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Assesment of the use of zero-emission vehicles and microbial fertilizers in beverage production

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ABSTRACT

Greenhouse gas emissions of food production increased from 680 to 2.2 Gt/year between 1961 and 2011. Greenhouse gases are not emitted as a consequence of the field level agriculture or farm level husbandry only, the later stages of production such as processing, packaging and transportation make additional contributions to both energy utilization and the subsequent greenhouse gas emissions. Huge energy savings reported in the literature for individual production steps of food production usually correspond to a modest percentage in the total farm-to-fork production chain. Chemical fertilizers are usually the most energy intense inputs of these chains.

Energy utilization and the subsequent CO_2 emissions are calculated based on the data adapted from the literature for the entire farm-to glass-production chain of ten beverages. The calculations are then repeated for the cases where chemical fertilizers are replaced with their microbial counterparts and the vehichles and the agricultural equipment are replaced with their zero-emission counterparts. These replacements are estimated to reduce energy utilization from 18,393 to 3508 MJ/t and the emission from 493 to 43 kg CO_2/t in powdered coffee drink production. If the same replacements are implemented globally and the same average reductions, e.g., 38.1% as calculated in this study are achieved, 0.84 Gt/year of greenhouse gas emission may be prevented globally.

1. Introduction

In food production, GHG (greenhouse gas) emissions increased from 680 to 2.2 Gt/year between 1961 and 2011 (Porter et al., 2016). Studies are being carried out now to reduce them to stop the climate change (Vermeulen et al., 2012; Thornton, 2012). In a recent study, Kendall et al. (2015) calculated the energy utilization during almond production in California as 35 MJ/kg almonds, which resulted in 1.6 kg of CO_2 equivalent GHG emission, where nitrogen fertilizers and irrigation were the major causes of energy utilization. Using economic allocation methods reduced the energy utilization to 33 MJ/kg almonds and the associated GHG emission to 1.5 kg of CO_2 equivalent (Kendall et al., 2015). After reviewing 369 studies on 168 different types of foods, Clune et al. (2017) listed 1718 global warming potential values and concluded that production of grains, fruit and vegetables had the lowest, production of meat from the ruminants had the highest impact on the environment. In the food industry, GHG emissions are not the consequence of the field level agriculture or farm level husbandry only. The later stages of production, such as processing, packaging and transportation make additional contributions to both energy utilization and the subsequent GHG emissions (Carlsson- Kanyama and Faist, 2000; Foster et al., 2006; CIAA, 2007; Masanet et al., 2008).

Interest towards energy accounting and savings started in the food industry with economic reasons after quadrupling of the world oil prices between October 1973 and January 1974 (Park, 1992). Rigorous research started (Steinhart and Steinhart, 1974) and carried out (Singh et al., 1980) since that time. By the early 2000s, energy utilization in the chemical fertilizer factories approached to the theoretical minimum (Kongshaug, 1998; Anundskas, 2000). In the following period, energy efficiency improved by about 1% every year in the Dutch food industry (Ramirez et al., 2006). British brewing industry was among the most successful sectors, where energy utilization decreased by 54% (CIAA, 2007). The next generation of the studies focused on the comparison of energy utilization and carbon dioxide emissions during production of the competing products (Karakaya and Özilgen, 2011), detecting the inefficient steps of a given process (Özilgen and Sorgüven, 2011; Sorgüven and Özilgen, 2012; Genç

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and Hepbasli, 2015) and replacing them with more energy efficient ones (Rodriguez-Gonzales et al., 2015).

Chemical fertilizers are among the most energy intense agricultural inputs. In the U.S, in the early 2000s, approximately 3% of the total natural gas production was allocated to ammonia production. Almost 90% ammonia was used by the fertilizer industry and about 1090 to 1250 m^3 of natural gas was used to produce 1 t of anhydrous ammonia. Between 70 and 80% of the energy used in fertilizer production was provided by natural gas (Gellings and Parmenter, 2004). Du Pont process of ammonia production was used to be carried out at 500 °C and 900 atm in the presence of promoted iron catalyst to obtain 40–85% of conversion (Shreve and Brink, 1977). FAO (2011) forecasts global increase in the demand for almost every major chemical fertilizer. Energy equivalencies of the chemical fertilizers and the agrochemicals are 60.6 MJ/kg for the nitrogenous fertilizer, 199 MJ/kg for the phosphorus fertilizer, 99 MJ/kg for the potassium fertilizer (Ören and Özturk, 2006). In the developing countries chemical fertilizer use is generally not based on soil analysis and much more than what is actually needed is used in the fields (Esengun et al., 2007). Fertilizer management practices may reduce energy utilization up to 72%; consequently, herbicide utilization and pollution also decrease (Clements et al., 1995; Hülsbergen et al., 2001; Snyder et al., 2009; Ren et al., 2010). Use of nitrogen fertilizers in the agricultural soils initiate 50% of the total global anthropogenic N_2O emissions (Shcherbak et al., 2014), therefore a successful fertilizer management program may also decrease such emissions.

