Shelf life Extension as solution for environmental impact mitigation: A case study for bakery products

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Abstract

Over the last years, increasing attention has been paid to environmental concerns related to food production and potential solutions to this issue. Among the different strategies being considered to reduce the impact food production has on the environment, only moderate has been paid to the extension of shelf life; a longer shelf life can reduce food losses as well as the economic and environmental impacts of the distribution logistics.

The aim of this study is to assess the environmental performance of whole-wheat breadsticks with extended shelf lives and to evaluate whether the shelf-life extension is an effective mitigation solution from an environmental point of view. To this purpose, the life cycle assessment (LCA) approach was applied from a "cradle-to-grave" perspective. Rosmarinic acid was used as an antioxidant to extend the shelf life.

To test the robustness of the results and to investigate the influence of the choices made in the modelling phase, a sensitivity and uncertainty analysis were carried out.

The achieved results highlighted how, for 10 of the 12 evaluated impact categories, the shelf-life extension is a proper mitigation solution, and its effectiveness depends on the magnitude of product loss reduction that is achieved. The shelf-life extension doesn’t allow for the reduction of environmental impact in the categories of human toxicity, cancer effects and freshwater eutrophication.

Keywords

Life Cycle Assessment, Breadstick, food loss, impact mitigation, shelf life extension

1 Introduction

Food production and consumption are responsible for remarkable negative effects on the environment (Holt et al., 2016). Previous studies estimated that the agri-food system impacts the environment considerably, accounting for almost 70% of freshwater and 20% of energy use, and contributing dramatically to greenhouse gas emissions and land use (Aiking, 2011; Perignon et al., 2017, Lamastra et al., 2017). Over the years, consumer awareness about this issue has grown, and the demand for "environmentally friendly" food has increased (Galli et al., 2017). Several studies show that consumers are quite aware of environmental sustainability and its relation to their food choices. More in detail, Flash Eurobarometer 367 (European Commission, 2013) reports that 84% of EU27 citizens declare that the environmental impact of a product is for them ‘very’ (38%) or ‘fairly important’ (46%) when choosing which products to buy. Indeed, 26% of the respondents declared that they ‘often’ buy environmentally friendly products, while 54% declared to do so ‘sometimes’. Moreover, 89% of the Eurobarometer respondents declared to ‘strongly’ (50%) or ‘tend to agree’ (39%) that ‘buying environmentally friendly products can make a real difference to the environment’. Moreover, many respondents believed that the following personal actions related to food have ‘the greatest impact on solving environmental problems in their countries’: recycling and minimising waste (54% of respondents); buying local agricultural products (35%); making efforts to use less water (31%); buying products by eco-friendly producers (23%) (European Commission 2013).

Over the last years, guidelines and studies for the reduction of negative environmental consequences due to food production were developed (De Luca et al., 2017, Corrado et al., 2017). Further detailed attention has been paid to this environmental concern and its solutions (e.g., by reducing the energy consumed during food processing, by valorising the by-products and wastes) (Kummu et al., 2012; Beretta et al., 2013; Mo et al., 2018). A recent EU Project (Stenmarck et al., 2016) stated that 89 million tonnes of food is wasted per year, and the projection of food waste for 2020 could lead to a 40% increase. What is definitely clear is that food losses occur throughout the entire food system, from households (42%), manufacturers (39%), retail (5%), and catering (14%) (Kosseva and Webb, 2013).

According to Gustavsson et al. (2011), about 45% of fruit and vegetable products, 30% of cereal products, 20% of dairy products, 20% of oilseed and legume are lost each year. In September 2015, the EU and Member States committed to meeting the Sustainable Development Goals (SDG) (EU, 2016), including a target to halve per capita food waste at the retail and consumer levels by 2030 and reduce food losses along the food production and supply chains. The reduction of food losses will involve considerable environmental benefits. In this regard, among the different strategies that can be implemented, (e.g., improvement of storage techniques, optimization of the distribution logistic, etc.), only little attention has been paid to the extension of shelf life. The shelf life is the period of time that corresponds, in proper storage conditions, to a tolerable decrease in the quality of a packaged food (UNI 10534, 1995). The shelf life of a product does not necessarily relate to its real life, which ends with the loss of the hygienic and/or nutritional properties, but generally corresponds to the end of its marketability in terms of an unacceptable worsening of its particular physical and sensory features (Piergiovanni and Limbo, 2010). Falcone et al. (2017) evaluated the environmental and economic benefits of the shelf-life extension of mozzarella cheese, considering different governing liquids (namely the saline and slightly acidic solution in which mozzarella is stored). Gutierrez et al. (2017) evaluated the environmental benefits related to shelf-life extension for cheesecake. Considering different packaging, Calligaris et al. (2007) developed a shelf-life prediction model of lipid-containing biscuits, while Bavin et al. (2006) studied an edible coating to extend the shelf life of dry bakery products.

From the consumer's perspective, the positive impact of shelf-life extended products relies on improved convenience attributes, such as less time spent shopping and cooking. Moreover, the longer shelf-life period should increase the consumer's ability to manage food provision, storage, and preparation and, consequently, minimize domestic food waste (Amani and Gadde, 2015; Falcone et al., 2017; Spada et al., 2017).

In fact, a longer shelf life can reduce food losses as well as the economic and environmental impacts of the distribution logistics. As pointed out by Alamprese et al. (2017), shelf life extension can be achieved by acting at different levels: on formulation, processing conditions, packaging and storage conditions both during distribution, sale and household use.

For bakery products, the main causes of quality decay are related to crunchiness loss and lipid oxidation. Lipid oxidation is undoubtedly the major cause of quality losses of low-moisture bakery products containing whole or partially refined wheat flours or wheat bran fractions, (e.g., whole-wheat breadsticks and crackers). Due to the high content of unsaturated fatty acids and lipolytic enzymes, wheat bran is subject to oxidation phenomena, which is consequently one of the primary causes of shelf-life reduction (Alampresse et al., 2017). To limit oxidative reactions, the addition of antioxidant compounds to the formulation of a product has proven to be an effective solution (Peng et al., 2010; Jensen et al., 2011; Smith et al., 2014; Alampresse et al., 2017).

The aim of this study was to assess the environmental performance of a whole-wheat[1] breadstick with extended shelf life and to evaluate whether the shelf-life extension can be an effective mitigation solution from an environmental point of view. Derived from the environmental assessment, the *hotspots* of the system were identified. To this purpose, the LCA approach (ISO, 2006) was applied from a “cradle-to-grave” perspective. The shelf-life extension has been evaluated as a solution to reducing food losses, but its relationship to the environmental impact of the produced food has not been assessed.

