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Assessment of the energy utilization and carbon dioxide emission reduction potential of the microbial fertilizers. A case study on "*farm-to-fork*" production chain of Turkish desserts and confections

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ABSTRACT

Energy utilization and carbon dioxide emission during production of some industrially produced desserts and confections are calculated. The results showed the possibility of 9%–90% reduction in the energy utilization and 4%–80% reduction in the carbon dioxide emission if the chemical fertilizers are replaced with their microbial counter parts. Reductions were more influential in the cases where only a small fraction of an agricultural product was edible and the rest was discarded. The greatest reduction in the energy utilization and carbon dioxide emission was observed with the hazelnut ice cream topping, where the shell and water content of the hazelnut were removed during processing. The second highest reduction in energy utilization, 50%, and carbon dioxide emission, 29%, was observed with the hazelnut spread. Baked semolina-dessert revealed 26% reductions in the energy utilization and 18% reduction in the carbon dioxide emission, after replacing the chemical fertilizers with their microbial counterparts.

1. Introduction

In the food industry, production-phase greenhouse gas emissions increased more than three times between 1961 and 2011, from 680 to 2.2 Gt/year (Porter et al., 2016). After reviewing 369 published studies Clune et al. (2017) provided 1718 global warming potential values for 168 varies of fresh produce. Greenhouse gas emissions is not the consequence of the farm level agriculture or field level husbandry only; the later stages of the food production, such as processing, packaging and transportation make additional contributions to the emissions. Most of these emissions are related with energy utilization. In the food industry, natural gas is generally used for heating, electric power is used for cooling and diesel is used for transportation. In rural areas, where natural gas distribution network is not available, diesel may be used to substitute it. During electric power generation from natural gas, among all the gasses emitted CO_2 accounts for 99% of all the emissions by mass (Spath and Mann, 2000). Özilgen (submitted), after assessing the contribution of each of these factors to the overall CO_2 emissions in the *farm-to-glass production chain* of nine beverages concluded that replacing the chemical fertilizers with their microbial counterparts would make the most significant effect towards reducing these emissions.

Bardi et al. (2013) refers to modern agriculture as "*technology that transforms fossil fuels into food*". Between 1970 and 2010, world-average annual energy utilization for food production increased from 10,008 to 11,850 kJ/person (Smith et al., 2014). Determining energy utilization in the *farm-to-fork production chain* and replacing their inefficient stages with more efficient ones is necessary to achieve energy savings. In a comprehensive review, Rodriguez-Gonzales et al. (2015) examined the energy requirement of alternative food-processing technologies - high-pressure processing, membrane filtration, pulsed electric field and ultraviolet radiation to determine the less energy efficient technologies and suggested their replacement with more energy efficient ones. Xu and Flapper (2011) after carrying out a study with the literature data suggested that the carbon equivalent emissions might be reduced by 9–14 million t/y, if energy consumption reducing measures should be implemented globally in the dairy plants. Wu et al. (2013) through modeling and improving the control approaches suggested implementations for energy reduction in continuous frying systems. So far energy utilization in the production chains of many products, including hamburgers (Carlsson-Kanyama and Faist, 2008), bread (Değerli et al., 2015) and meat (Opio et al., 2013) has been assessed with this purpose.

Modern agricultural practices rely heavily on fertilizer use. Chemical fertilizer production is an energy intense process as

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described by Gellings and Parmenter (2004). Between 1970 and 2010 global cereal yields improved from 1600 to 3030 kg/ha with the increase of the fertilizer use from 32 to 106 Mt/year (Smith et al., 2014). Substituting chemical fertilizers with their microbial counterparts appears like a viable option to reduce energy utilization and CO_2 emission in agriculture (Özilgen, submitted). Assessment of the energy utilization and CO_2 emission reduction potential of the microbial fertilizers in "*farm to glass*" production chain of beverages including orange juice, lemon drink, beer and wine, brandy and whiskey milk, powdered and instant coffee and hot chocolate has shown that the huge energy savings reported in the literature for the individual steps of the beverage production would actually made only a modest percentage of contribution to the savings in the final product. Although utilization of the zero emission trucks in transportation made only a modest influence, significant reductions in energy utilization and CO_2 emissions were reported to be achieved with almost every drink by replacing the chemical fertilizers with their microbial counterparts.

2. Literature review

Chemical fertilizers are plant nutrients, but the microbial fertilizers are not. They convert the readily available chemicals such as nitrogen of the air and the rocks or minerals of the soil in other forms so the plants can uptake them (Li and Zhang, 2001). There are numerous publications in the literature claiming that substitution of the chemical fertilizers with their microbial counter parts may either decrease, or eliminate totally, the need for the chemical fertilizers. Salvagiotti et al. (2008), based on six hundred and thirty-seven sets of data presented a detailed review of the subject. Commercial microbial fertilizers are available for sale in the market with similar claims. The response of the soil microorganisms to the presence of the chemical fertilizers may be confusing. Geisseler and Scow (2014) after reviewing 107 datasets from 64 long-term trials around the world, reported that the application of urea and ammonia fertilizers, may temporarily increase pH, osmotic potential and ammonia concentrations to levels inhibitory to microbial communities. The response of the specific microbial groups to repeated applications of mineral fertilizers may vary considerably and depend on environmental and crop management related factors. All the nitrogen fixing or mineral dissolving microorganisms are not equally beneficial for microbial fertilization; therefore, screening studies are needed to determine the most beneficial species (Khalid et al., 2004).

