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Pilot scale thermal and alternative pasteurization of tomato and watermelon juice: An energy comparison and life cycle assessment

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The energy balance and life cycle assessment (LCA) of conventional (thermal) and alternative (pulsed electric fields (PEF) and high pressure processing (HPP)) technologies for preservation of tomato and watermelon juice have been evaluated. A comparison between technologies was performed at an equivalent level of microbial inactivation whilst considering the same production capacity on a pilot scale using industrial scale equipment. The data included in the study, such as selected processing conditions, energy consumption, water use, cleaning agents and maintenance, were experimentally collected. For the LCA two main systems were identified: (1) the first system reviewed only the processing stage of juice production (from “gate to gate”), and (2) the second included the expansion of the boundaries to the agricultural production stage and waste treatment during juice preparation and processing (from “farm to gate”).

Comparable energy uptake was observed when the same technology for two different juices was compared. In terms of energy consumption, the highest specific energy uptake was recorded for HPP, resulting in an energy consumption of 0.20 kWh/l of juice. Slightly less energy was required by PEF processing with 0.12 kWh/l, followed by thermal with 0.04 kWh/l of juice. As to the environmental impact, expected differences were observed between the technologies based on the differences in energy consumption. Even though the differences of processing stage were assigned to the use of energy, the largest environmental impact was associated with the 250 ml PET bottles production (~85%). Considerable differences were outlined between the two juices for the “farm to gate” analysis, where tomato juice had a higher impact compared to watermelon juice. From the sensitivity analysis, different strategies for diminishing the impact were identified. They are associated with raw material production (field tomatoes), waste amount decreasing (type of watermelons selection) and relevant packaging selection (HDPE vs. PET).

1. Introduction

With substantial growth of world's human population, there is a higher demand for food which consequently results in more energy needed by the agro-food sector. In Europe, around 26% of the EU's final energy consumption in 2013 was needed to cultivate, process, pack and distribute food to final consumers. After crop cultivation, food processing is considered as the most intense phase of the food system, followed by logistics and packaging, accounting all three together for nearly half of the total energy used in the food system (Monforti-Ferrario et al., 2015). Energy consumption during industrial food processing (conversion of raw materials to end-products) encompasses several energy means such as heat (e.g. blanching, drying, preservation), electrical energy (conveyors, pumping), cooling (during processing or storage), lights and some others (Dalsgaard and Abbotts, 2003). In order to make their activities more energy efficient and sustainable, food industry is constantly looking into new solutions either through usage of

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renewable energy or utilization of energy in a more efficient way by modification of existing or introduction of new processes. In last few decades several food processing technologies for gentle preservation of food and more efficient energy utilization were investigated and discussed. Those technologies rely on other energy sources such as mechanical, electrical, electro-magnetic or others, compared to conventional, well-established ones using mostly thermal energy. Among several investigated technologies for food preservation, high pressure processing (HPP) and pulsed electric fields (PEF) have been described as the most promising ones (Knorr, 1999; Knorr et al., 1994; Pardo and Zufía, 2012; Pereira and Vicente, 2010; Rodriguez-Gonzalez et al., 2015; Toepfl et al., 2006).

So far great progress was made for better understanding the basic principles of PEF and HPP, kinetics of microbial and enzyme inactivation, as well as their impact on food quality attributes (Deeth et al., 2007; Hendrickx and Knorr, 2001; Knorr et al., 2011; Raso et al., 2006; Tewari, 2007). At the same time development of alternative food processing technologies was driven by consumers' trend for minimally processed food with improved quality attributes compared to thermal counterparts (Devlieghere et al., 2004). This was at least the case in more developed countries. Although technological innovations and changes from “conventional-to-novel” often come with economic and success risks, at the same time they could represent long-term perspective for sustainable development and competitive production. As a result of intensive research and technological achievements, as well as increased consumer awareness and needs, today, more than 250 high pressure (HP) and over 40 PEF units operate in food industry. Around 65 HP units are owned by juice producers and around 25 machines operate in toll processing (Tonello Samson, 2015; Toepfl, 2015).

Besides improving products' quality and safety, great benefit of alternative technologies is seen in the potential to generate added-value products from agricultural crops. Food waste is responsible for around 5% of total energy use in the EU food system. The vast amount of food waste (100 million tons in 2014) was generated at the manufacturing and household level (Monforti-Ferrario et al., 2015). Considering the amounts of energy involved in food production and waste disposal, reducing the food waste is of great importance for energy improvement of the whole food chain. Thus, application of alternative technologies, in particular for seasonal products (such as watermelons, tomatoes and similar) for shelf-life extension without compromising product quality would allow utilization of large, often excess amounts of products during the harvest period and conversion into high quality products with prolonged shelf-life.