2 Materials and methods

LCA is a holistic method of assessing the environmental impacts and resources used throughout the life of a product (process or activity), from raw material extraction, production and use, to waste disposal (ISO 14040, 2006). Over the years, LCA became the reference approach for assessing the environmental impact of agro-food productions; it has been widely considered to determine the environmental profile of numerous agricultural systems (Roy et al., 2007; Bacenetti et al., 2015b; Corrado et al., 2017; Falcone et al., 2017).

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1 According to the Whole Grains Council, whole-wheat foods are foods containing all the essential parts and naturally-occurring nutrients of the entire grain seed in their original proportions.

2.1 Goal and scope definition

The goal of this study was to evaluate the environmental performance of whole-wheat breadstick production, paying particular attention to the environmental consequences related to the addition of rosmarinic acid as an antioxidant able to extend the shelf life. This study was driven by the following questions:

1. What is the environmental impact for whole-wheat breadsticks with and without rosmarinic acid?
2. What are the main hotspots associated with the whole-wheat breadstick production system?
3. Can the shelf-life extension be an effective mitigation solution, even if it involves an increase of the environmental impact related to change in the production process?
4. Can the reduction of product losses (due to shelf-life extension) overcome the impact increase (due to the process modification)?

The outcomes of this analysis will be useful for the identification of the conditions leading to the lowest environmental impact and, accordingly, the study will be helpful to producers of bakery products, technicians and large retail sectors involved in the bakery production process and, in particular, in the logistic aspects.

2.2 Functional unit

According to ISO standards, the functional unit (FU) is defined as the main function of the system expressed in quantitative terms (ISO 14040, 2006). The functional unit is the reference to which all other data in the assessment are normalised. 1 kg of whole-wheat breadsticks was selected as functional unit in this study.

2.3 Description of the production system

The production systems of the whole-wheat breadstick with SLE involves:

1 - Wheat flour production. This section involves wheat cultivation. Wheat production involves organic fertilisation performed using a slurry spreader, soil tillage carried out by

ploughing (depth 30 cm) and harrowing (1 with rotary harrow) and, finally, sowing with a line seeder. After that, crop management is carried out, (i.e., weed control, usually carried out by the applications of herbicides). Harvesting is performed with a self-propelled combined harvester in June, and the transport of grain to the farm is carried out with two farm trailers. The produced straw is collected by round baler to be sold.

2 - Production of the rosemary extract. The practice of rosemary cultivation is performed over a 6-year cultivation cycle and foresees soil tillage (harrowing at 10 cm depth), transplanting and harvesting. Harvesting of the leaves takes place once per year. After drying (leaves are dried at low temperature by means of a diesel-fuel dryer), the rosmarinic acid is extracted with the SFE (Supercritical Fluid Extraction). SFE is the process of separating the rosmarinic acid (the extractant) from the leaves (the matrix) using supercritical fluids as the extracting solvent (Carbon dioxide is the most-used supercritical fluid) (Rodriguez-Meizoso et al. 2012; Harde et al., 2013).

3 - Breadstick production in the bakery, where all the different ingredients (wheat flour, wheat bran, salt, olive oil, water, rosmarinic acid, yeast) are mixed, the dough is cooked and the product packed.

4 - Use and “end-of-life” of the breadstick. This last section of the production system takes into account the losses of product as well as the management of waste produced (discharged products and packaging).

2.4 System boundary and allocation

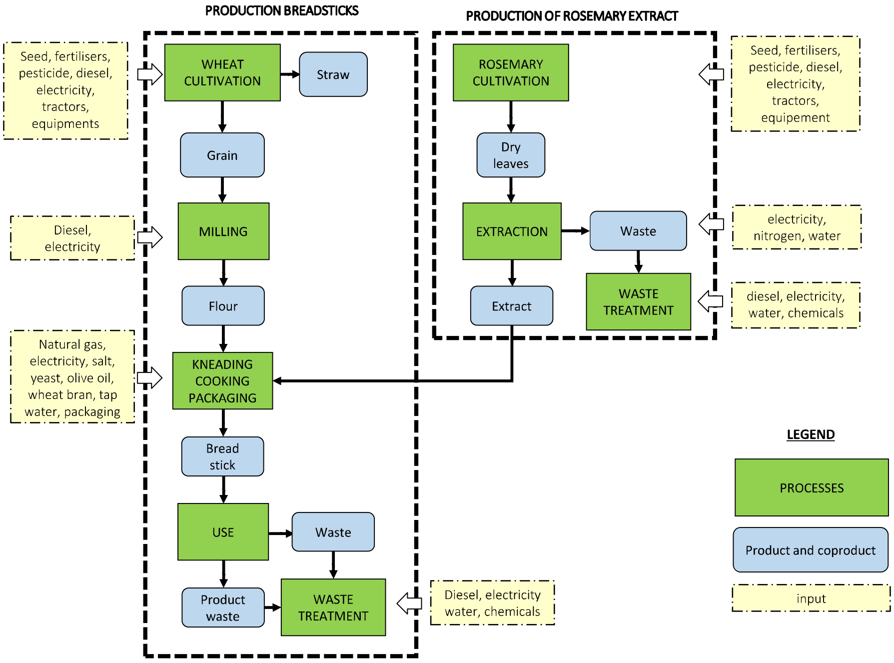
A cradle-to-grave perspective was adopted. Specifically, the following activities were included in the system boundary:

1. extraction of raw materials (e.g., fossil fuels);
2. manufacture of the different inputs used for crop production (e.g., seeds, fertilisers, herbicides, fungicides and agricultural machines); flour and olive oil production, rosmarinic acid extraction (electricity, natural gas and chemicals), tap water and salt withdrawal, breadstick kneading (electricity), cooking and packing (electricity, natural gas, packaging materials);

3. use of inputs (e.g., fertiliser and pesticides derived emissions, diesel fuel emissions from the different field operations involved in crops production) as well as maintenance and final disposal of machines (e.g., tractors and operative machines) and devices (e.g., oven);
4. packaging, transport, distribution and “end-of-life” of breadsticks.

The system boundaries for the production system of breadstick with and without rosmarinic acid are depicted in **Figure 1**. The only difference between the production systems of the whole-wheat breadstick with extended shelf life is the use of rosmarinic acid.

Figure 1 - System boundary for the whole-wheat breadstick with extended shelf life.



Two types of breadsticks were compared:

1. Whole-wheat breadstick without rosmarinic acid and, consequently, without an extension of the shelf life (Scenario no AoX);
2. Whole-wheat breadstick with rosmarinic acid and, consequently, extended shelf life (Scenario AoX).

Consistent with other LCA studies facing multi-functionality in agro-food production systems (e.g., Noya et al., 2015; Renzulli et al., 2015; Schmidt Rivera et al., 2017), an economic-based allocation method was implemented in order to partition input and output to the different products of wheat cultivation (grain and straw).