Chemical fertilizers induce fertilization via supplying nutrients to the plants. Whereas, the microbial fertilizers induce fertilization either via converting nitrogen of the air in a chemical form which may be utilized by the plants or by dissolving the rocks or other minerals of the soil and make them available to the plants (Li and Zhang, 2001). The mineral solubilizing effect of the microbial fertilizers was reported by Toro et al. (1997), Rodriguez and Fraga (1999), Sundra et al. (2002) and Wu et al. (2005) and (Orhan et al., 2006). A mechanism for improved nitrogen fixation is the farmland via signal exchange between the legumes and the Rhizobium species was suggested by Broughton et al. (2003). The beneficial effects of the microbial fertilizers have been reported for numerous agricultural crops including barley and sugar beet (Cakmakci et al., 1999; Canbolat et al., 2006), rice (Pati, 1992; Das and Saha, 2003), wheat (Khalid et al., 2004) and maize (Wu et al., 2005). There are similar studies carried out with fruits, including apricots (Esitken et al., 2003), apples (Aslantas et al., 2007), sweet cherries (Esitken et al., 2006), oranges (Abd el Migeed et al., 2007; Mohamed et al., 2013), raspberries (Orhan et al., 2006) and strawberries (Ipek et al., 2014). The other commodities, where the beneficial effects of the microbial fertilizers are demonstrated, include agriculture of peas (Engqvist et al., 2006), tomatoes (Woitke et al., 2004), canola (Bertrand et al., 2001), radishes (Yildirim et al., 2008) and coffee (De Beenhouwer et al., 2015). The beneficial effects of the microbial fertilizers may vary significantly depending on the environmental conditions, bacterial strains, plant and soil conditions (Uyanöz, 2007). Under the most beneficial conditions, they may eliminate the need for the chemical fertilizers totally (Pati, 1992; Li and Zhang, 2001; Khan, 2005; Wu et al., 2005; Aslantas et al., 2007; Canbolat et al., 2006; Cakmakci et al., 2014). Although reduction of energy utilization and carbon dioxide emission is the major goal of this study, another benefit of replacing the chemical fertilizers with the microbial fertilizers is the reduction of the N_2O emissions, since the chemical fertilizers from the agricultural soils and are responsible for about 50% of the total global anthropogenic N_2O flux (Shcherbak et al., 2014).

Current technological advances offer possibilities to make food production more environment-friendly. The recent review by Rodriguez-Gonzales et al. (2015) offers serious recommendations regarding substitution of the less energy efficient process steps with more energy efficient ones, and may be regarded as one of the major publications pointing the direction to the food industry towards increasing the energy efficiency, and decreasing the environmental pollution. Substitution of the fossil fuels with the renewable resources would definitely be helpful to reduce the environmental impact of these processes. Yildirim and Genç (2015) recently reported the use of geothermal energy in pasteurization of milk, Ochoa et al. (2014) reported substantial savings with the use of solar and wind energy for the irrigation of the farms. In the present study, energy utilization and carbon dioxide emission in *"farm to glass"* production chain of the beverages will be calculated first with the conventional technology, and then calculations will be repeated to see the potential improvement if the chemical fertilizers can be replaced with the microbial fertilizers and zero emission vehichles can be used in transportation and agriculture. Although there are studies in the literature assessing the effect of these factors in the individual stages of production, the entire chain of "*farm to glass*" production process will be assessed for the first time.

2. Materials and methods

Energy utilization data for agriculture and processing of orange juice, lemon drink, beer and wine, brandy and whiskey, milk, powdered and instant coffee and hot chocolate, as described in Figs. 1–6, were collected from the literature or from the

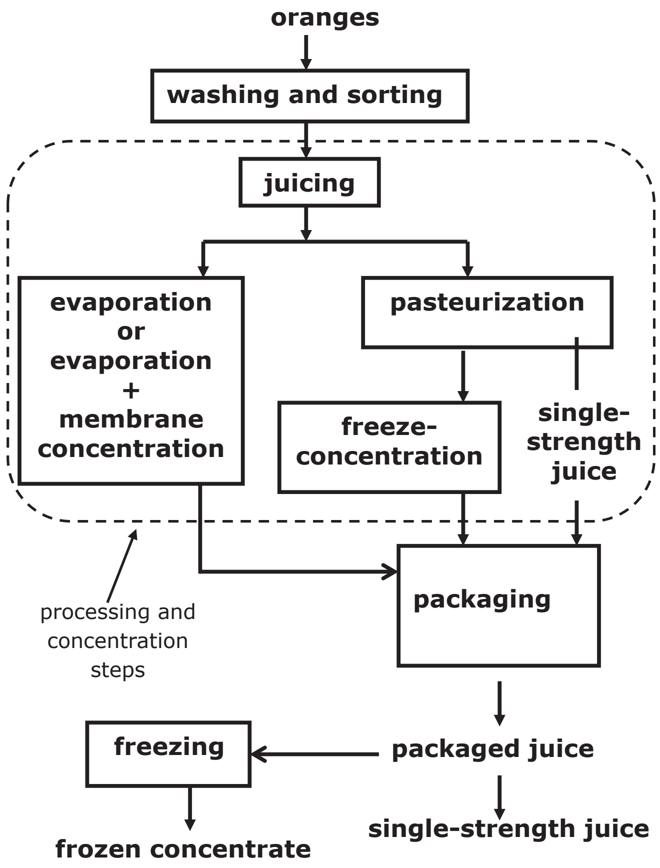

Fig. 1. Flow diagram of the orange juice or concentrated orange juice production processes.