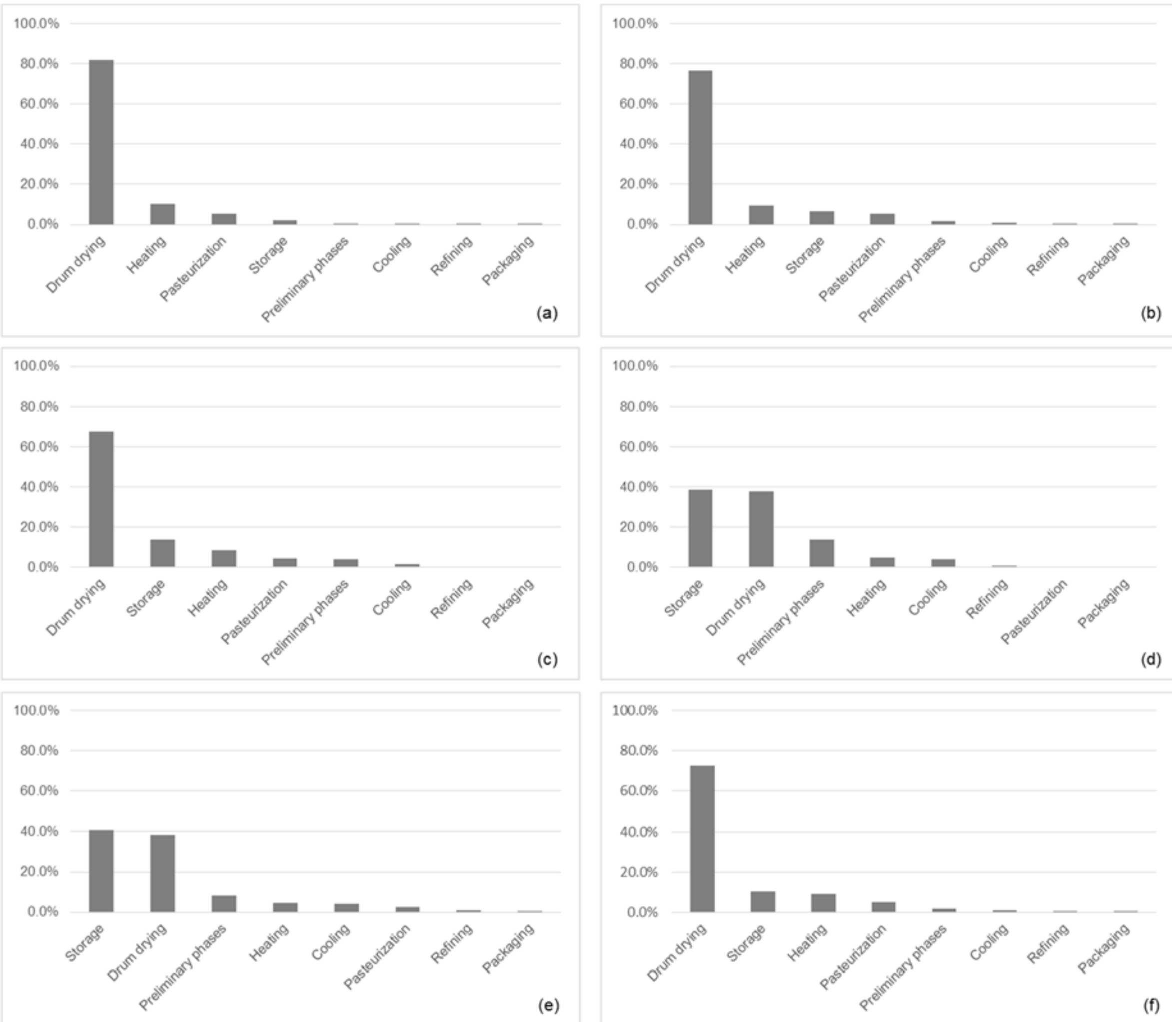

Figure 3: Emissions of the industrial stages during the apple powders production; (a) carcinogens, kg C_2H_3Cl eq/FU; (b) non-carcinogens, kg C_2H_3Cl eq/FU; (c) aquatic acidification kg SO_2 eq/FU; (d) aquatic eutrophication, kg PO_4^{3-} eq/FU; (e) global warming potential, kg CO_2 eq/FU; (f) non-renewable energy, MJ eq/FU.

Table 3: Contributions to the environmental impacts of the industrial phases. Carcinogens (C) in kg C_2H_3Cl eq/FU; Non-carcinogens (NC) in kg C_2H_3Cl eq/FU; Aquatic acidification (AA) in kg SO_2 eq/FU; Aquatic eutrophication (AE) in kg PO_4^{3-} eq/FU; Global warming potential (GWP) in kg CO_2 eq/FU; Non-renewable energy (NRE) in MJ eq/FU.

Phase	C	NC	AA	AE	GWP	NRE
Storage	1.13E-02	3.75E-03	2.33E-03	6.17E-05	5.46E-01	9.33E+00
Washing and sorting	3.18E-04	1.14E-04	6.54E-05	1.72E-06	1.50E-02	2.53E-01
Coring and peeling	7.87E-04	2.60E-04	1.62E-04	4.29E-06	3.80E-02	6.49E-01
Grinding	2.39E-04	7.91E-05	4.93E-05	1.30E-06	1.15E-02	1.97E-01
Heating	5.71E-02	5.58E-03	1.43E-03	7.47E-06	6.34E-02	8.26E+00
Refining	2.39E-04	7.92E-05	4.94E-05	1.31E-06	1.15E-02	1.97E-01
Stabilization	8.88E-04	5.79E-04	3.77E-04	1.47E-05	4.68E-02	5.68E-01
Pasteurization	3.11E-02	3.04E-03	7.79E-04	4.16E-07	3.46E-02	4.50E+00
Drum drying	4.61E-01	4.50E-02	1.15E-02	6.02E-05	5.10E-01	6.66E+01
Cooling	1.20E-03	3.97E-04	2.48E-04	6.55E-06	5.79E-02	9.90E-01
Packaging	4.42E-05	1.46E-05	9.12E-06	2.41E-07	2.13E-03	3.65E-02

4. Conclusions

In this study, a quantitative analysis based on a life cycle approach of the environmental performances of the industrial stages of apple powders production was made. Both the drum drying and the storage are the steps that have high impacts (more than 35% each one) on GWP and on AE; for the other midpoint categories, the main contribution (> 67 %) is due to drum drying. Further developments will include industrial stage modifications in order to lower the impacts related to those two steps.

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