2.5 Life Cycle Inventory (LCI) data

2.5.1 LCI for crop productions

Data concerning wheat cultivation were obtained via questionnaires and surveys from 15 farms located in the Po valley area (45° 60’ - 44° 77’ lat. N, 7° 65’ - 12°22’ long. E). These cereal farms have an overall cultivated area of 2780 ha and were selected considering their representability in terms of size (agricultural area between 40 and 300 ha), cultivation practice (integrate pest management farms while no organic farms were not considered) and mechanization of the field operation (intensive mechanization of field operations were considered). More specifically, concerning wheat production, data regarding fertilisers and plant protection products were collected by consulting the “Quaderni di campagna”. The latter is a mandatory Italian document that, for plant protection products, must report the applied dose and the timing of application. Concerning the mechanization, the required inventory data (data, characteristics of tractors and operative machines, fuel and lubricant consumptions, working time and age), were collected by a specifically developed survey data sheet.

Considering the grain yield over a 3-year period (2014-2016), an average value of 6.1 ± 1.2 $t \cdot ha^{-1}$ (14% moisture content) was considered. According to Schmidt Rivera et al. (2017), the straw production was estimated considering: (i) a Harvest Index (HI)[2] of 0.48 (Baldoni and Giardini, 2000), (ii) that 15% of the straw is not collectable because it is the basal portion of culms; (iii) a 90% collection efficiency for round-baler. Therefore, only 76.5% of the produced straw is collected (4.34 $t \cdot ha^{-1}$ dry matter).

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[2] The term “harvest index” (HI) is used in agriculture to quantify the yield of a crop versus the total amount of above-ground biomass that has been produced.

Data related to olive grove cultivation were directly collected from 10 farms, with an agricultural area between 10 and 20 ha. Considering a 4-year period (2013-2016), the survey was made by means of face-to-face interviews and included: data on machinery utilization (typology of tractors and operative machines, fuel and lubricant consumptions, working time and age); data on fertilization and phytoiatric treatment (quantity, type, period and distribution mode of fertilizers, insecticides, fungicides and herbicides); data on supplemental irrigation (water consumption, typology of water distribution and related energy consumptions); yield, and distance of transports from the olive grove to the milling plant. For the production of rosemary leaves, secondary data was used, 1.7 tons of dry leaves·ha^{-1} per year (Mulas et al., 2002; Carrubba and Catalano, 2009).

Table 1, **2** and **3** report the main inventory data used for wheat, rosemary and olive cultivation, respectively.

Concerning N-compounds, the emissions into air, soil, and water due to the fertiliser application were evaluated according to Brentrup et al. (2000). These emissions were evaluated in further detail by considering soil characteristics (i.e. pH, slope, texture and the Cation Exchange Capacity), climatic conditions (wind, temperature and rainfall), as well as considering the type of fertilisers (organic or mineral) and the application techniques. Emissions of P-compounds were estimated using the SALCA-P model (Prasuhn, 2006). Furthermore, two different phosphorus emissions pathways to water were considered: leaching into the ground water and run-off into surface water.

Table 1, 2 and 3 - around here

According to the EPD (Environmental Product Declaration) for arable crops (EPD, 2013), the pesticide-derived emissions were assessed considering that 100% of the pesticides were considered as released into the soil.

Carbon sequestration into the soil was not included within the system boundaries (Restuccia et al., 2013; Bacenetti et al., 2015, Noya et al., 2015).

Regarding the different field operations, the processes reported in the Ecoinvent database® v.3 (Weidema et al., 2013) were modified by considering, for each machine, the fuel consumption ($kg \cdot ha^{-1}$), the annual working time ($h \cdot year^{-1}$) as well as the physical (h) and the economic (years) lifespan (Lovarelli and Bacenetti, 2017). The information regarding physical and the economic lifespan were retrieved from Bodria et al. (2006).

Background data for the production of wheat seeds, diesel fuel, agro-chemicals (herbicides and fungicides), tractors and agricultural equipment were obtained from the Ecoinvent database® v.3 (Weidema et al., 2013) as well as data on tap water and salt.

2.5.2 LCI for olive oil, flour and rosmarinic acid production

Primary data concerning the energy and materials consumption were collected in the biggest mill in the district of Lodi (Lombardy), while secondary data were used for the rosmarinic acid.

With regards to the olive oil production, inventory data were collected from a milling plant in Southern Italy; data on energy consumption were collected by means of Fluke 179 True RMS Digital Multimeter instrument, while data on water consumption were collected by means of a water flow meter.

Concerning the production of rosmarinic acid, according to Rodríguez-Meizoso et al. (2012), to produce 1 g of rosmarinic acid, the following data were considered: 15.4 g of dry leaves, 1.9 g of ethanol, 3.9 kWh of electricity, 14.4 g of solid waste and 1.9 g of solvent mixture. The rosmarinic acid (the antioxidant substance) is extracted from the leaves together with other substances (ratio 1:10) and, before being used in the breadstick dough, it is further diluted (ratio 1:10) to be stabilized and easily dosed (Azmir et al, 2013).

2.5.3 LCI for breadstick

Table 4 reports the ingredients for whole-wheat breadsticks with (Scenario AoX) and without (Scenario no AoX) the rosmarinic acid.

Table 4 - around here

For breadsticks without rosmarinic acid (Scenario no AoX), primary data concerning the consumption of energy (electricity and heat), natural gas, cleaning agents, packaging materials and waste were collected by means of surveys and questionnaires in a food industry located in the District of Milan (65 km from the mill) that produces about 1600 t·year^{-1} of whole-wheat breadsticks. **Table 5** reports the main inventory data collected from the food industry.

Table 5 - around here

2.5.4 Evaluation of shelf-life extension and food losses

Laboratory tests were performed to assess the shelf life of the different breadsticks. Sensory evaluation was performed by consumer acceptability tests carried out over four sensory sessions (100 consumers, ranging from 19 to 65 years old). Consumers were asked to only sniff the samples and immediately answer the question, “Would you normally consume this product?” by saying “Yes” or “No”. More detail about the sensory evaluation can be found in Alamprese et al. (2017). Thanks to the addition of rosmarinic acid, the shelf life increased from 116 to 154 days.

Concerning product loss, according to Bravin et al., (2006), Kantor et al. (1997) and Gustavsson et al. (2011), about 10%−25% of bakery products are lost (e.g., due to the presence of mould or because it is beyond the expiration date) during the consumption step of the entire production system.