The most important step of the nitrogenous chemical fertilizer production is the ammonia synthesis via the Haber -Bosch process, e.g., an artificial nitrogen fixation process discovered more than 100 years ago. The Haber–Bosch process occurs typically at high pressure (50–200 bar) and high temperature (650–700 K), and is a high-energy-utilizing and high CO_2 emitting process. Although a lot of research has been carried and the ammonia synthesis process has been optimized substantially since it was discovered, the catalyst and its prevailing conditions in the industry are still surprisingly similar to that of the original discovery (Vojvodic et al., 2014). Smil (1999), after stating that "*without the Haber – Bosch synthesis, almost two-fifths of the world's population would not be here*" argued that its discovery was the most important invention of the 20th century.

Public perception of the chemical fertilizer has changed substantially since the time that they were discovered first. Although the mechanism of the severe effects of DDT *Dichloro-diphenyl-trichloroethane*) and the chemical fertilizers on the environment are substantially different, the time course of the public concern about them is similar in numerous ways: both of them were first introduced with great expectations, inventor of the DDT Hermann Müller (Raju, 1999) and the inventors of the ammonia synthesis Fritz Haber (1868–1934) and Carl Bosch (1874–1940) were awarded Nobel prizes. The negative impacts of DDT and the chemical fertilizers on the environment were observed later, first their uses are restricted, and then the use of DDT is banned. In the developed countries, crop yields have reached almost to their biological maximum and increasing the fertilization rate is not expected to change the crop yield, but this is not the case in the developing countries, where the over-use of the chemical fertilizers is causing an environmental disaster and fertilizer management programs are started in many countries to limit their use (Good and Beatty, 2011). Substitution of the chemical fertilizers with their microbial counterparts is one of the ways of limiting their use. Although it is very well known that chemical fertilizer production is an energy intense process (Gellings and Parmenter, 2004) and the employment of the microbial fertilizers in agriculture may either reduce or totally eliminate their use, there is no publication available yet to quantify the probable energy utilization and carbon dioxide emission reductions, which may be achieved after replacing the chemical fertilizers with their microbial counterparts in farm-to-fork food production. The present study aims to fill this gap by focusing on the case of the production chains of Turkish desserts and confections.

3. Methodology

Details of the methodology of dessert and confection making processes, including natural gas (N), electric power (E) and diesel (D) utilization in every step of production is described in the Appendix. Carbon dioxide emission caused by the respiration of the plants or its up take during photosynthesis is not accounted in this study. Only the CO_2 emissions occurring because of the energy utilization in the industrial processes are considered. Carbon dioxide emission during production of each dessert and confection was calculated after multiplying the energy utilization values with the emission coefficient of each energy source and adding up these numbers. Carbon dioxide emission factors were 5.83 g/MJ (EPA, 1997) with natural gas, 140 g/MJ (PAS, 2008) with electricity and 16 g/MJ with diesel, based on energy yield of 57.5 MJ/kg diesel and emission of 0.94 g CO_2/kg diesel as reported by Lal (2004). Calculations were carried out twice: the first round of calculations was carried out for the cases where chemical fertilizers were used in agriculture. The second round were carried out for the cases where only the microbial fertilizers were used.

3.1. Energy equivalents of the chemical fertilizers and agrochemicals

Fertilizers, water for irrigation, agrochemicals and seeds, natural gas, electricity and diesel are the inputs of the agricultural processes. In the present study, half of the pumps employed for irrigation were assumed to be running with electric power, the other half with diesel. Natural gas was used during the production of the seeds; chemical fertilizers were produced by using natural gas (85%) and electricity (15%); diesel used in the farmland was not allocated to transportation. Energy needed to produce the chemical fertilizers is 60.6 MJ/kg nitrogen fertilizer, 199 MJ/kg P_2O_5, 99 MJ/kg K_2O (Ören and Özturk, 2006) and 10 MJ/kg CaO (Canadian Lime Institute, 2001). Energy content of manure is 0.30 MJ/t (Sorgüven and Özilgen, 2012). The word "*agrochemicals*" refers to the pesticides, insecticides, herbicides and fungicides. The nut weevil *Curculio nucum* may cause high yield losses in hazelnut crop, if not regularly controlled by using pesticides (Guidone et al., 2007). In Turkey, most of the hazelnuts are grown in Ordu. The Local agricultural authority in Ordu (2012) advised farmers to apply