To assess the environmental impacts of different processing technologies, the use of Life Cycle Assessment (LCA) seems to be the most suitable way (Guinée et al., 2011). This approach allows not only the analysis of direct environmental influences, but also the estimation of indirect impacts, which might occur along the supply chain of a product or a technology. Quite often outsourced elements of the supply chains have the highest impacts (Roy et al., 2009). LCA provides results of different impact categories assessment and integration of the impacts into single units (Goedkoop et al., 2013; Goedkoop and Spriensma, 2001; Jolliet et al., 2003). In this way, LCA allows reviewing the technological process as a complete system and as a part of more complex supply chain.

As opposite to quality evaluation and processing impact comparison of alternative technologies where numerous studies are available, the environmental impact of these technologies was not so often in the focus of the research, resulting in a lack of studies on this topic. The study performed by Pardo and Zufía (2012), assessed LCA of different technologies (autoclave pasteurization, microwaves, high hydrostatic pressure and modified atmosphere packaging) for production of a ready-to-eat meal based on fish and vegetables. Due to different product and processing conditions considered, the results of the study are difficult to compare with our current study. Nevertheless, together with few other authors, they pointed out the importance of processing stage in the whole life cycle (Andersson et al., 1998; Davis and Sonesson, 2008). The LCA study performed on cooked tuna-tomato dish reported fish harvesting and supply as the most important stage (Zufia and Arana, 2008). Calderón et al. (2010) investigated canned ready meal where production showed the highest environmental impact, together with significant contribution of gas and electricity used at industrial level. In the study of Davis et al. (2010) the environmental impact of PEF and HPP as compared to thermal pasteurization of carrot juice was addressed. It has been concluded that the energy used for pasteurization was relatively small compared to total life cycle energy use, resulting in no significant differences between technologies in general.

The objective of the present study was to perform energy balance comparison and life cycle assessment of conventional (thermal) and alternative (PEF and HPP) technologies for pilot scale preservation of tomato and watermelon juice on industrial scale units. The pilot scale production capacity was chosen based on the batch-nature of the smallest industrial high pressure unit, often used by small start-up companies as well as for toll processing of beverages. The study was based on collected experimental data (processing conditions resulting in an equivalent level of microbial inactivation and expected shelf-life of the juices; measured energy consumption of PEF and HPP), while considering the same production capacity for each technology. Results of the study could be used to identify the most impacting elements of the system and, therefore, imply where potential improvements could be made towards more sustainable food production, regardless if involving thermal or alternative technologies.

2. Materials and methods

2.1. Tomato and watermelon fruits and juice preparation

Tomatoes (*Solanum lycopersicum*, var. *Arvento*) and watermelons (*Citrullus lanatus* var. *Rayada*) were obtained from the local store in Germany. Tomatoes were grown in the Netherlands and watermelons in Spain. The juice was produced at German institute of food technologies (DIL e.V., Quakenbrueck, Germany). Tomatoes and watermelons were first washed and subsequently crushed using cutter equipped with vacuum (30L VK 5000 express, Kilia Wertstoff-Technik GmbH, Germany). In the case of watermelons, before the chopping the flesh was separated from rind. After the chopping, vacuum was applied to the freshly prepared juice for air removal injected during chopping.

2.2. Pasteurization of tomato and watermelon juice

Processing conditions for thermal and alternative pasteurization of tomato and watermelon juice, resulting in equivalent microbial inactivation were experimentally selected and are described in our previous work (Aganovic et al., 2014, 2015). An overview of the selected conditions resulting in at least 5-log inactivation of *Escherichia coli*, *Lactobacillus plantarum* and *Listeria innocua* in tomato and watermelon juice is presented in Table 1.

For the trials, pilot and industrial scale equipment was used. Thermal treatments were carried out using a continuous pilot-scale plate heat exchanger type S4A-IT10-16-TL-Liquid (Sondex, Hamburg, Germany). The heat exchanger consisted of 16 plates with a filling volume of 0.188 L per plate and maximum heat transfer rate of 12 kW. For the PEF treatment a continuous, pilot-scale unit (HVP 5 kW, DIL e.V., Quakenbrueck, Germany) was