In this study, the two scenarios considering 0% loss were initially compared (in order to highlight the environmental impact related to the addition of rosmarinic acid), and then the no Aox scenario (with a 15% loss) was compared to the Aox scenario, considering a wide range of losses. Furthermore, the environmental break-even point was calculated considering increasing losses of the breadstick with rosmarinic acid (scenario no AoX). This point represents the threshold of product loss for the breadstick with AoX beyond which the breadstick without Aox becomes less impactful. In other words, if the losses of breadsticks with Aox are higher than the break-even point, the addition of rosmarinic acid is not an effective solution to reduce the environmental impact.

2.6 Impact assessment and uncertainty analysis

Using the characterisation factors reported by the midpoint ILCD method (Wolf et al., 2012), the following impact categories were considered:

- Climate change (CC, expressed as kg CO_2 eq.),
- Ozone depletion (OD, expressed as mg CFC-11 eq.),
- Human toxicity, cancer effects (HTc, expressed as CTUh),
- Human toxicity, non-cancer effects (HTnoc, expressed as CTUh),
- Particulate matter (PM, expressed as g PM2.5 eq),
- Photochemical oxidant formation (POF, expressed as g NMVOC eq),
- Terrestrial acidification (TA, expressed as molc H+ eq),
- Freshwater eutrophication (FE, expressed as g P eq),
- Terrestrial eutrophication (TE expressed as molc N eq),
- Marine eutrophication (ME, expressed as g N eq),
- Freshwater ecotoxicity (FEx, expressed as CTUe),
- Mineral fossil and renewable resource depletion (MFRD, expressed as mg Sb eq).

The inventory data were processed using Simapro software (version 8.3).

Finally, an uncertainty analysis using the Monte Carlo statistical technique was carried out (5000 iterations) to determine how uncertainties in the inventory data affect the reliability of the results.

3 Results and Discussion

In this section, the environmental results for the two types of whole-wheat breadsticks (Scenario AoX and Scenario no AoX) are reported.

3.1 Environmental hotspots for breadstick production

For the production of whole-wheat breadsticks with (scenario AoX) and without rosmarinic acid (scenario no AoX), **Figure 2** shows the environmental *hotspots* for each impact category under evaluation considering 0% of food loss.

Due to the consumption of wheat grains, wheat flour is the main hotspot for:

- CC (from 55% to 59% of the impact), due to field operations for wheat cultivation and the consumption of diesel and related emissions of carbon dioxide in the tractor engine exhaust gas emissions;
- OD (from 58% to 62% of the impact) due to the production of diesel used for wheat cultivation and the consumption of electricity during milling;
- PM (from 43% to 47% of the impact) and POF (from 56% to 60% of the impact) mainly due to emissions of pollutants (carbon monoxide, nitrogen oxides and particulate matter) in the tractor engine exhaust gas emissions;
- TA (from 62% to 65% of the impact), TE (71% of the impact for both scenarios) and ME (from 76% to 78%) mainly due to the fertilizer related emissions of ammonia and nitrate.

For the production of the whole-wheat breadstick without and with the rosmarinic acid, the absolute impact related to the consumption of flour is equal, but, for the first, the share of the impact related to flour is higher because there is no impact for the antioxidant.

For both the breadsticks, the energy consumption is the main hotspot for FE (due to the emissions of P during mining activities, FEx and HT-noc (due to the emissions of heavy metals such as copper, zinc, and nickel).

The consumption of water and salt (“other production factors”) has a small role for all the evaluated impact categories (<1%), except for the toxicity-related ones (4% in HT-noc; 3% in HT-c and FEx) and MFRD (8%). Finally, a negligible impact (<1% for all the evaluated impact categories) is associated with the packaging (manufacturing and end-of-life).

For the breadstick with AoX (scenario AoX) the impact associated with the rosmarinic acid is <5% only for ME (0.4%), TE (1.4%) and TA (4%); in the other impact categories, it ranges from 6% (POF) up to 19% for FEx.

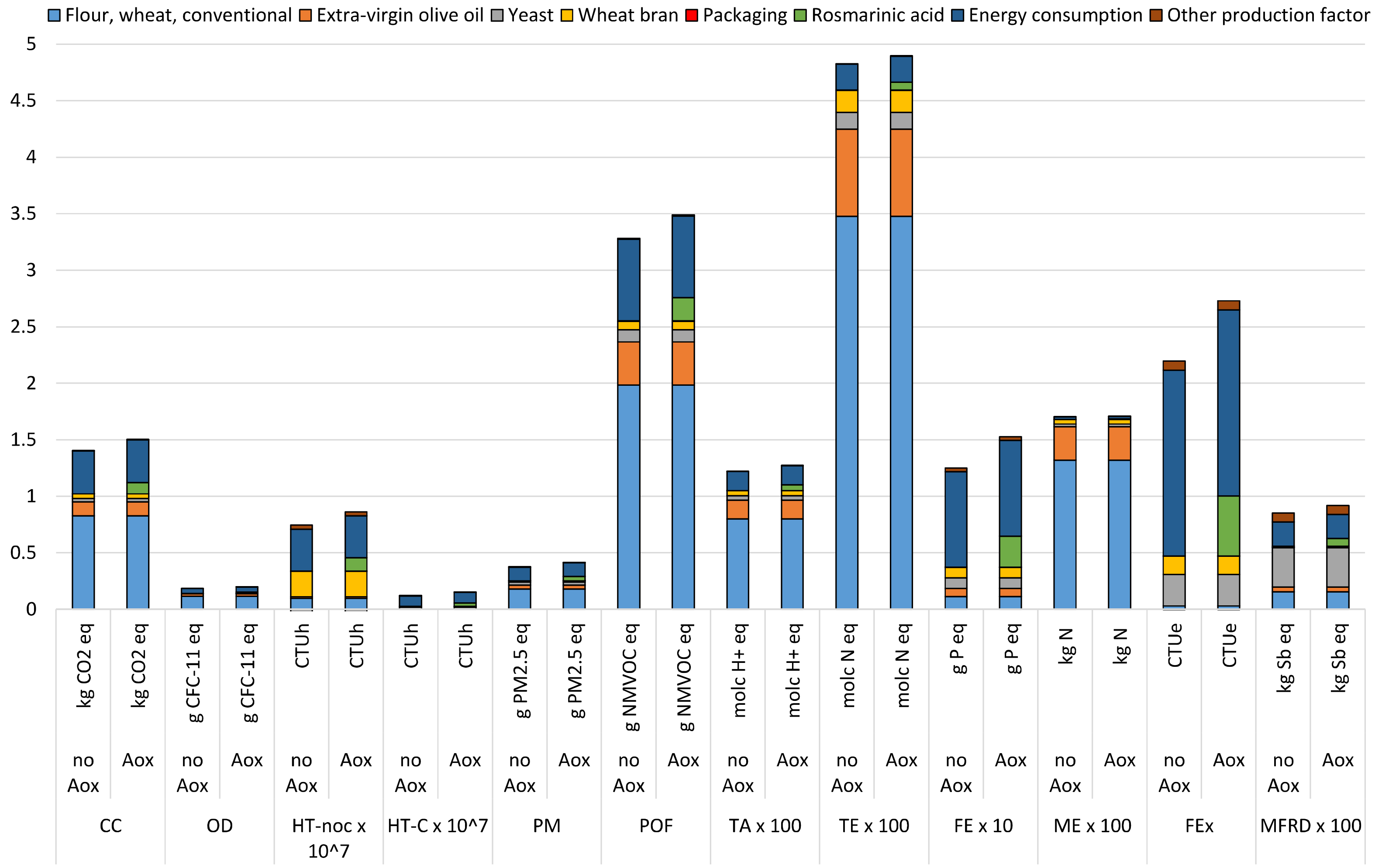


Figure 2 - Hotspot identification for the two types of breadstick with 0% of food loss ("packaging" includes the end-of-life of the packaging materials, "other production factors" includes water and salt)

Table 6 reports the comparison between the absolute impacts of the two scenarios without taking into account the product loss. The addition of rosmarinic acid involves an impact increase ranging from +0.4% in ME to about +24% in HT-c and FEx. As seen in **Figure 3**, the environmental load of rosmarinic acid is mainly due to the consumption of electricity during the extraction process. The production of rosemary leaves plays a minor role: for 7 of the 12 evaluated impact categories, it is responsible for less than 5% of the impact and only for TA (13%), TE (32%) and ME (35%) Its impact, due to emissions related to fertilizer application to the soil, is higher than 10%.

Table 6 - around here

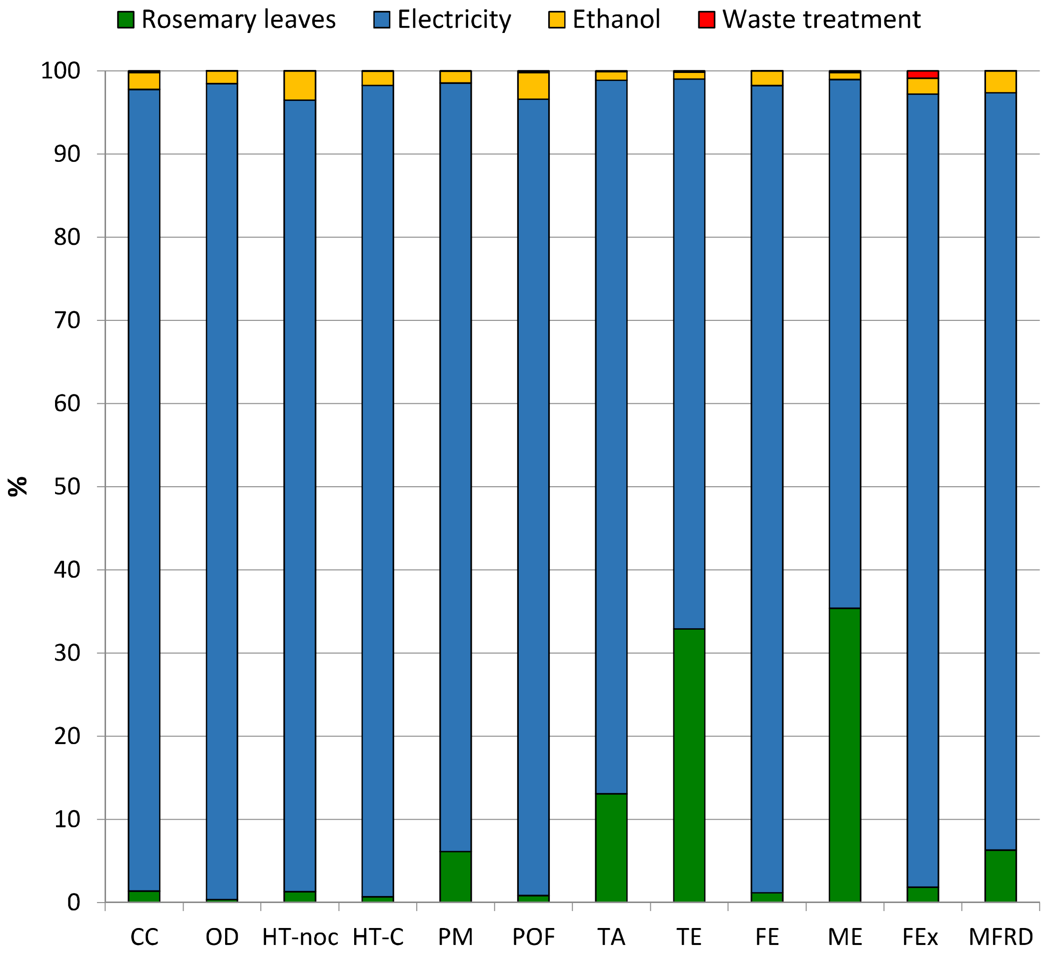


Figure 3 - Environmental hotspots for rosmarinic acid (FU = 1 g of rosmarinic acid).

3.2 Sensitivity analysis

To test the robustness of the results and to investigate the influence of the choices made in the modelling phase, a sensitivity analysis was carriedout for whole-wheat breadsticks with rosmarinic acid (scenario AoX). The following parameters were considered due to their relevance to the environmental performances:

1. The grain yield of wheat is considered to be ±20%. The variation range was selected considering the average yield variation in the 15 farms where the inventory data were collected;
2. The energetic consumption at the bakery industry. In this regard a ±25% was considered (Carlsson-Kanyama and Faist, M, 2000).

Table 7 shows the results of the sensitivity analysis carried out for the AoX Scenario, changing one parameter at a time. The percentage variations reported in Table 7 refer to the AoX scenario assessed considering the wheat yield and the energy consumption at the bakery, the values previously reported in the inventory data (see. sections 2.5.1 and 2.5.3). Among the evaluated impact categories, the sensitivity associated with the two tested parameters strongly varies. Furthermore, the variation of wheat yield does not affect HT-noc, HT-c, and FEx but has a strong influence on the impact categories most affected by the wheat fertilization (TA, -13 %, + 15%; TE, -14%, + 17%; and ME, -15%, + 18%). On the other hand, HT-noc (-9%, + 11%), HT-c (-12%, + 15%), and FEx (- 12%, + 15%) shows a strong sensitivity to energy consumption in contrast to TA, TE, and ME. Both the variation of energy consumption and the wheat yield affect other environmental categories (CC, OD, POF and MFRD); however, on the change in yield involves higher impact variations.

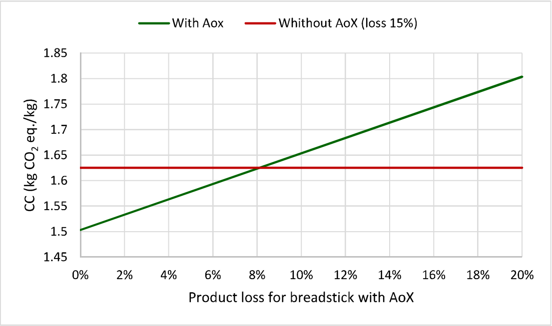
Table 7 - around here

3.3 Environmental break-even point

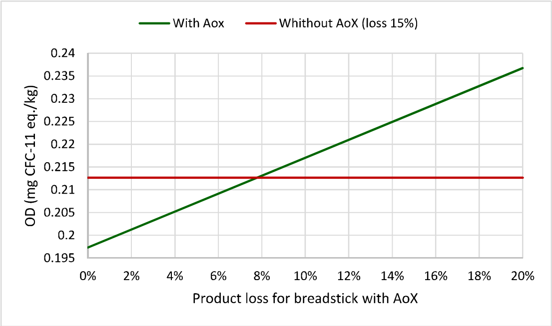
Figure 4 reports, for the different impact categories, the environmental break-even points.

For some impact categories, the break-even point is reached only if unrealistic product losses are considered for the breadsticks with Aox. For two of the 12 evaluated impact categories, HT-c and FE, the breadsticks with AoX, independently from the product loss, shows a higher environmental impact compared to the breadstick without Aox; consequently, for HT-c and FE, there is no environmental break-even point. For the other impact categories, the break-even point is lower than 7% for PM (4.5%) and HT-noc (6.5%), around 8-9% in CC, OD, POF and MFRD, higher than 10% for TA (11%), FEx (12.5%), TE (13.5%), and ME (14.5%).

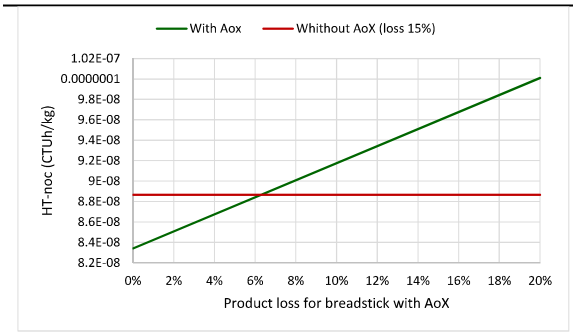
In terms of climate change, the breadsticks with extended shelf lives (scenario AoX), become less impactful than those without rosmarinic acid. Waste should be reduced from 15% to 8% thanks to the shelf-life extension.



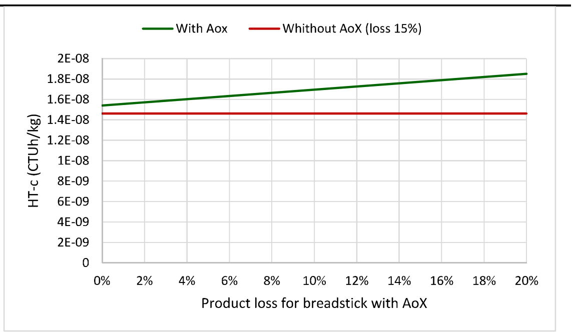
Climate Change (CC)



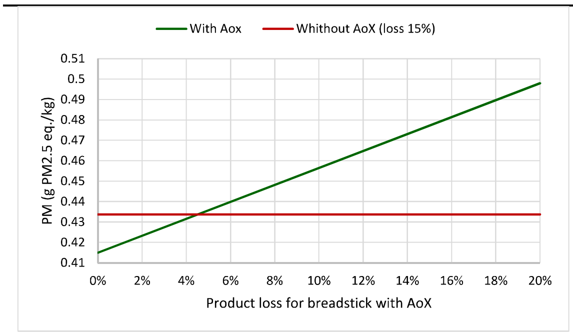
Ozone depletion (OD)

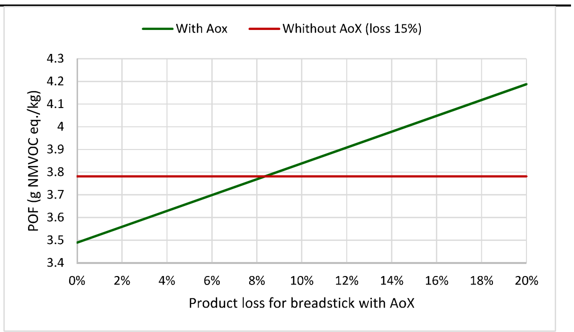


Human toxicity, non-cancer effects (HT-noc)



Human toxicity, cancer effects (HT-c)





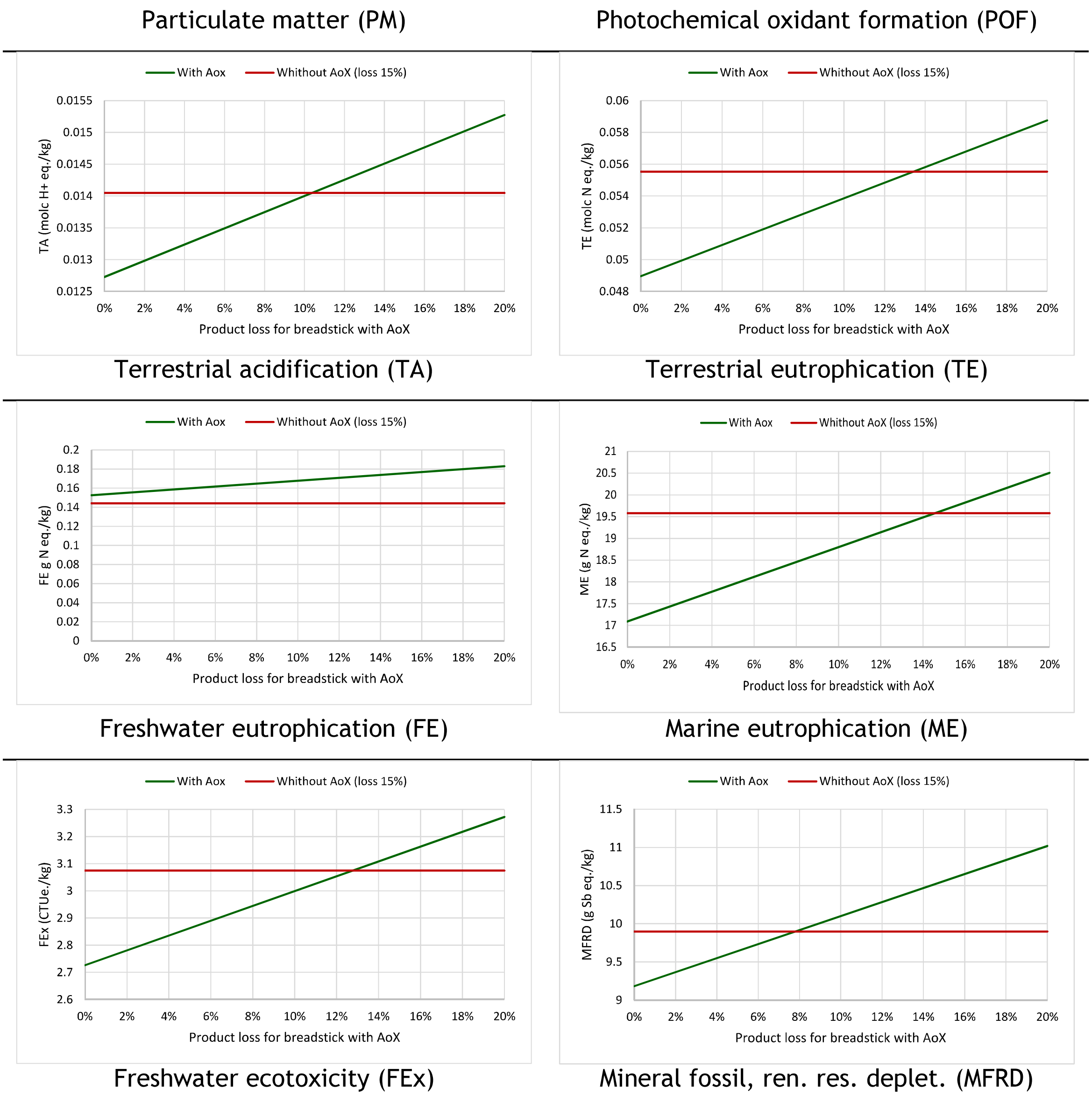


Figure 4 - Environmental break-even point for the evaluated impact categories

In order to test the robustness of the comparative LCA results within the lifecycle interpretation step, an uncertainty analysis of the inventory data using the Monte Carlo statistical technique was performed between the whole-wheat breadsticks with Aox and those without Aox. For the scenario without Aox, 15% of product losses were considered while, for the scenario Aox, based on the results on the break-even calculation, 9% of product loss was considered. **Figure 5** shows the results of the uncertainty analysis.

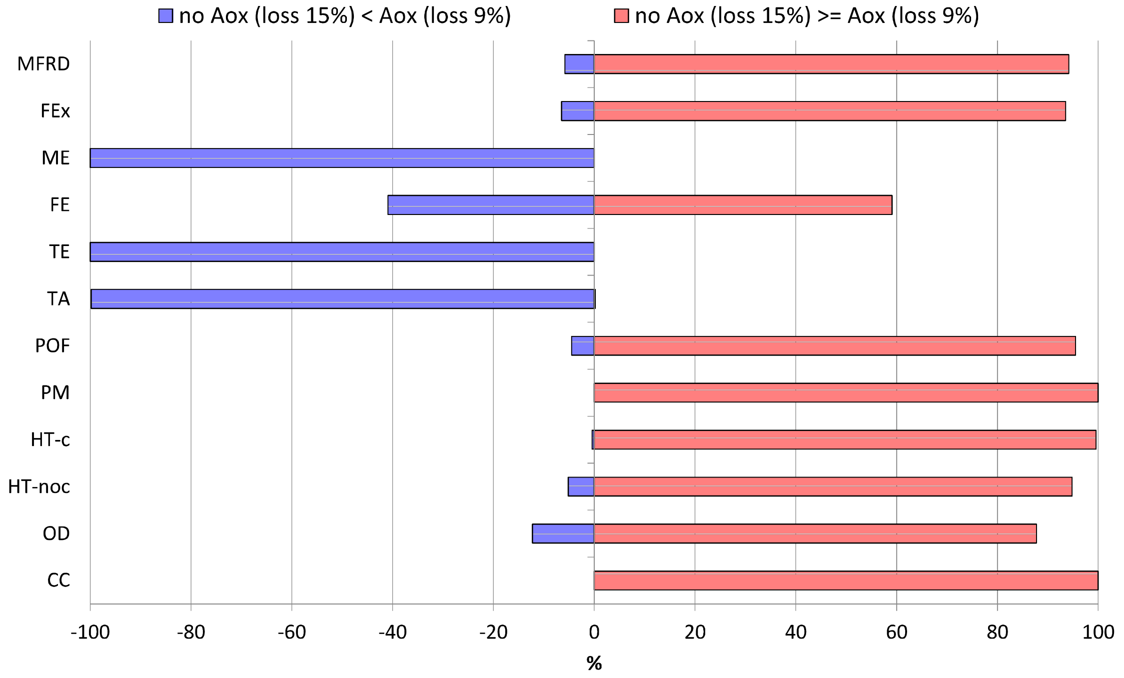


Figure 5 - Results of the uncertainty analysis for the comparison between the whole-wheat breadsticks with Aox and those without Aox.

The results confirm that the impacts of the whole-wheat breadsticks with rosmarinic acid (Scenario Aox) are less significant than those of the breadsticks without Aox (Scenario no AoX) for TA, TE and ME (level of statistical significance = 100%). On the contrary, the scenario Aox shows lower impact compared to the scenario with Aox for CC, HT-noc, HT-c, PM and POF with a level of statistical significance ≥ 95% and for OD, FEx and MFRD with a level of statistical significance ≥ 90%. With the exception of freshwater eutrophication, the results for all the evaluated impact categories show a low level of uncertainty.

These results show that uncertainty due to the life-cycle inventory analysis were associated with the cumulative effects of model imprecision, and input and data variability affected only freshwater eutrophication, whereas the other impact categories present a lower level of uncertainty.

4. Conclusions

Considering the environmental impact related to food production and consumption, considerable environmental benefits can be achieved by reducing food losses. Among the different strategies that can be implemented for this purpose, little attention has been paid to the extension of shelf life. SLE can reduce food losses through the entire production system and, in particular, during the consumption step. In this study, the environmental consequences related to the SLE for a bakery product (the whole-wheat breadstick) have been assessed using the LCA approach. The trade-off between the impact increase due to the addition of rosmarinic acid and the environmental benefits related to the reduction of food loss was evaluated for a full set of environmental impacts. For some impact categories (2 of the 12 evaluated), the shelf life extension is not a proper mitigation solution, while, for the others, its effectiveness depended on the magnitude of product loss reduction that was achieved.

The outcomes of this study will be useful for stakeholders involved in the logistics aspects of the bakery production system as well as for food engineers and operators involved in the design of a more sustainable food production system. In this regard, future research activities should consider the combination of the use of antioxidant compounds and alternative packaging materials or conditions (e.g., packing in N_2 atmosphere), as well as the evaluation of the benefits arising from SLE for other food category products more perishable than bakery ones.

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TABLES

Table 1 - Main inventory data for wheat cultivation and drying

Field Operation	Repetitions	Equipment		Tractor		Fuel Cons.	Input	
		Machine	Duration: economic & physical	kW	kg	kg·ha^{-1}	Product	Amount
Organic fertilisation	1	Manure spreader	8 years 1500 h	120	6800	30.5	Manure	30 t·ha^{-1}
Ploughing	1	Plough 3 furrow	12 years 2000 h	120	6800	26.5		
Harrowing	1	Rotary harrow	10 years 2000 h	90	5100	22.5		
	1	Tine harrow	12 years 2000 h	90	5100	11.5		
Sowing	1	Line Seeder	8 years 1500 h	90	5100	8.4	Seed	200 kg·ha^{-1}
Top Fertilisation	1	Fertiliser spreader	8 years 1500 h	90	5100	5.3	Ammonium nitrate	100 kg·ha^{-1}
Weed control	2	Sprayer	6 years 1500 h	90	5100	3.3	Tribenuron-methyl Difensulfuron Bromoxinil 2,4 D	12.5 g·ha^{-1} 12.5 g·ha^{-1} 238 g·ha^{-1} 238 g·ha^{-1}
Harvesting	1	Combine harvester	10 years 3000 h	350	13500	35.5		
Drying	1	Dryer	15 years 3000 h	n/a	n/a		Grain 14% moisture	6.1 t·ha^{-1}

Table 2 - Main inventory data for rosemary cultivation and drying

Field Operation	Repetitions	Equipment		Tractor		Fuel Consumption	Input	
		Machine	Duration: economic & physical	kW	kg	kg·ha^{-1}	Product	Amount
Organic fertilisation	1	Manure spreader	8 years 1500 h	120	6800	28.5	Cattle manure	20 t·ha^{-1}
Ploughing	1	Plough 3 furrow	12 years 2000 h	120	6800	26.5		
Harrowing	1	Rotary harrow	10 years 2000 h	90	5100	19.5		
Planting	1	Planter	8 years 1500 h	90	5100	11.0		
Fertilisation	6	Fertiliser spreader	8 years 1500 h	90	5100	5.3	Urea	80 kg·ha^{-1}
Weed control	6	Sprayer	6 years 1500 h	90	5100	3.3	Pendimetalin	0.8 kg·ha^{-1}
Harvesting	6	By hands	n/a	n/a	n/a			
Drying	6	Dryer	10 years 1500 h	n/a	n/a		Dry leaves	1700 kg·ha^{-1}

Table 3 - Main inventory data for olive production

Field Operation	Repetitions	Equipment		Tractor		Fuel Consumption	Input	
		Machine	Duration: economic & physical	kW	kg	kg·ha^{-1}	Product	Amount
Fertilization	1	Fertiliser spreader	8 years 1500 h	63.4	2340	6.00	N 20% P10% K10%	1350 kg.ha^{-1}
Soil Tillage	2	Rotary harrow	10 years 2000 h	63.4	2340	22.75		
Chopping	1	Shredder	Rotary harrow	63.4	2340	19.80		
Weed control	1	Sprayer	6 years 1500 h	63.4	2340	5.50	Glyphosate	4 kg.ha^{-1}
Insects control	5	Sprayer	6 years 1500 h	63.4	2340	5.50	Dimethoate	1.2 kg.ha^{-1}
Patogens control	5	Sprayer	6 years 1500 h	63.4	2340	5.50	Copper Oxychloride	4 kg.ha^{-1}
Harrowing	1	Rotary harrow	10 years 2000 h	63.4	2340	21.20		
Harvesting	1	Self-propelled trunk shaker	8 years 2500 h	72.5	4950	60.15	Olive	15.6 t/ha

Table 4 - Ingredient for the production of 1 kg of breadsticks in the two scenarios

Ingredient	Unit	Scenario no AoX	Scenario Aox
Wheat flour	kg	0.840	0.840
Water	kg	0.412	0.412
Wheat bran	kg	0.092	0.092
Olive oil	kg	0.032	0.032
Salt	kg	0.017	0.017
Brever’s yeast	kg	0.013	0.013
Rosemary extract	kg	-	0.0017

Table 5 - Inventory data from the food industry

Input	Consumption	
Electricity	0.560	kWh/kg
Water	0.00127	m^3/kg
Natural gas	0.11432	m^3/kg

Table 6 - Comparison between the two wheat whole breadsticks (with and without the rosmarinic acid) with 0% of product loss

Impact category	Unit	No AoX	AoX	Δ
Climate change, CC	kg CO_2 eq	1.405	1.503	7.0%
Ozone depletion, OD	mg CFC-11 eq	0.185	0.197	6.7%
Human toxicity, non-cancer effects, HT-noc	CTUh	$7.16\cdot10^{-08}$	$8.34\cdot10^{-08}$	16.5%
Human toxicity, cancer effects, HTc	CTUh	$1.24\cdot10^{-08}$	$1.54\cdot10^{-08}$	24.4%
Particulate matter, PM	g PM2.5 eq	0.377	0.415	10.2%
Photochemical ozone formation, POF	g NMVOC eq	3.283	3.489	6.3%
Acidification, TA	molc H+ eq	0.012	0.013	4.2%
Terrestrial eutrophication, TE	molc N eq	0.048	0.049	1.4%
Freshwater eutrophication, FE	g P eq	0.125	0.153	22.1%
Marine eutrophication, ME	g N eq	17.020	17.089	0.4%
Freshwater ecotoxicity, FEx	CTUe	2.195	2.727	24.2%
Mineral, fossil & ren resource depletion, MFRD	mg Sb eq	8.510	9.183	7.9%

Table 7 - Results of the sensitivity analysis for the scenario AoX considering variation of wheat yield as well as of energy consumption at bakery.

Impact category	Wheat yield		Energy consumption at bakery	
	+ 20%	- 20%	+ 25%	- 25%
Climate change	-10%	12%	6%	-5%
Ozone depletion	-10%	12%	5%	-4%
Human toxicity, non-cancer effects	0%	0%	11%	-9%
Human toxicity, cancer effects	0%	0%	15%	-12%
Particulate matter	-9%	10%	7%	-6%
Photochemical ozone formation	-10%	12%	5%	-4%
Acidification	-13%	15%	3%	-3%
Terrestrial eutrophication	-14%	17%	1%	-1%
Freshwater eutrophication	-2%	3%	14%	-11%
Marine eutrophication	-15%	18%	0%	0%
Freshwater ecotoxicity	0%	0%	15%	-12%
Mineral, fossil & ren resource depletion	-3%	3%	6%	-5%